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Novel Aspects of the Remediation of PCB-Contaminated Soils in the Canadian Arctic: Excavation and PRB Technology

Indra Kalinovich (indra@ce.queensu.ca), Allison Rutter (ruttera@biology.queensu.ca), John S. Poland, and R.K. Rowe (Queen's University, Kingston, Ontario, Canada)

ABSTRACT: Resolution Island, Nunavut, just southeast of Baffin Island, is part of a North American military defense system established in the 1950s and became heavily contaminated with PCBs during its operational years. Remediation of this soil will be completed by the end of 2005. The scale of contamination coupled with fractured bedrock, topography, extreme weather conditions and remoteness of the site heighten the challenges of an effective remediation. Remediation through excavation of the PCB contaminated soil at Resolution Island began in 1999 and at its completion almost 5 tonnes of pure PCBs in approximately 25, 000 m^3 of soil will have been remediated.

Remediation strategies were based on both quantity of soil and level of contamination in the soil. Soils with PCB concentrations greater than 50 ppm were shipped off site to be incinerated at a licensed facility. Soil with concentrations of PCB between 5 and 50 ppm and 1 and 5 ppm were landfilled on site. The former were placed in a lined facility with sufficient top cover to permanently freeze the contents of the landfill while the latter were placed in an unlined facility.

Inevitably some PCB contamination will remain in rock crevices and in inaccessible areas of the site. In addition, the excavation of the surface material will leave a small amount of contaminated soil that will be particularly susceptible to erosion and runoff. In order to control the mobilization of the material within the drainage system and hence its dispersion into the environment, permanent barrier systems to treat both contaminated water and soil have been designed and constructed as of 2003. For the last two years both the design and construction of the barriers have been amended as a result of field observations and laboratory testing. The barriers will be subjected to a long term monitoring regime.

This paper will chart the field progress of PCB remediation at Resolution Island.

INTRODUCTION

The eastern headland of Resolution Island, Nunavut is the site of a former military base in the Canadian Arctic that was part of the Polevault Line series of radar stations. These stations served to connect the Distant Early Warning (DEW) Line to southern defence headquarters in the United States (Poland *et al*., 2001). The base was built during the cold war and subsequently abandoned in 1972. An environmental assessment of the site in 1993 (ESG, 1994) confirmed the presence of widespread PCB contamination and discovered that the migration of the PCBs had reached the ocean. As a result, a major cleanup of the site was initiated in 1994 and undertaken over the period 1997-2005. The 1994 site work entailed a detailed assessment of the site and also included the construction of interceptor barriers to prevent further PCB migration (ASU, 1995). The first phase of the remediation project involved the excavation of all materials containing greater than 50 ppm PCBs (ASU, 1998 to 2002). The second phase was initiated by

Indian and Northern Affairs Canada (INAC) based on new policy instituted in 2002, and which included the clean up to 1 ppm PCBs (ASU, 2003).

When the military base was abandoned, the equivalent of approximately 9000 kg of pure PCBs (Aroclor 1260) remained on the site. About 4000 kg was predominantly in oil and was removed from the site in 1999. The remaining 5000 kg of PCBs was distributed in over 15,000 m^3 of soil. At Resolution Island, the field season is short, access to the site is difficult and climatic conditions are harsh. Remediation of the PCB contaminated soil under these conditions required the development of a unique cleanup strategy and a novel remediation technology. Disposal and excavation techniques were adapted to accommodate three different contamination levels that corresponded to three PCB concentration ranges. New excavation protocols were required for areas that were difficult to access.

The difficult terrain and the fractured bedrock of the site ensured that some PCB contaminated soil would remain on site. Long-term remediation goals were established to minimize PCB migration into the Arctic ecosystem. Technology to demobilize movement of PCBs in sediment and surface water was developed to meet these goals. Surface funnel-and-gate permeable reactive barriers were designed and constructed on-site. The initial barrier was installed in 2003 and since then, various modifications have been added to improve the performance of the barrier. Two additional on-site permanent barriers have since been constructed and monitored. This paper will describe the development and implementation of the cleanup strategy, the excavation and disposal of the PCB contaminated soils, and the design and construction of the permeable reactive barriers.

