

## **Verification Survey of Uranium Mine Remediation - 9537**

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### **ABSTRACT**

The Canadian Nuclear Safety Commission (CNSC) contracted an independent verification of an intensive gamma radiation survey conducted by a mining company to demonstrate that remediation of disturbed areas was complete. This site was the first of the recent mines being decommissioned in Canada and experience gained here may be applied to other mines being decommissioned in the future. The review included examination of the site-specific basis for clean-up criteria and ALARA as required by CNSC guidance. A paper review of the company report was conducted to determine if protocols were followed and that the summarized results could be independently reproduced. An independent verification survey was conducted on parts of the site and comparisons were made between gamma radiation measurements from the verification survey and the original company survey. Some aspects of data collection using rate meters linked to GPS data loggers are discussed as are aspects for data management and analyses methods required for the large amount of data collected during these surveys. Recommendations were made for implementation of future surveys and reporting the data from those surveys in order to ensure that remediation was complete.

### **INTRODUCTION**

The uranium mine site, located in Northern Saskatchewan Canada, began operation in the 1970s and completed extraction and milling in the 2000s. Mining was primarily from open pit operations; however, there was some underground recovery.

This was the first of the modern mines in Canada to be decommissioned and technology and regulatory structure has changed from the historic mines. The mine is being decommissioned on a staged approach beginning with those areas most affected by mining operations (i.e. the mining areas, the mill and the tailings management areas). The mining company developed dose based criteria for these areas, completed remediation and conducted a gamma radiation survey to ensure that remediation was complete.

### **Evolution of Gamma Radiation Surveys**

Historically, verification surveys had been conducted with hand-held measurements on 10 m grid points with the measurements recorded by hand along with the co-ordinates. The measurements were collected on contact with the ground and at a height of one meter above the soil. The process required establishing the geographic grid points through surveying and hand recording of the data collected.

Currently, the mining company and others have linked gamma radiation detectors with global positioning system (GPS) data loggers that automatically and electronically store both the gamma radiation measurements and the geographic co-ordinates. This allows the collection of high-density surveys through roving over the area of interest and automatically collecting the required data. The benefits of this approach are reducing the time required to conduct the surveys, the higher density of surveying, reducing the data recording errors and facilitating data analyses including daily review of data while in the field.

### **Canadian Nuclear Safety Commission (CNCS) Requirements**

The CNCS is the regulator responsible for uranium fuel cycle activities in Canada. It has guidelines for the reclamation of fuel cycle properties that include the development of site-specific criteria for properties. As part of their mandate, the CNCS is required to review the reclamation of properties.

CNCS contracted an independent verification survey to review the three important components of the gamma radiation survey program including the basis for the clean-up criteria, review whether procedures were followed and to conduct an independent survey of some of the areas.

### **REVIEW OF CRITERIA BASIS**

The site is isolated from other uranium fuel cycle operations; therefore, it is extremely unlikely that a member-of-the-public would be exposed to radiation doses from other facilities; therefore, it is considered acceptable to set the radiation dose limit to 1 mSv/y. In other settings, where multiple facilities are more closely located, alternatives to the full 1 mSv/y dose limit for an individual site may need to be considered.

A site-specific stakeholder meeting was previously conducted by the mining company with members of the local community. The disturbed areas of the site were considered not suitable for permanent habitation and occupation (casual access) would be limited to 1,000 hours per year over areas of 10,000 m<sup>2</sup>. Since the allowable dose standard for members of the public is currently 1 mSv/y for this site, the gamma radiation dose criterion was determined to be 1 µSv/h (i.e. 1 mSv/y divided by 1,000 h/y). However, there are other sources of radiation exposure associated with this site including exposure to airborne radon releases and radionuclides in water pathways therefore, the 1 µSv/h criterion would be included in a sum rule to control total dose.

A criteria for an individual gamma radiation measurement was established from provincial regulations for the reclamation of uranium mines and was interpreted by the mining company to mean at individual points. The previously established value was 2.5 µSv/h although the specific dose basis for this factor is unclear.

The mining company established a requirement of at least one measurement for every 100 m<sup>2</sup> to ensure coverage. In addition, the mining company had established ALARA guidelines for the disturbed areas; first, the concentration averaged over a 100,000 m<sup>2</sup> area (10 hectare) was set at 0.3 µSv/h. Second, the survey density was increased to 10 measurements per 100 m<sup>2</sup> in areas with average gamma radiation levels exceeding 1.0 µSv/h to reduce the probability that a maximum location was missed. Third, a guideline was established to reduce the probability of clustering of small areas with higher gamma radiation levels.

