Development of a Long-term Monitoring Program for the Rehabilitated Rayrock Uranium Mine

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Abstract

Mining and milling of uranium ore at the Rayrock Mine resulted in the contamination of soil and water resources in the vicinity of the mine and associated tailings disposal areas. Located northwest of Yellowknife, NT, the minesite was abandoned in 1959 after two years of continuous operation.

In the years following abandonment, several assessments were undertaken to evaluate the extent of contamination and environmental impacts. Studies conducted over the period of 1979 to 1995 included sampling of surface and groundwater, lake sediments, soils, vegetation and aquatic macrophytes for metals and radionuclide analysis. Gamma radiation and radon gas surveys were also included in some of the studies. Rehabilitation of the Rayrock minesite began in 1996. The project was managed by Public Works and Government Services Canada (PWGSC) on behalf of Indian and Northern Affairs Canada (INAC). Rehabilitation efforts focused on sealing the mine adit and ventilation shafts, removing radioactive material from the dump, disposing of dump material on the tailings, and capping the north and south tailings piles with a thick layer of silty-clay. The objective of the remedial program was to contain contaminants at the site and thereby limit exposures to persons who may frequent the area.

A short-term monitoring program conducted in 1996/97 provided a baseline of information to evaluate the effectiveness of rehabilitation efforts. Following the short-term program a long-term monitoring program was developed in 1999. The long-term monitoring program was designed based on analysis of critical exposure pathways. A review of the long-term program was undertaken in the first quarter of 2002 to evaluate the results of the rehabilitation program and develop a revised long-term monitoring program manual for the site.

Introduction

The Rayrock Uranium Mine is located 145 km northwest of Yellowknife, NT (Figure 1). Mining and milling of uranium ore in the form of pitchblend (UO_2, UO_3) occurred over a 2 year period (1957 – 1959) and saw the processing of 70,000 tonnes of ore producing 207 tonnes of uranium concentrate (yellowcake). Slurried tailings were surface-discharged without neutralization into two disposal areas near the minesite.

Site rehabilitation was undertaken in 1996 and a short-term monitoring program was subsequently initiated. The 1996/97 short-term program involved sampling of several environmental media including: surface and groundwater, aquatic sediment, terrestrial soils, radon, and gamma radiation. Intermediate and final receptors (aquatic macrophytes, aquatic mammals, fish, terrestrial vegetation, terrestrial mammals, and birds) were also sampled to determine the spatial extent of contamination in the vicinity of the former minesite. The results from the short-term program indicated that the health risk due to radiation exposure was low following the 1996 site remediation work (LLRWMO, 1998; Golder, 1999).

Based on this assessment, a focused long-term monitoring program was initiated in the fall of 2000. The long-term program was scheduled for implementation on an annual basis for an initial 10 years followed by a reduction in monitoring frequency. Results from the first 2 years (2000 and 2001) of the program were reviewed in early 2002 in order to evaluate potential revisions to the program and to determine whether any site maintenance was required.

Site Characteristics

The Rayrock site is located in the sub-arctic Mackenzie climate district and receives an average of less than 15 cm of precipitation annually. Drainage from this area flows into the Marian River drainage basin, which is characterized by a large number of lakes. The site is also situated in the traditional hunting and trapping region of the Dogrib First Nation. Local communities include Wha Ti and Gameti.

Mining operations took place underground with a mine adit positioned on the southern slope of the Marian Fault located on the north shore of Sherman Lake. Figure 2 presents an overview of the mine and associated infrastructure. Uranium ore was processed at a mill facility located immediately southeast of the adit. Waste rock was deposited adjacent to the adit and was also used in the construction of area roads and building foundations. Tailings were surface-discharged at two locations south of the mill facility. The north tailings are situated on a slope leading from the Marian Fault bedrock to the shores of both Lake Alpha and Lake Beta. The larger south tailings area stretches over a gentle slope leading into Gamma Lake.