Clean Up Criteria. The Canadian Environmental Protection Act (CEPA) regulates the removal and destruction of PCBs at concentrations greater than 50 ppm, regardless of the matrix (CEPA, 1999). Soils with over 50 ppm PCBs are referred to as CEPA soils. For the DEW Line sites, the CCME (Canadian Council of the Ministers of the Environment) guidelines were not available in 1991 and therefore levels, known as the DEW Line Cleanup Criteria (DCC), were developed based on actual uptake of contaminants by plants as well as reference to guidelines from other countries (ESG, 1993). The DCC were developed as part of the larger DEW Line Clean Up (DLCU) Protocol, which defined what would happen to the soils contaminated at various levels as well as what should be done to remediate old landfills, dumps, abandoned buildings, physical debris and barrels (ESG, 1991; Poland and Riddle, 2003; INAC, 2005). Two DCC levels were developed: Tier II and Tier I. Tier II levels essentially corresponded to the 1996 CCME parkland guidelines (CCME, 1996). However, for lead and PCBs, a lower level, Tier I, was instituted to take account of the mobility of these two contaminants in the Arctic and Antarctic, which, by 1991, had been detected at a distance of several miles from point sources and recently up to 50 km away from the source of contamination (Pier *et al*, 2003). The three soil PCB concentration ranges, CEPA, Tier II and Tier I (Table 1) correspond to three disposal and excavation protocols on site based on the DLCU protocol.

TABLE 1: Cleanup criteria and the DLCU protocol (Poland et al., 2001).

Level	Concentration	DEW Line Cleanup Protocol
CEPA	> 50	Remove
DCC Tier II	5 – 50	Isolate from the Arctic ecosystem
DCC Tier I	1 –5	Burial in non-hazardous landfill

METHODS

Delineation and Grid Maps. Soil contamination levels were determined in the assessment phases. To facilitate remediation, a grid was overlaid on the contaminated areas. Areas were sectioned off into 20 m × 20 m grids using a differential global positioning system (DGPS) and Autocad Map 2000. The grid was established on site by using waypoint navigation and were checked with traditional methods and re-established at the beginning of each field season as necessary. Areas of contamination, CEPA, Tier II and Tier I were delineated on site using a coloured rope system and spray paint. Additional samples were taken as required to clearly establish the areas.

Sampling and Analysis. All soil samples were taken from depths of 0 to 10 cm where possible and placed in Whirlpak bags. Point samples were taken to confirm the Tier I, Tier II and CEPA areas as necessary. Confirmatory testing during excavation was carried out using composite samples. A mobile laboratory was set up on site to conduct PCB analysis (Rutter *et al*., 2003). During excavation, analysis for PCBs in soil was performed using a modified shaker method developed to improve turnaround time. Soils were analysed by accurately weighing 10 g (dry weight equivalent), spiking with an internal standard solution (decachlorobiphenyl) and extraction with 50 mL of a 1:1 mixture of hexane and acetone for 20 minutes on a platform shaker. Extracts were analysed by gas chromatography with electron capture detection (GC/ECD).

Excavation. Excavation followed the grid system wherever possible. The construction of clean roads into the various areas created access to contaminated soils. Contaminated soil was removed using heavy equipment by initially excavating the first 0-30 cm. A composite sample of the excavated area was then taken and analyzed. If necessary, excavation continued by removing 30 cm layers until the remaining soil had a PCB concentration below criterion or bedrock was reached. When laboratory analysis confirmed grid squares were cleaned to the appropriate criteria, they were signed off. In most cases, CEPA soil was removed from all grid squares followed by Tier II and then Tier I. The actual remediation work was conducted by the Qikiqtaaluk Corporation, Iqaluit under contract to INAC.

DISCUSSION

Soil Excavation and Remediation. Three technologies were initially examined for possible use at Resolution Island, namely, incineration, thermal desorption and solvent extraction. The use of all these technologies on site was eventually eliminated after review by the Nunavut Impact Review Board largely, due to concerns regarding transport and maintenance of equipment in a harsh environment and the associated environmental and financial risks. Excavation of soils and incineration at a southern disposal facility was therefore chosen as the remediation technology for destruction of CEPA soils from Resolution Island (Poland *et al.*, 2001). Excavation protocols were modified for Tier I and Tier II soils as described below.