## **REVIEW OF MINING COMPANY GAMMA RADIATION SURVEY REPORT**

The review of the mining company report was a table-top study considering procedures, the gamma radiation data collected, the survey unit boundaries and the reporting. Elements of the review included examination of whether procedures were followed, reconstruction of the reported results and review against established criteria.

### **Procedures**

Detailed procedures were provided for collection of gamma radiation measurements including daily QA/QC checks on instrument performance, the data collection procedure and the management of the data collected from the surveys. The review indicated that these procedures were followed. Procedures for analysis of the data were less clearly described and investigation required more detailed study.

### **Data Analysis**

There were several different averaging areas considered in the criteria and guidelines and these were evaluated by considering several overlapping circular areas within the region of interest. For example, the criteria and guidelines were evaluated on a 1 m grid over the region of interest. At each 1 m grid, a circular area was defined relative to the averaging area of interest and the measurement data within that circle was averaged. Therefore the area of interest was covered with a series of moving and overlapping averages rather than a single average over a uniquely defined survey unit with strict boundaries.

The mining company report provided maps showing the average concentrations or data density for each of the survey units along with a summary statistics table for comparison against the criteria and ALARA targets. Intermediate data summaries were not provided in the report so that the review approach was to independently construct maps and do a visual comparison with maps produced in the mining company report and to summarize the maximum levels for each of the areas.

During the review, two discrepancies were noticed; first, some measurement data from outside the survey unit boundary were used to calculate averages. Construction of maps indicated better agreement when the data from outside the boundary were used to create the maps compared with only using the data from inside the survey unit boundary. However, this did not make a substantive difference in the highest average gamma radiation level on the survey unit.

It was also discovered that the averaging process used by the mining company did not account for the non-uniform density of data points but simply averaged all points within a given radius of the point of interest. An alternate method was used where the averaging was conducted on a uniform density presentation of the data (e.g. data were interpolated to a regular grid). The two averages at the same location could vary by a factor of two based on the uneven data density; however, the maximum average tended to be higher using the non-uniform density approach. This was likely due to higher density measurements in localized areas with higher gamma radiation levels.

The appearance of these two discrepancies could be related to the lack of established formal procedures for data management and analysis.

### **Comparison to Criteria**

The maximum statistics for each of the nine survey units were compared to the criteria and the ALARA guideline values. All survey units were below the relevant criteria and guidelines with one exception. One survey unit was above the ALARA guideline of 0.3  $\mu\text{Sv/h}$  for a 10 hectare area; however, this area

had been measured a number of years after the original remediation and vegetation had become well established. Continued remediation of the survey unit was not recommended by the mining company in order to preserve the established vegetation.

### **Conclusion of Mining Company Report Review**

The review indicated the procedures were followed and the measured results acceptably met the established criteria and ALARA guidelines. The improvements arising from more defined procedures for the analysis of data in future surveys were noted along with the unusual aspects of using data from outside the boundaries and the non-uniform averaging of data.

