DEVELOPMENT OF ENVIRONMENTAL TECHNOLOGY IN SUPPORT OF THE DECOMMISSIONING OF URANIUM TAILINGS AT CLUFF LAKE MINE

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ABSTRACT

Cogema Resources Inc., together with the Unsaturated Soils Group at the University of Saskatchewan, initiated a multi-year research program at the Cluff Lake Mine during the summer of 1995. The objective of the research program is to investigate three key areas of environmental technology related to the decommissioning of uranium tailings in northern Saskatchewan. The first area of research is to evaluate methods for predicting the net flux of water across the tailings/atmosphere boundary. This research area consists of two phases; Phase I involves field monitoring of two sites (a tailings surface and a natural surface), while Phase II consists of numerical modelling. The second area of research is the characterization of the geochemistry and the development of methods for estimating the potential (leachable) contaminant mass. The last area of research is the characterization of paste tailings and involves determining the hydraulic and mechanical properties of the tailings. This paper briefly outlines the research program with a particular emphasis on the field instrumentation program currently being undertaken at Cluff Lake Mine.

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INTRODUCTION AND BACKGROUND

A critical element in mine development is the design of containment facilities for waste rock and mine tailings. These materials have the potential to release contaminants to natural groundwater and surface water systems which in turn provide pathways for these contaminants to biological receptors. It is important that engineering technology be developed in this area in order to enhance the level of environmental protection provided in the design of waste management facilities.

Cogema Resources Inc. and the University of Saskatchewan signed a contract in January, 1995 to initiate a three year research program at Cluff Lake Mine. The research program consists of three key areas in which environmental-technology related to the decommissioning of uranium tailings can be developed within Saskatchewan. The three studies involve defining the chemical and hydraulic response of the tailings, as well as the physical characterization of the waste material. The studies are not intended to be comprehensive in their coverage of technical concerns related to the decommissioning of uranium tailings; rather, they focus on key technical issues of concern industry-wide.

The purpose of this paper is to briefly describe the three areas of the research program and describe in detail the field instrumentation portion of the program. At this stage only a small quantity of field data has been collected. Therefore, the focus of this paper will be on the design of the field instrumentation program and the field installation.

RESEARCH PROGRAM - OVERVIEW

The objective of the research program is to investigate three key areas of environmental technology related to the decommissioning of uranium tailings in northern Saskatchewan. The first area of research is to evaluate methods for predicting the net flux of water across the tailings/atmosphere boundary. This research area consists of two phases; Phase I involves field monitoring of two sites (a tailings surface and a natural surface), while Phase II consists of numerical modelling. The second area of research is the characterization of the geochemistry and the development of methods for estimating the potential (leachable) contaminant mass. The last area of research is the characterization of paste tailings and involves determining the hydraulic and mechanical properties of the tailings. In the next sections the key background issues, methodology, and the contribution of each study to technology development are described.

Hydraulic Definition

Defining the hydraulic response of the tailings is critical to the prediction of contaminant release and transport to the environment. The net flux of water across the tailings surface controls the volume of effluent generated and the degree of saturation in the waste material. This latter condition controls rates of radon release as well as rates of oxygen ingress and subsequent acidification of acid generating waste.

In order to more accurately define this flux of water a two phase study is being undertaken. The first phase involves the establishment of instrumented field sites at the Cluff Lake Tailings Management Area (TMA). The instrumentation includes site specific meteorological measurements as well as detailed monitoring of the temperature, water content, and water pressure within tailings and natural surface soils. The monitoring will continue over the three year duration of the research program.

The second phase of this study is to verify the applicability of a previously developed numerical model for flux prediction. This model (SoilCover, (MEND, 1993)) was developed at the University of Saskatchewan as part of the MEND program. Once verified and calibrated for this site it should become a useful tool for the design of the final tailings configuration and cover.