Remediation of CEPA Soils. All contaminated areas that were in violation of the CEPA regulations were excavated to ensure that all soil contaminated at CEPA levels was removed. The geology of the site is fractured gneiss and therefore excavation to bedrock, using only heavy equipment, left significant amounts of soil on the ground. If the remaining soils were contaminated with PCBs at the CEPA level, residual soils were then removed with a vacuum truck to ensure near complete remediation of this highly contaminated soil. Figure 1 illustrates the topography of the site in the main areas of PCB contamination. The volume of CEPA soils was approximately 2500 m^3 in the S1/S4 valley and 2000 m^3 at the S1/S4 beach area. Remediation at the S1/S4 beach was particularly challenging due to the steep cliff in its upper zone. Some CEPA soil still remains in the area because the steep grade made the region impossible to access safely.

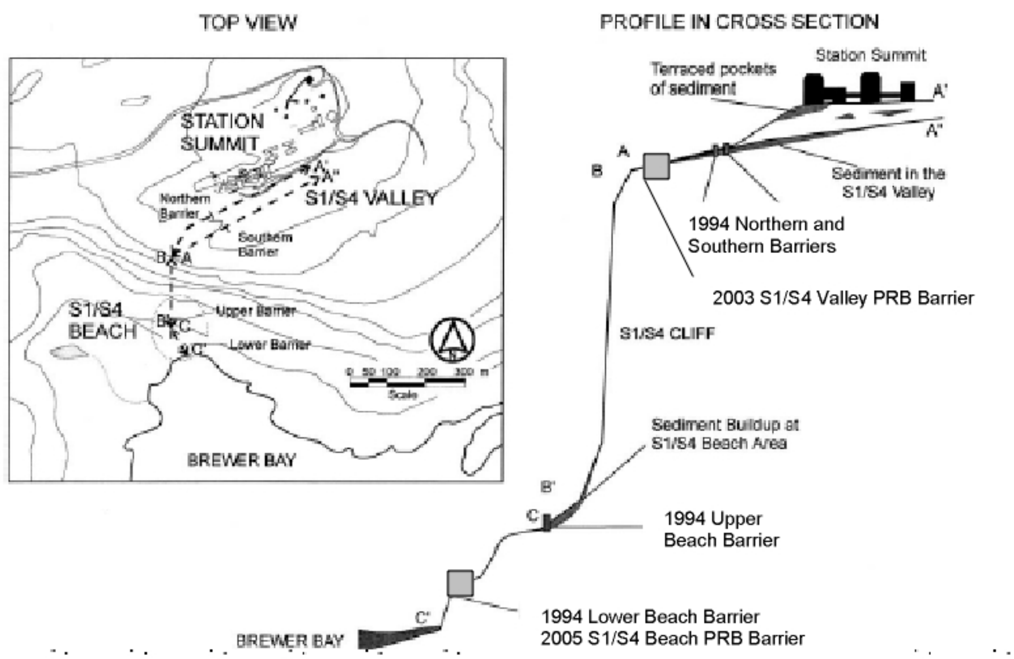

FIGURE 1. Profile of the S1/S4 drainage pathway, (Poland et al., 2001).

All excavated material was screened to separate particles larger than 5 cm from small particles to reduce overall volume and costs. The fine material was containerised and shipped south for destruction by incineration. The coarse material retained on the sieve was classified as Tier II material. Approximately 5000 m^3 of CEPA soil was excavated. Over a period of three years, the stockpiled soil was ultimately containerised into 3.1 m^3

steel containers, loaded by barge onto a ship and incinerated at a disposal facility in southern Canada.

Once these soils had been removed 96% of all PCBs by mass had been remediated. The remaining 4% of PCBs was distributed in approximately 15,000 m^3 of Tier I and Tier II soils.

Remediation of Tier I and Tier II Soils. In 2002, the remediation plan was amended to include excavation of both Tier I and Tier II soils. An engineered, lined landfill, the Tier II landfill, was chosen as the most viable disposal technology for the Tier II contaminated soil on Resolution Island. The lined landfill would immobilize the contaminated soil, effectively removing the contaminants from the Arctic ecosystem. As well as being lined, the landfill was designed to contain the contaminated soil in permafrost (Corrigan *et al.,* 2005).

Once the CEPA soil was removed, the excavation of the Tier I/II soils was started. Because the contamination levels were lower, a number of modifications were made to the excavation protocol. Once excavated, the soils were not screened as the cost savings were not significant at this lower concentration. Soils were not containerized but placed directly in the Tier II landfill. Soils remaining, after excavation to bedrock using heavy equipment, were not vacuumed. Tier II soil was largely removed prior to excavation of Tier I soils. In difficult to access areas Tier I and Tier II soils were removed together.