The 1996 rehabilitation program was designed to limit the off-site migration of contaminants and thereby reduce human exposure to on-site radioactive contamination. The main components of the program included:

- Sealing the mine adit with waste rock;
- Cementing the entrance to the vent shaft and placing a chain-link fence around the collar;
- Placing a 1 metre layer of silty-clay over the north and south tailings disposal areas and seeding with grasses and clover; and
- Construction of lined/rip-rapped drainage ditches on the surface of the tailings covers to facilitate shedding of surface water and reduce infiltration into the tailings.

Site Contaminants

Studies conducted prior to the 1996 rehabilitation program identified several contaminants at the Rayrock site including metals and radionuclides in the aquatic environment (surface and groundwater) as well as gamma radiation and ambient radon gas.

Metals and Radionuclides

Water quality investigations conducted by Kalin (1984) and Veska and Eaton (1991) identified elevated concentrations of uranium, radium^{226}, polonium^{210}, iron and copper in surface and groundwater in the vicinity of the mine and tailings areas. Short-term monitoring conducted after rehabilitation also identified thorium^{230} and lead^{210} contamination. A series of bedrock and overburden groundwater monitoring well sets were installed in 1996 in an effort to delineate groundwater contamination. Paired well sets (bedrock and overburden) were positioned downstream of the former mill facility as well as along the downstream perimeter of the capped tailings areas.

Radon Gas and Gamma Radiation

Detectable levels of gamma radiation and ambient radon gas are well documented at Rayrock. Investigations undertaken by the Low-Level Radioactive Waste Management Office (LLRWMO, 1998) confirmed that elevated levels of radon gas and gamma radiation continued to be associated with the waste rock and the tailings disposal areas.

Long-Term Monitoring

The completion of the 1996 rehabilitation program required that a monitoring program be implemented in order to evaluate the overall effectiveness of remediation efforts. A long-term monitoring program was recommended in 1999 focussing on media that offer the most appreciable potential for unacceptable exposures balanced with the feasibility of sample collection (Golder, 1999). Media were then ranked according to potential for human exposure. The following ranking was subsequently generated:

1. External exposure to gamma radiation;
2. Ingestion of surface water from receiving water bodies (*e.g.,* Beta Lake);
3. Inhalation of radon;
4. Inhalation of radioactive dust; and
5. Ingestion of radioactive wild meat or fish flesh.

The potential for human exposure was then compared to the estimated ease of sample collection so as to ensure the program was as logistically feasible as possible. Potential monitoring components that satisfied these criteria included:

1. Visual inspection of physical barriers (tailings covers, and adit/vent shaft caps);
2. Gamma radiation surveys of rehabilitated tailings areas;
3. Radon measurements in the vicinity of the adits/shafts and tailings areas;
4. Surface water sampling of receiving lakes and streams;
5. Groundwater sampling downstream of Mill Lake; and
6. Fish tissue collection in a reference lake and Sherman Lake.

The program was scheduled for implementation on an annual basis for 10 years followed by a reduction in frequency to once every 10 years for a further 100 years.

Program Results

Long-term monitoring was initiated in October of 2000 and again in September of 2001. Visual inspections of the adit/vent shaft caps and tailings covers determined that each of these physical barriers remained in good condition. Various species of grasses and clover seeded on the tailings caps in 1996 have established a competent layer of erosion protection over the covers.

Gamma radiation transect surveys of the rehabilitated north and south tailings areas were completed using a Ludlum Model 19 radiation detector. Each of the surveys confirmed the results of the visual inspections indicating that emissions of gamma radiation were well below the 2.5 microSieverts per hour (μSv/h) rehabilitation objective (Golder, 2001; Rescan, 2001).

Ambient radon was measured using a Thompson and Nielson (Model TN-IR-21) instant radon progeny detector. Both the 2000 and 2001 surveys determined that radon was not detectable at any of the monitoring stations (reference or on-site stations). It was concluded that high winds and the presence of snow cover had prevented the accumulation of detectable concentrations of ambient radon.