The specific aspects of technology development associated with this project are: (1) the development of instrumentation systems for TMA monitoring, (2) the development and verification of software for flux predictions, and (3) the development of a methodology for the design of surface covers for decommissioning of uranium mine waste in northern Saskatchewan.

Chemical Definition

One key technical concern related to the performance of the TMA following decommissioning is the definition of the mass of Ra-226 which will be leached from the tailings with time. This is a critical issue for all methods of tailings disposal including in-pit disposal methods. In a conventional TMA, like Cluff Lake, the concentration of Ra-226 within the tailings as it is leached by surface and groundwater inflows must be known in order to predict mass loadings to the environment following decommissioning. As a result, there is a need for an accurate and reliable technique by which the "leachable" fraction of Ra-226 released from mine tailings can be determined.

A laboratory program will be conducted in which conventional tailings or paste tailings will be tested. These tailings will be placed in conditions similar to those present in the field and would then be allowed to leach through diffusion into a reservoir containing groundwater. This technique has been developed jointly by the University of Saskatchewan and the National Hydrology Research Institute.

This program will produce a procedure by which the tailings source chemistry and its total potential contaminant loading to the environment can be estimated. Many current predictions of contaminant loading to the environment utilize a constant source concentration. If a decrease in source concentration due to leaching at the tailings boundaries is utilized, significantly lower loadings to the environment will be predicted.

Physical Definition

The search for innovative techniques for tailings containment initially led to the engineering of the TMA through the use of cutoffs, liners, or pervious surrounds. In recent years, however, there has been increased interest in engineering the properties of the tailings themselves (Robinsky, 1975; Barbour et al., 1993). In many instances the optimum performance of the TMA with respect to low hydraulic conductivity, minimal influx of water, uniform hydraulic and geochemical properties, and saturated conditions can be enhanced by controlling the properties of the tailings during deposition. One of these new placement technologies is the use of paste tailings.

This study will utilize the paste tailings currently being considered for deposition at the Cluff Lake TMA. The testing will include not only standard geotechnical properties, but also hydraulic properties (moisture retention, hydraulic conductivity, etc.), thermal properties (thermal conductivity, specific heat) and geochemistry. Field verification of the laboratory characterization will also be required, particularly as it relates to the depositional nature of the paste tailings. Numerical modelling of the role of the paste tailings in controlling seepage and contaminant transport from the TMA will then be undertaken.

The future design of TMAs for uranium mines includes the ability to "design" the properties of the tailings themselves. The results from this program will provide a fundamental understanding of the properties and benefits of paste tailings on the design and performance of a TMA.

FIELD INSTRUMENTATION PROGRAM

The main objective of the field monitoring program is to characterize the soil/atmosphere flux boundary conditions of the mine tailings and natural surface soils at Cluff Lake Mine. Additional objectives are as follows:

(1) To install and monitor field instrumentation on the tailings and natural surface soils,

(2) To measure the net flux of water across the surface of the mine tailings and natural soils, and

(3) To establish a comprehensive set of field data for field response modelling.

The quantity of water which flows downward through the tailings can be defined as the net infiltrative water flux for groundwater recharge and leachate production. The net infiltrative flux is controlled by the water balance at the soil surface which includes precipitation, runoff, infiltration, evaporation and/or evapotranspiration, and changes in soil moisture storage. In general terms, the net infiltrative flux through a specified depth and time period can be calculated as the total precipitation less runoff, evapotranspiration and change in soil moisture storage. Therefore, site specific measurements of precipitation, runoff, evapotranspiration, and volumetric water content are required to properly evaluate net infiltrative fluxes.

Swanson (1995) demonstrated that accurate predictive modelling required an initial field response, or calibration stage. Field responses refer to conditions that develop within a soil system such as changes in moisture content, matric suction, and temperature. The ability to accurately describe field conditions must first be demonstrated before a model can be used to predict net infiltrative fluxes. As a result, the input parameters required by the model lay the foundation for the field instrumentation program.