Excavation of Tier I soils was similar to Tier II soils. In some areas the Tier I soil were excavated to bedrock rather than by 30 cm stages, to facilitate excavation. Two other options were included in the protocol for Tier I soils; disposal in the onsite non-hazardous landfill and covering in place with clean fill. However the majority of the Tier I soil was used in the Tier II landfill as intermediate fill and as the initial layer of fill capping this landfill. In total, over 10,000 m^3 of Tier I/Tier II material was excavated at the site.

Barrier Design and Construction. As discussed above, PCB contaminated soil remains after excavation. Some of the soil is trapped in the fractured bedrock and some soil cannot be accessed because it is on very steep terrain that cannot be accessed for logistical and safety reasons.

Excavation of the contaminated areas loosened the soil structure, allowing soil that is contaminated to be freely mobilized by surface water. This can be expected to occur during summer rainstorms, and during the annual spring melts. A long-term remediation action plan was required to prevent migration of contaminated soil and surface water into the ocean via the drainage pathways at the site. After careful review of various remediation technologies, the remediation technology chosen for this particular site was a funnel-and-gate permeable reactive barrier (PRB).

In 2003, the first trial barrier system was installed in the S1/S4 valley and consisted of gabions and geosynthetic liners to form the funnel and a 1.2 m wide stainless steel gate. The design was based on previously reported funnel-and-gate barrier systems (Starr and Cherry, 1994), but altered for surface remediation. The wide funnel mouth would enable better entrapment of the contaminated runoff and help to slow down flow and deposit contaminated soils (Figure 2). The gate consisted of a stainless steel box into which up to four filter cassettes could be placed. A clean cell was installed directly behind the barrier to help monitor barrier efficiency.

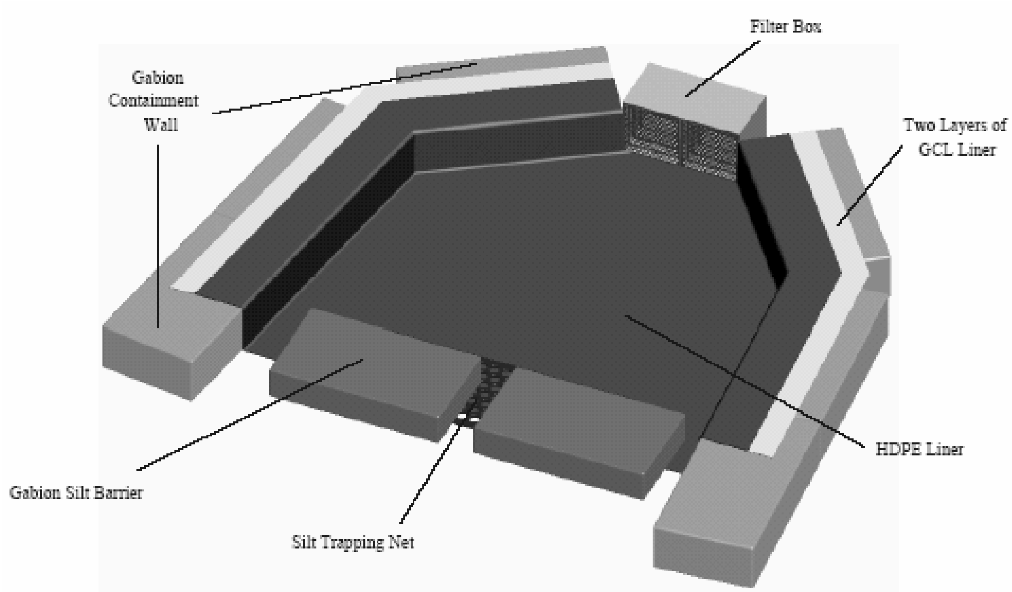

FIGURE 2. Trial barrier design (ASU, 2004).