Samples of surface waters from Lake Alpha and Sherman Lake indicated that concentrations of dissolved metals and radionuclides were generally consistent with those measured by the LLRWMO (1998). The only exceptions were a 25-fold reduction in dissolved thorium^{230} concentrations and a 7-fold increase in uranium concentrations.

Results from bedrock groundwater samples collected downstream from Mill Lake in the fall of 2000 indicated consistency with previous concentrations of dissolved metals and radionuclides assessed by the LLRWMO (1998).

Fish tissue samples from Sherman Lake indicated that tissue radionuclide activity was indistinguishable from background tissue samples obtained from Maryleer Lake (a reference site) (Golder, 2001). Additional fish tissue sampling was subsequently not recommended unless conditions at the site change.

Review of Long-Term Monitoring Program

The long-term monitoring program was reviewed in the first quarter of 2002 in order to evaluate the results from the first 2 years of the program and to refine operating procedures. The review was also intended to determine if there was any need for site maintenance works.

Inspection of Physical Barriers

The continued integrity of the adit and vent shaft caps and tailings covers is central to the long-term effectiveness of the 1996 rehabilitation program. Visual inspection of these areas is inexpensive relative to associated sampling campaigns and provides valuable planning information for any future maintenance activities that may be required. The visual inspection program was therefore recommended as an on-going component of the long-term monitoring program.

Gamma Radiation Surveys

The objective of the gamma radiation survey is to monitor the highest potential dose pathway and thereby detect any deficiencies in the integrity of the tailings covers. The monitoring protocol includes the use of standard monitoring equipment combined with transect survey techniques.

The 2002 program included plotting of gamma radiation survey data so as to produce radiation isopleths for comparison with results from the visual inspections (Rescan, 2002). Figure 3 presents the spatial distribution of gamma radiation over the reclaimed north tailings area.

Gamma radiation surveys remain a highly cost effective means for measuring the highest potential dose pathway. Plotting of these data provides a useful visual tool for tracking the performance of the tailings covers. As a result of these observations, gamma radiation surveys were also recommended for continued implementation as part of the long-term program.

Radon Gas Sampling

Radon gas has been identified as a significant potential exposure pathway. Detection of radon using progeny detectors was unsuccessful for both the 2000 and 2001 monitoring seasons. The monitoring program review indicated the use of portable progeny detectors was likely hampering efforts to detect ambient radon. A return to the use of activated charcoal canisters was subsequently recommended. Compared to progeny detectors, charcoal canisters are left exposed to ambient air for much longer sample periods (24 – 48 hours) and are therefore able to screen a wider range of field conditions.

Charcoal canisters provide an accurate means for measuring radon concentrations over short time periods but are not able to measure variability that is likely over several days or weeks. Therefore, to enhance the radon-monitoring component, a longer-term sampling methodology was recommended for implementation alongside the charcoal samplers in 2002 and 2003. The longer-term samplers are known as E-Perms and are utilized by the US EPA for long-term radon monitoring programs.

Results from the latest monitoring effort undertaken in the summer of 2002 indicated that radon concentrations were consistently lower on a monthly basis (E-Perm method) as compared to daily measurements (charcoal canisters). Figure 4 presents the results of the two sample methods for each of the monitoring locations.

Surface Water Sampling

Potential sources of surface water contamination include:

- the former mine and milling site adjacent to Mill Lake;
- the rehabilitated north tailings area adjacent to Lake Alpha and Sherman Lake; and
- the rehabilitated south tailings and waste dump areas upstream from Gamma Lake.

Surface water sampling was recommended for a total of four receiving water locations (2 additional over the original program). Sampling locations include:

- Mill Stream - downstream of Mill Lake and the former mine area;
- Sherman Lake - immediately south of the Rayrock site;
- Lake Alpha - adjacent to the north tailings area; and
- Gamma Lake - adjacent to the south tailings area.

The suite of surface water monitoring parameters includes physical parameters, total and dissolved radionuclides and metals. Table 1 lists each of the proposed monitoring parameters along with the associated Canadian Council of Ministers of the Environment (CCME) guideline value or range.