General Features of Field Program

The general features of the field monitoring program at Cluff Lake Mine are: (1) data acquisition systems, (2) back-up monitoring methods, (3) the selection of the sampling frequency, and (4) the establishment of two monitoring sites.

The use of automated systems for data collection greatly reduce the need for human intervention and in particular, the requirements of mine site personnel. A data acquisition system usually consists of a datalogger, multiplexer, and storage module, contained in an environmentally sealed enclosure, and a solar panel/rechargeable battery power source. A multiplexer increases the number of sensors that may be scanned by the datalogger. A storage module reduces the frequency of trips required to download data and in the event of a power loss, will retain all stored data.

In order to ensure that the field data is representative of actual conditions, more than one method should be used to monitor a given parameter. If only one method is available for monitoring, then more than one of the selected instruments should be installed. Problems such as defective or poorly calibrated instrumentation can be detected if back-up systems are included in the field program. Periodic manual measurements during site visits allows for error checking in the automated monitoring systems.

Selection of the proper sampling frequency is another key element in any field instrumentation program. The ultimate use of the data aids in establishing the need for measuring fluctuations in the signals. For example, wind speed often fluctuates rapidly and as a result, a high rate of sampling is required for an accurate representation of wind speed. For this study, sampling frequencies will be established by initially collecting data at a rapid pace. Once the data has been reviewed, the rate of data collection will be slowed to meet the necessary data requirements while still maintaining sufficient accuracy. A reduced rate of sampling maximizes the memory space of the storage modules.

The field program at Cluff Lake Mine involves the establishment of two monitoring sites, one site on the uranium tailings and one on the natural surface soils (sandy till). The sites were situated so that the depth to the water table was maximized, allowing for the monitoring of an unsaturated soil system. The purpose of the natural surface monitoring site is to provide a natural analogue to the performance of a potential till cover.

Design of Field Program

The design of the field instrumentation program involved the selection of robust instruments that required minimal calibration and maintenance. The methods and instruments selected for the monitoring of climatological and hydrological conditions at Cluff Lake Mine are discussed below.

Climatological Monitoring

Site climatic conditions are measured with a fully automated weather station. Meteorological measurements include air temperature, relative humidity, wind speed and direction, net radiation, and precipitation. These measurements are used as input to SoilCover for the calculation of potential evaporation (Swanson, 1995). The temperature and relative humidity probe is housed in a radiation shield to minimize the effects of solar radiation. All sensors are connected to a data acquisition system.

The automated weather station collects hourly averages of temperature, relative humidity, wind speed and direction, and net radiation. Data is output as rainfall occurs in order to generate intensity-duration curves for rainfall events. The daily maximum and minimum values of air temperature, relative humidity, and wind speed are recorded, along with the total precipitation for the day. In order to check the validity of these measurements, comparisons will be made with data collected from the Cluff Lake Meteorological Station.

Hydrological Monitoring

Evaporation - Soil evaporation is a coupled process which depends on both atmospheric conditions (i.e. net radiation, temperature, humidity, wind speed) and soil properties (i.e. soil water potential, hydraulic conductivity and moisture retention properties). If a soil surface is saturated, water can evaporate at a rate equivalent to that of a free water surface (Penman, 1948). This rate, often termed the potential evaporation rate, represents the upper limit at which water can be supplied to the atmosphere and is solely a function of atmospheric demand. As the soil dries and becomes unsaturated, the rate of evaporation declines below the potential rate. This actual rate of evaporation depends on both atmospheric conditions and soil properties (Wilson, 1990).

The field program at Cluff Lake Mine utilizes the Bowen Ratio energy balance method to measure actual evaporative fluxes (Bowen, 1926). The Bowen Ratio instrumentation, developed by Campbell Scientific Inc. (1988), is illustrated in Figure 1. It is a self-contained tripod structured meteorological monitoring system. Variables measured include air temperature (at two heights), vapour pressure (at two heights), net radiation, and soil heat flux. The Bowen Ratio system measures these variables every twenty minutes and operates during the summer months only.