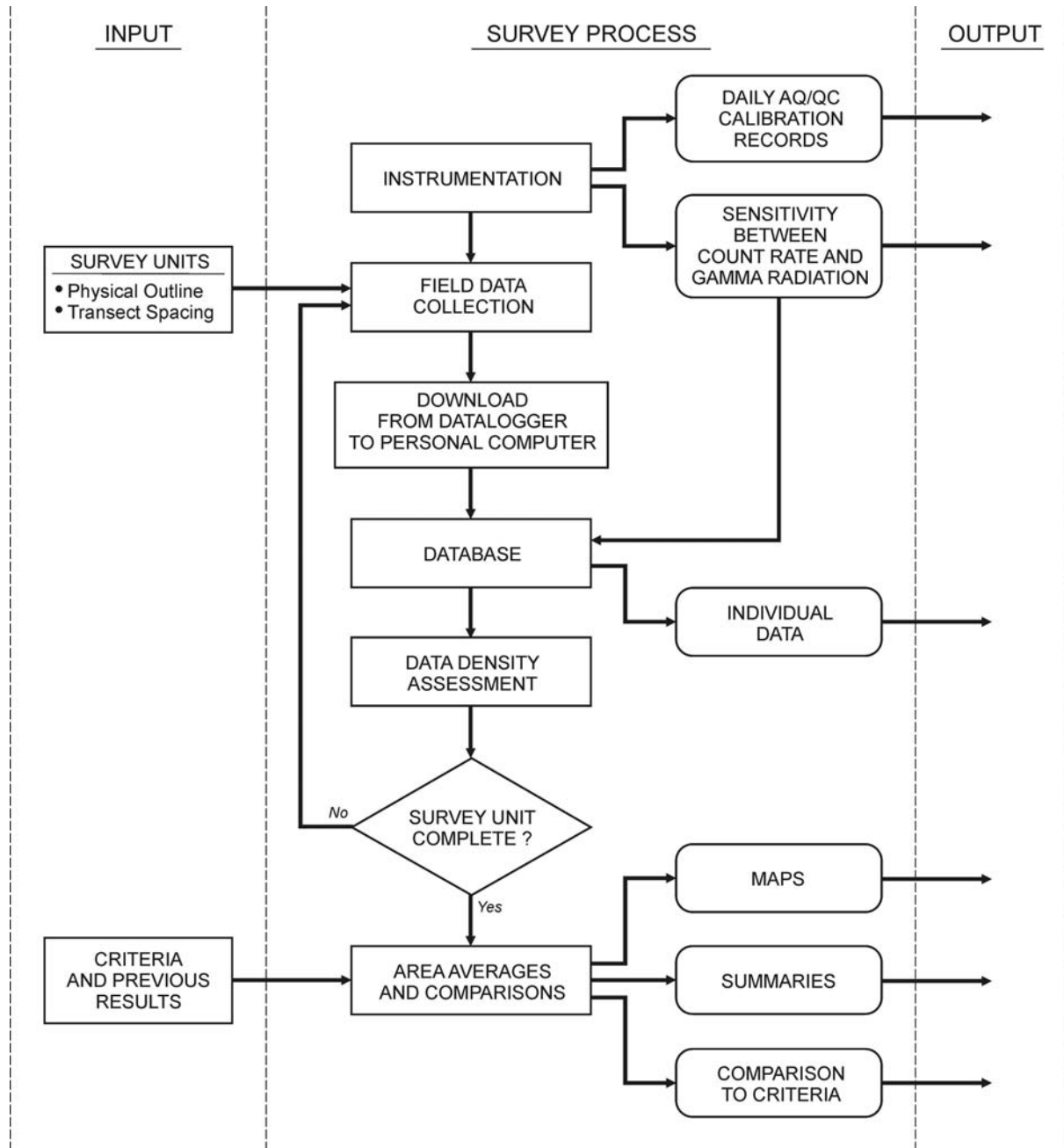
### **VERIFICATION SURVEY**

An on-site verification survey was conducted to confirm that measurements were similar and to verify the conclusions and assessment of the mining company report.

#### **Design**

The design of the survey considered the steps with Figure 1 which adopts many elements of the data quality objective (DQO) process. The inputs (survey requirements) and output (deliverables) were recognized and the survey procedures to conduct the survey were defined.

**Figure 1**  
**Survey Flow Chart**



Several survey units were defined by the CNSC for field measurement with established priorities. The mine owner provided the geographic co-ordinates for the corners of these survey units which were

imported into a GIS system. These boundaries were used for report presentation and as background files on the data loggers during sample collection. Survey requirements for the verification survey were to measure 25 m<sup>2</sup> or 100 m<sup>2</sup> blocks (i.e. squares of 5 m by 5m or 10 m by 10 m) depending on the survey unit. The completeness objective for the verification survey was that at least 95% of blocks were surveyed.

## **Instrumentation**

The systems used were Ludlum 2221 ratemeters with Model 44-10 2" by 2" sodium iodide (NaI) detectors. These detectors measure count rates and do not have energy discrimination for radionuclide concentrations or to support calculation of gamma radiation dose rates. The count rates in these detectors are relatively insensitive to the gamma radiation from cosmic radiation as the muons can not be measured and the capture efficiency for cosmic photons is low.

A conversion to exposure rate from the count rate is required; however, this conversion depends on the radionuclides present and the spatial orientation of the source. Two general approaches are available to determine the sensitivity of count rate per exposure rate; first, is by site specific tests between count rate and the gamma radiation measured with a pressurized ion chamber (PIC) or PIC- equivalent meter. For this study, the response of count rate to the radionuclide concentrations in test pads of known radionuclide concentration were analyzed to get the count rate to exposure rate relationship for natural radionuclides. The second approach was used for this project and a factor of about 2150 cps per  $\mu\text{Sv/h}$  for uranium series radionuclides in equilibrium with its progeny was the sensitivity used for these meters.

Firmware electronic chips are available for the rate meter in order to export gamma radiation count rate at a regular rate with the 1 second chip preferable for the moving surveys. A typical low background count rate with the 2" NaI detector is about 100 counts per second which corresponds to a one sigma standard deviation of +/- 10 cps and therefore a 95% interval of +/- 20 cps due to counting statistics. The relative precision decreases with increasing count rate; therefore reliable measurements are available with a 1 second counting interval for background levels. Use of a 1 second reporting chip is recommended over the 2 second chip to provide a more accurate spatial characterization.

The GPS system and data logger used was a Trimble GeoHT (2005 series) unit which contains the antennae, GPS unit and data logger within a single hand-held unit. The instrument is capable of real-time differential correction to sub-meter in Northern Saskatchewan and to sub-foot in higher populated areas. These were found to be a substantial improvement over the larger units requiring a backpack to hold batteries and an antenna.