Table 1
Surface Water Quality Monitoring Parameters

Parameter	Units	Detection Limit	CCME Guidelines[1]
Physical			
pH		0.01	6.5 – 9.0
Hardness	mg/L	0.5	-
Total Suspended Solids	mg/L	3	-
Total and Dissolved Metals			
Aluminum	mg/L	0.005	0.100
Arsenic	mg/L	0.0001	0.005
Cadmium	mg/L	0.00005	0.000017
Chromium	mg/L	0.0005	0.001-0.0089
Copper	mg/L	0.0001	0.002
Iron	mg/L	0.03	0.300
Lead	mg/L	0.00005	0.001-0.002
Mercury	mg/L	0.00001	0.0001
Molybdenum	mg/L	0.00005	0.073
Nickel	mg/L	0.0005	0.025-0.065
Selenium	mg/L	0.001	0.001
Silver	mg/L	0.00001	0.0001
Uranium	mg/L	0.00001	0.100[2]
Zinc	mg/L	0.001	0.030
Total and Dissolved Radionuclides			
Lead210	Bq/L	0.02	0.1
Polonium210	Bq/L	0.005	0.2
Radium226	Bq/L	0.005	0.6
Thorium228	Bq/L	0.01	2
Thorium230	Bq/L	0.01	0.4
Thorium232	Bq/L	0.01	0.1
Uranium234	Bq/L	0.2	4
Uranium235	Bq/L	0.00008	4
Uranium238	Bq/L	0.00001	4

[1] Canadian water quality guidelines (CCME 1999a). CCME guidelines for metals are for the protection of aquatic life, guidelines for radionuclides are for drinking water quality. All CCME metal guidelines are for total values.
[2] Canadian drinking water quality guideline (CCME 1999b)

Groundwater Sampling

The potential sources of groundwater contamination at Rayrock include the waste rock pile adjacent to the former mine and mill area as well as the rehabilitated north and south tailings areas. Groundwater investigations of the north tailings area completed by Veska and Eaton (1991) indicated that the organic subsoils act to bind a portion of radioactive contaminants such as radium^{226} and lead^{210} mobilized by tailings porewater flow. Combined with the low permeability of the tailings covers, the potential for the rehabilitated tailings areas to act as long-term contaminant sources is considered low.

Review of the known site groundwater regime and the short-term monitoring results indicated that while the potential for contamination is low, monitoring of selected overburden wells on a long-term basis would be prudent. A total of 3 groundwater wells were subsequently recommended for long-term monitoring; an overburden well downstream of the former mine and mill area, an overburden well downstream of the north tailings area, and an overburden well downstream of the south tailings area.

Figure 5 presents the sampling locations of each of the monitoring program components outlined above.

Program Schedule

Each of the above long-term program components is scheduled for implementation on an annual basis for an additional 7 years (2003 – 2009) followed by a reduction in monitoring frequency to once every 10 years for a further 100 years. The length of the monitoring program is consistent with the nature of a radioactive site and the associated degree of physical stability that must be ensured in order to minimize exposures to individuals who may frequent the area.

Conclusions

A total of 3 years of post-rehabilitation long-term monitoring indicates that the 1996 rehabilitation program has been effective at containing potential sources of contamination and limiting associated exposures. Collection of successive years of monitoring data will allow for both re-assessment of the accepted monitoring frequency as well as determine any need to alter or reduce certain program components.