Matric Suction - Field matric suction is a measurement of the negative water pressure within a soil system. These measurements are important because matric suction describes the stress state within the soil and the hydraulic gradients. In other words, a change in the degree of saturation or water content of a soil system is caused by a change in matric suction within the soil. In addition, Swanson (1995) demonstrated that field matric suction measurements were useful for verifying the actual evaporative flux predicted by SoilCover.

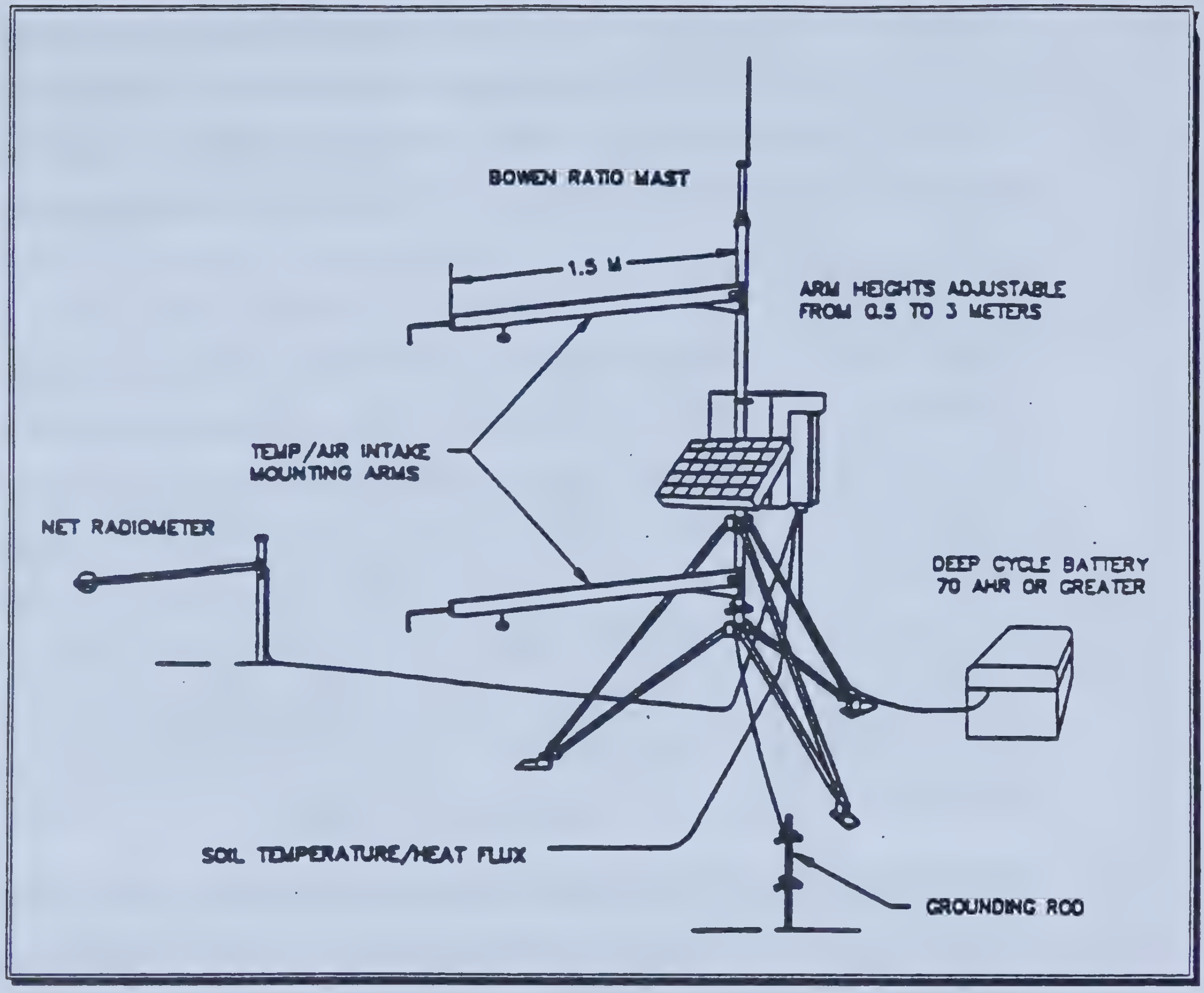

Figure 1. Schematic of the Bowen Ratio System (after Campbell Scientific Inc., 1988).

Measurements of insitu soil matric suction are made with thermal conductivity sensors and jet-fill tensiometers. The thermal conductivity sensor indirectly measures the matric suction in a soil while also measuring the temperature of the soil. These sensors are monitored continuously with a data acquisition system. Laboratory calibration of each sensor is essential in order to obtain representative field measurements of matric suction. Jet-fill tensiometers directly measure the negative pore water pressure in a soil. The tensiometers will be used to validate measurements by the thermal conductivity sensors.

Soil Temperature - In order to accurately predict heat fluxes with SoilCover, field measurements of soil temperature are required (MEND, 1993). A multi-point thermistor string is used in this program to verify the temperatures recorded by the thermal conductivity sensors. Each string consists of eight beads (thermistors) located at user-specified depths. The thermistor strings are connected to a data acquisition system for continuous monitoring of soil temperature.

Water Content - Measurements of insitu volumetric water content are needed to determine changes in soil moisture storage. Methods used to measure volumetric water content need to be fast, reasonably accurate, and nondestructive. The methods selected for the field program at Cluff Lake Mine are time domain reflectometry (TDR) and the neutron hydroprobe. TDR was selected because measurements at several depths within the soil can be made automatically with one TDR unit, calibration is not essential, and the system requires little maintenance. Neutron probe access tubes provide manual measurements of volumetric water content, which can be used to verify values obtained by TDR.