In 2004, it was observed that the amount of mobile contaminated soils greatly exceeded expectations and the gate became clogged with PCB contaminated silt. Two and a half cubic metres of Tier II contaminated material was removed from the barrier system in 2004. The design scheme was altered in 2004 to improve barrier performance. The design was modified to increase the capacity for soil retention within the funnel prior to reaching the gate. By increasing the ponding area, it became possible to trap contaminated soils further upstream, prior to reaching the gate. Flow impediments in the form of chevrons were constructed upstream from the funnel area to reduce flow velocity and trap contaminated sediment from the funnel area. Coarse aggregate was spread upstream of the barrier system to help widen flow path and homogenize and reduce flow velocity. A gabion was placed upstream from the aggregate to trap soil further upstream from the chevrons.

High permeability in the barrier filters is particularly important at Resolution Island where water flows are characteristically dynamic and effects from cold temperatures and freeze-thaw cycling are probable. In 2003, barrier filter materials consisted of geosynthetic sorbent, geotextile filters and granulated activated carbon (GAC). Based on laboratory results from sampling these filters, GAC proved to be as effective a sorbent as the geosynthetic sorbents but had greater potential for use in the barrier as the hydraulic performance of the granular filter was much greater than that of the geosorbents (Kalinovich *et al*., 2004). The GAC filter was multi-functional: it could both retain particles as well as adsorb PCBs. Using larger granular particles with a more uniform distribution will assist with freeze-thaw action (Snape *et al.,* 2001) as well as increasing the hydraulic performance of the barrier. A shift to using granular materials such as gravel (graded on site) and GAC in filters helped to increase the hydraulic performance of the barrier gate. The filter thickness was also increased to lengthen the residence time of PCBs in water as they flowed through the gate. The 2004 design scheme is shown in Figure 3.

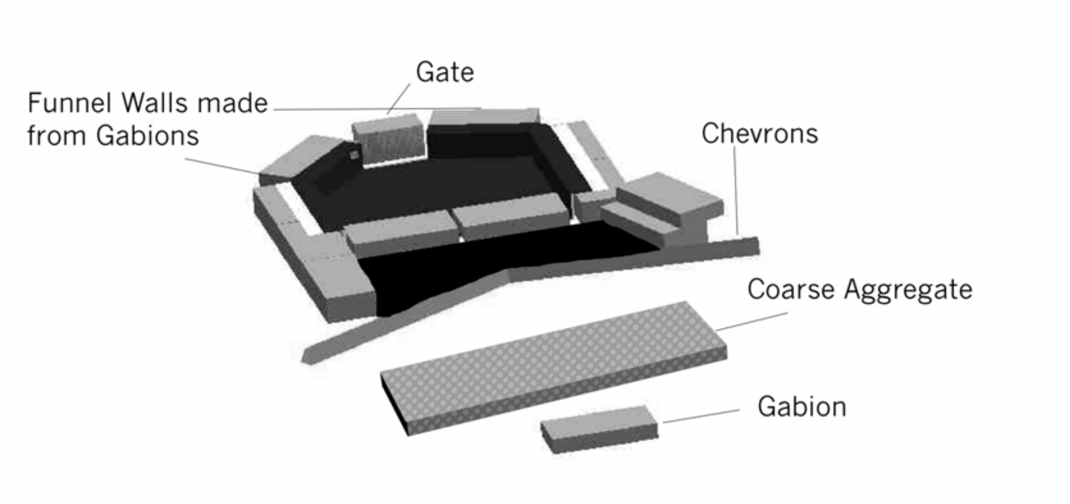

FIGURE 3. 2004 Barrier design scheme.

In 2005, it was observed that the modifications to the barrier system were successful in retaining contaminated soils without hindering hydraulic flow throw the permeable reactive gate. Seven cubic metres of Tier II material was collected in the barrier system during the period September 2004 to June 2005.

The highest amounts of soil erosion were expected during the spring run-off in 2005, as loose non-compacted soils had resulted from the excavations in the valley. It is anticipated that the amount of sediment will be reduced significantly over the next few years, which will enable additional geosynthetic sorbent and geotextile filters to be reintroduced into the filter box. Two additional barrier systems have now been constructed in view of the good performance of the modified barrier design.

CONCLUSION

The remediation of PCB contaminated soils at a remote site with an extreme climate such as Resolution Island has been successful. In total, 5000 m^3 of CEPA contaminated soil was excavated and shipped off site for destruction by incineration, and 15,000 m^3 of Tier I/Tier II materials have been excavated and removed from the Arctic ecosystem by placement in an on-site lined landfill. A long-term remediation and monitoring plan has been set-up on site which included the construction of surface funnel and gate permeable reactive barriers.

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