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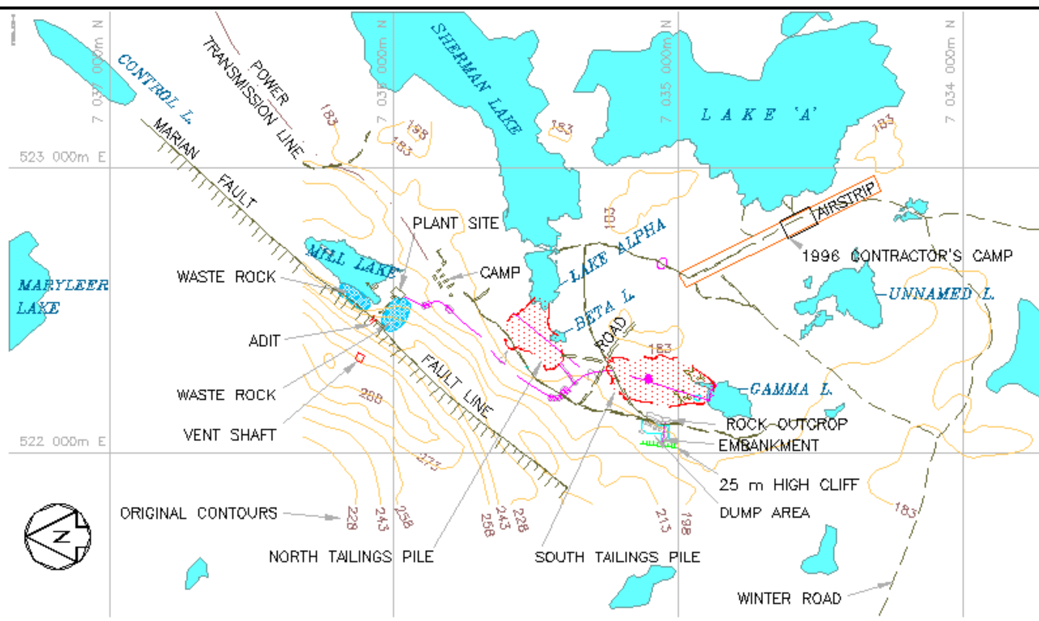
Rayrock Decommissioned Uranium Mine Site, Northwest Territories

FIGURE 1

Rescan™



Rayrock Decommissioned Uranium Mine and Associated Infrasture

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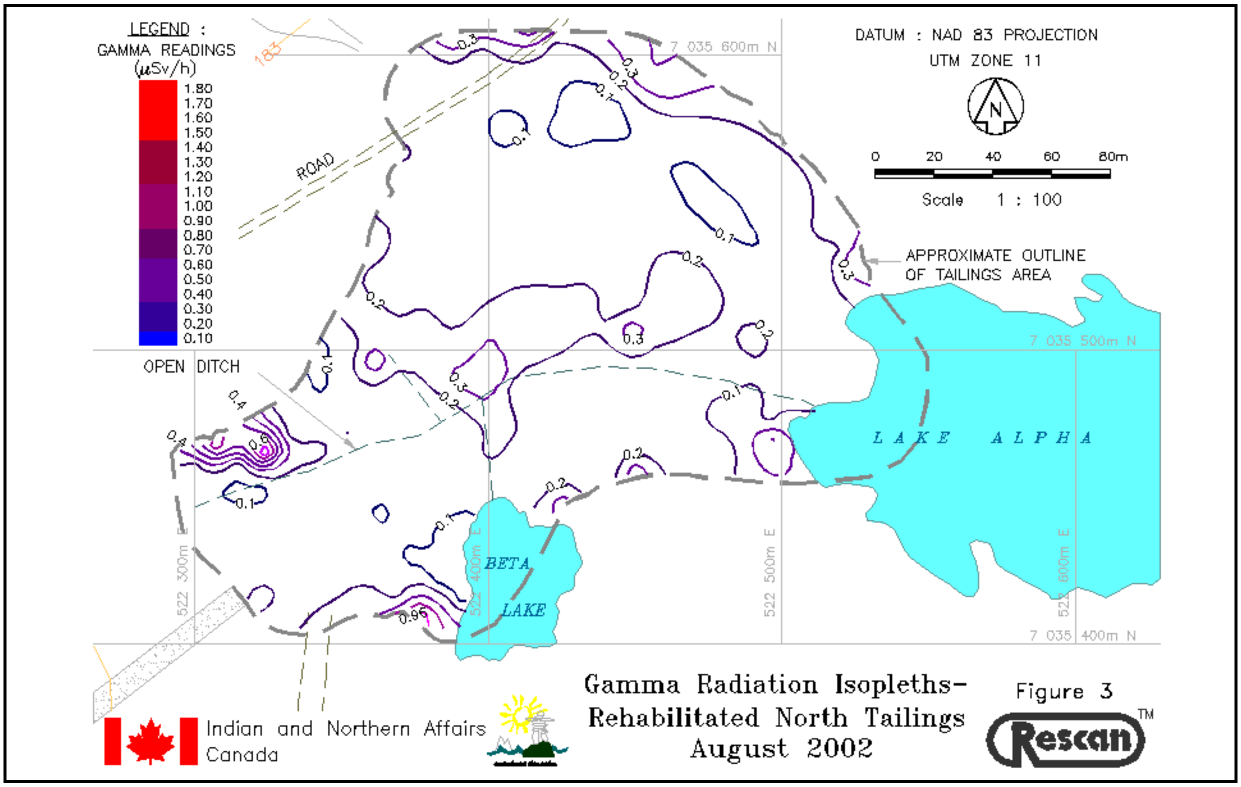
0 0.5 1.0 km