The principles behind measurement of volumetric water content using TDR have been described in detail elsewhere (Topp et al., 1980; Roth et al., 1990; Look and Reeves, 1992); they are reviewed briefly here. TDR is used to measure the apparent dielectric constant of soil, which is closely related to volumetric water content. Water has a dielectric constant on the order of 80, whereas the dielectric constant of soil solids is typically 3 to 5 (Topp et al., 1980). Consequently, changes in volumetric water content affect the apparent dielectric constant of soil. This study uses three-wire TDR probes and the TRASE System to monitor insitu volumetric water contents. Although calibration of TDR systems is not essential, both field and laboratory calibrations will be performed to secure accurate moisture readings.

In order to use a neutron moisture probe as a tool to measure water content of a soil an access tube must first be installed into the soil. The access tube allows the probe to be lowered into the soil. Field calibration of the neutron probe access tubes is essential. The neutron moisture gauge used in this study is the CPN 503/503DR Hydroprobe manufactured by Campbell Pacific Nuclear Corporation of Martinez, California.

Runoff - Local surface reservoirs will be installed near each of the main instrumentation locations at Cluff Lake Mine. A schematic of the design of the surface runoff measurement reservoirs is illustrated in Figure 2. The reservoirs are designed to collect runoff from storm events during non-freezing conditions. Surface runoff that occurs above the contributing areas is diverted away. The cross pieces which mark the lower boundary with respect to surface runoff of the contributing areas collect runoff which is then stored in large plastic pails below the surface. The volume stored in the pails is recorded and used to calculate local surface runoff from the contributing area.