A field study was conducted on the measurement of isolated locations with elevated gamma radiation using both a SENES and one of the mine site meters. The meters were both Ludlum 2221 rate meters connected to 44-10 detectors; however, the mine site rate meter exported the count rate every two seconds while the SENES meter exported data every one second. Also included in the test was variation of the speed of transect and the height above the soil surface. Each pass was conducted 10 times or more and Table 1 summarizes the median gamma radiation level measured during a pass. It can be seen that the two second count rate underestimates the gamma radiation exposure rate compared to the one second count rate and the difference is larger for the 2 m/s speed than the 1 m/s speed. Also, the roving measurement at a height of one meter tends to underestimate the static count present.

## **TABLE 1**

**MOVING DETECTOR MEASUREMENT ( $\mu\text{Sv/h}$ )  
OF A SMALL ELEVATED AREA**

	0.7 m Height	1.0 m Height
Static Measurement	9.3	5.7
Moving Surveys Directly Over Elevated Area		
1 m/s speed		
SENES (median)	8.5	5.1
Mining Company (median)	6.8	5.0
2 m/s speed		
SENES (median)	6.4	4.8
Mining Company (median)	5.6	3.8

The verification measurements were collected at a height of less than one meter to ensure that the individual gamma radiation level could be assessed if the meter passed over a spot exceeding  $2.5 \mu\text{Sv/h}$ . Typically this does not affect averages over larger areas but may overestimate the exposure rate at a height of 1 m for small isolated areas. Any location that indicated above  $2.5 \mu\text{Sv/h}$  was re-measured with the meter held at a height of 1 meter and a slower transit speed.

**Data Collection**

Each morning, instrument QA/QC checks were conducted using a Cs-137 check source and a background check. The instruments were within the operating range each day.

Walking surveys were conducted on many of the survey units since vegetation had been planted and there was concern that the vegetation might be damaged with use of all terrain vehicles (ATVs). Survey navigation was conducted by viewing the background file and survey progress that are displayed in real time on the GPS datalogger. On some survey units, the vegetation was well established and required careful negotiation while maintaining the desired coverage.

The tailings management area (TMA) was covered with long grass rather than tree seedlings so the survey was conducted using ATVs. It was not possible to see the previous path taken in the grass and navigation through viewing the GPS data logger was difficult due to possible obstructions such as large rocks and berms on the surface which were hidden by the long grass. The approach adopted was to place an orange pylon on the top of a shovel placed in the ground at the end of each transect. This provided straight survey lines over up to 800 m in length.

Daily reviews were conducted on the data collected to assess the performance of the instruments, to ensure that data coverage requirements were met and to identify features of interest for further investigation.

## Data Analyses

Two analyses were conducted; first, was to reproduce the original mining company approach on data from one of the original survey units and to address the presence of individual locations exceeding 2.5  $\mu\text{Sv/h}$ . The second was to complete small scale comparisons between the company and the verification survey.

The conclusion from applying the summary statistics as calculated by the company and by the verification survey was that there was no change in the assessment of gamma radiation levels. The criteria and ALARA guidelines were met with the verification data. There was one location on the TMA where the gamma radiation exceeded the 2.5  $\mu\text{Sv/h}$  guideline.

The detailed approach used a paired comparison between concentrations measured on 10 m by 10 m or 5 m by 5 m blocks from the mining company and verification survey. Comparisons were made on a block by block basis. In most cases, the averages on these blocks agreed within 0.05  $\mu\text{Sv/h}$  between the verification and the mining company survey. However, there were a number of contiguous areas that showed systematic differences between the surveys. These changes may be due in part to site condition (e.g. variations in soil moisture) and potential real changes due to additional remediation after the original survey or environmentally driven changes. The use of this type of gamma radiation surveys provides a useful means for ongoing monitoring of remediated areas.

## CONCLUSION

The review indicated that the mining company had developed a site-specific dose criterion for the site. Agreed to procedures were followed by the mining company and the maps and summary statistics could be re-produced during the review. The verification survey indicated that the pattern of measurements could be reproduced.

Recommendations for the future surveys arising from the review included:

- i) establishing reporting requirements for gamma radiation data and survey unit definition
- ii) use of a 1 second export chip for roving surveys
- iii) limit speed of survey speed to 2 m/s or less for surveys
- iv) analyses and averaging of data that accounts for the non-uniform density of data along with procedures to describe the method.
- v) the elevated gamma radiation level criteria should be for a small area rather than an individual measurement.

The site-specific dose criteria coupled with a high density survey using integrated radiation detection and GPS measurement provide a strong basis for demonstrating that remediation is complete.