Scale 1 : 20 000

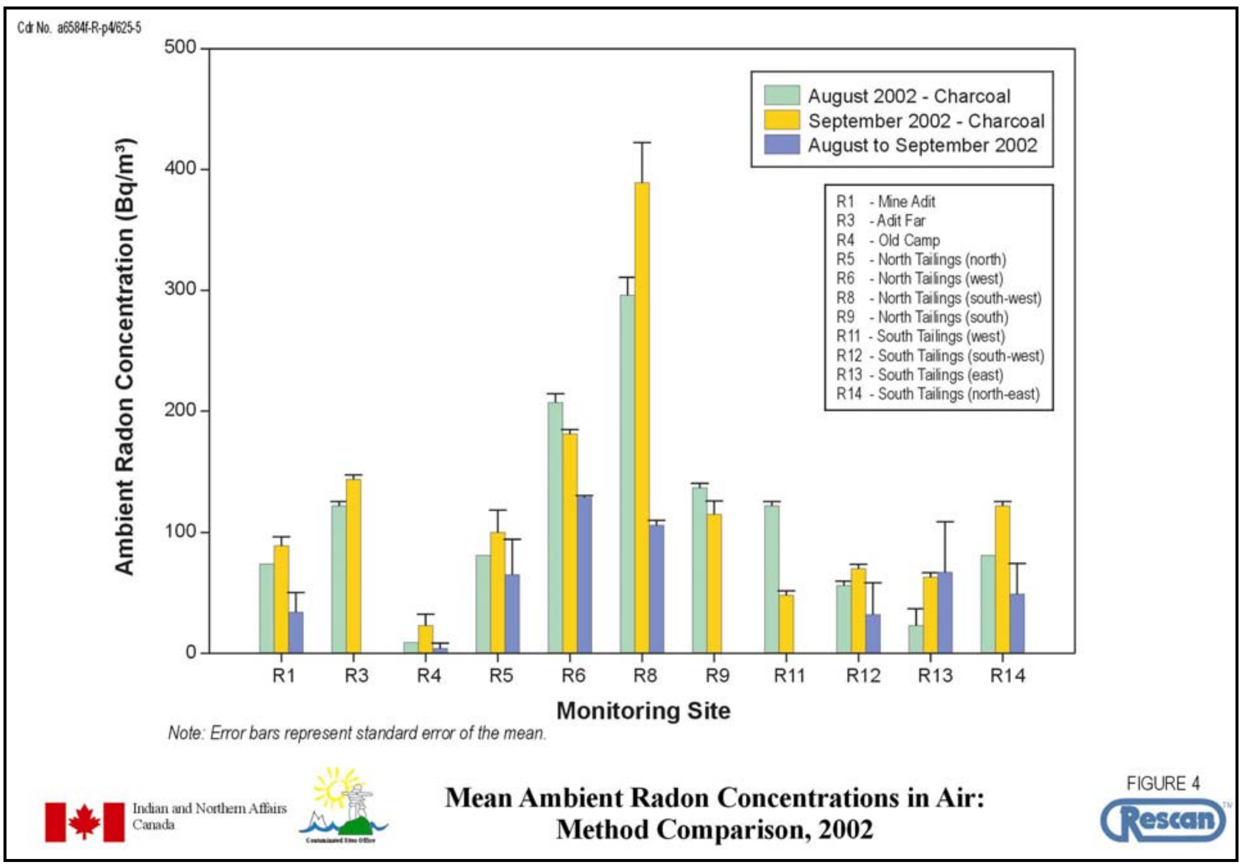
Figure 2

Rescan™



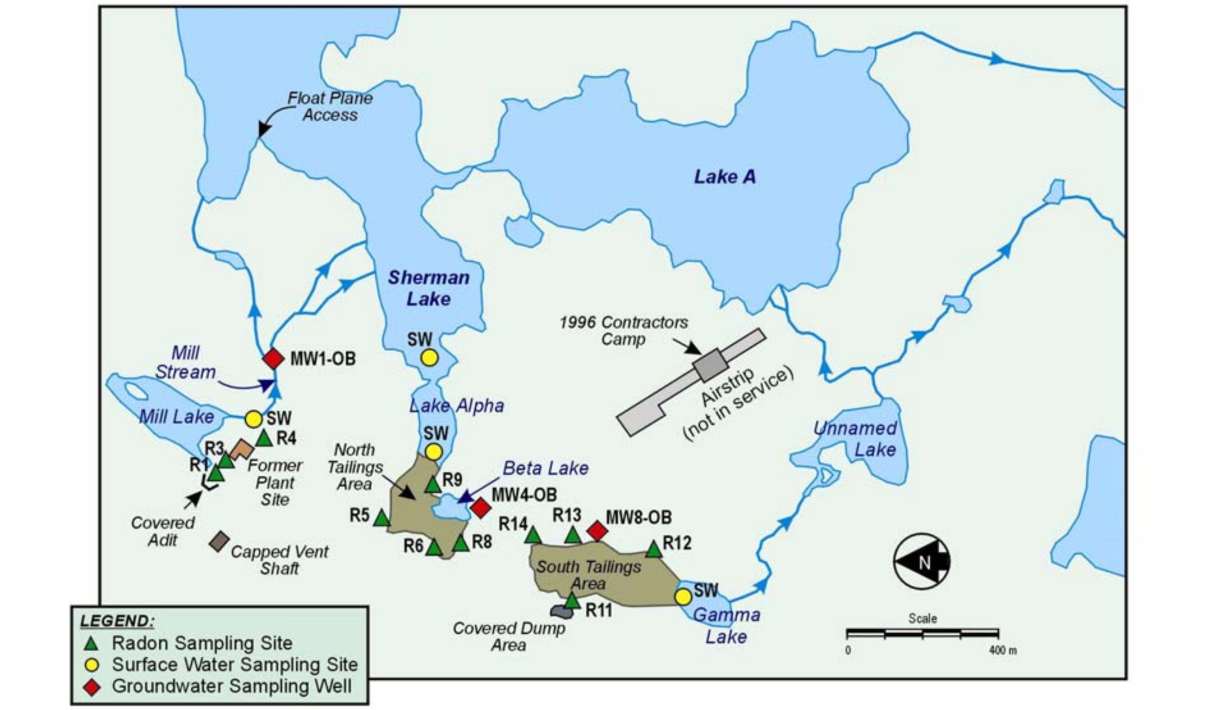
Gamma Radiation Isopleths-
Rehabilitated North Tailings
August 2002

Figure 3



Mean Ambient Radon Concentrations in Air:
Method Comparison, 2002

FIGURE 4



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Sampling Locations for Rayrock Long-Term Monitoring Program

FIGURE 5

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