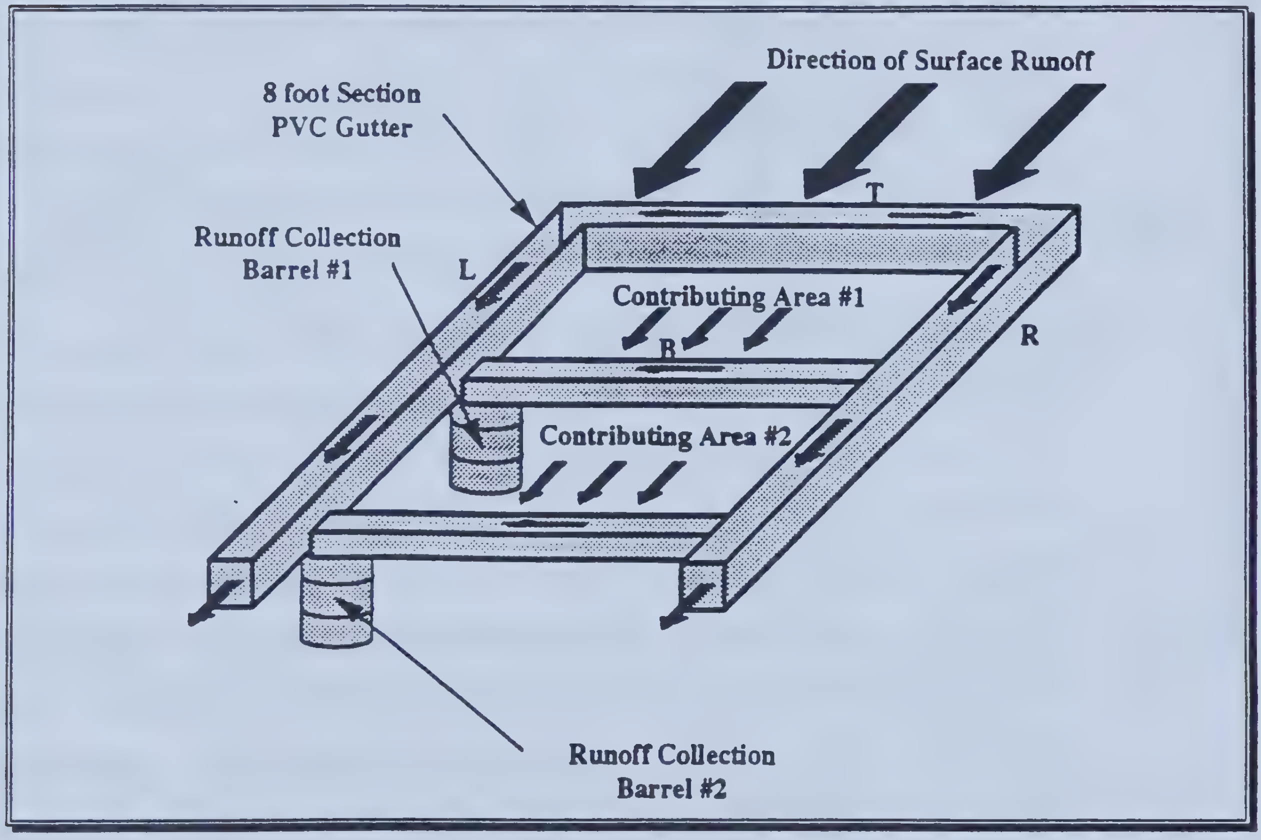

Figure 2. Schematic of the local surface runoff reservoirs (after O'Kane, 1995).

Field Installation

Field instrumentation of the natural surface soils and uranium tailings began in July, 1995. Site visits to install instrumentation took place from July, 1995 to September, 1995. A significant portion of the installation was completed during this time. However, site visits during the spring of 1996 will be required to complete the installation.

Figure 3 illustrates the location of all field instrumentation that will be installed at Cluff Lake Mine. The natural soil monitoring site (NSMS) and tailings monitoring site (TMS)

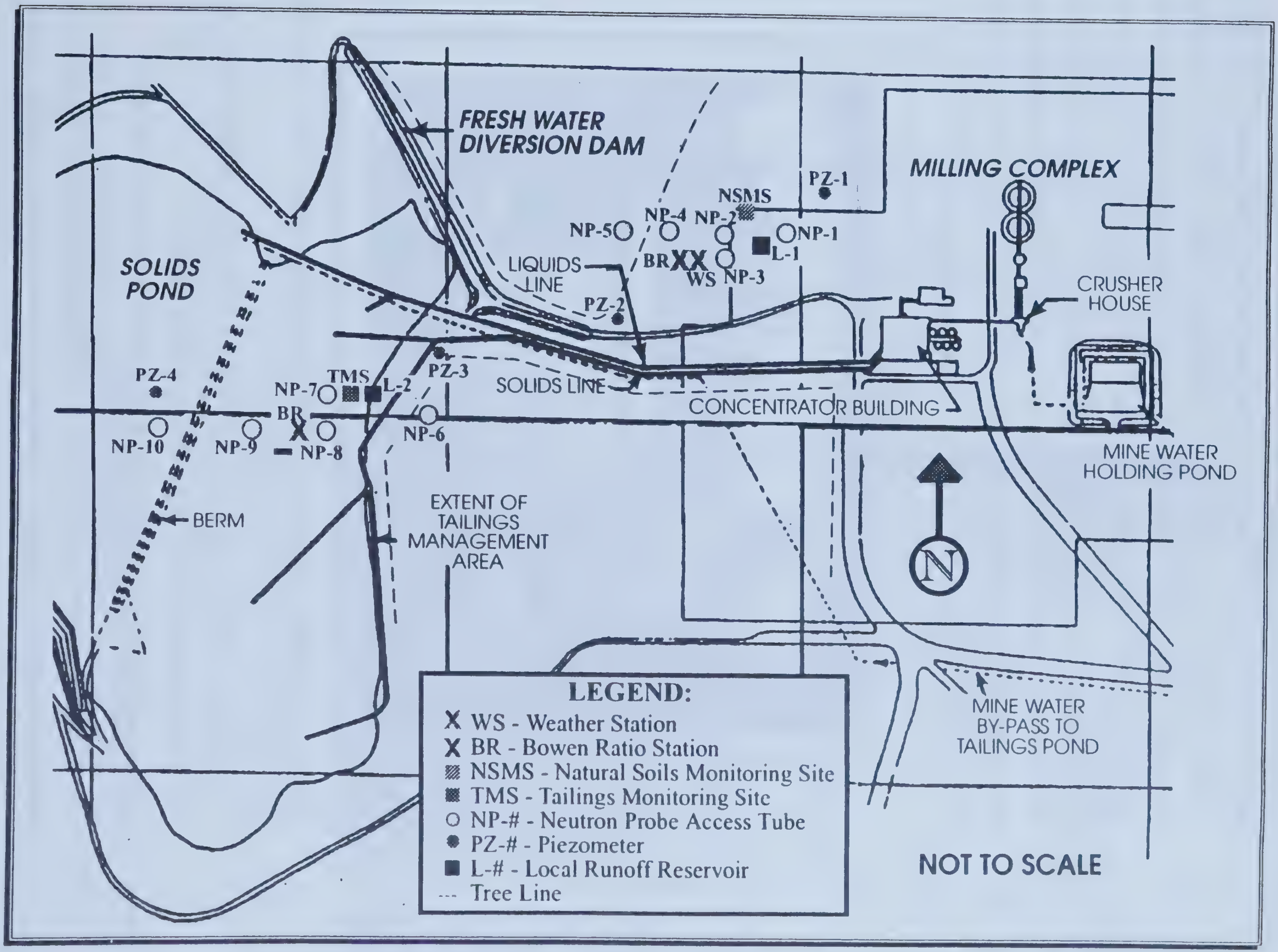

Figure 3. Site plan showing the location of field instrumentation at Cluff Lake Mine (after Ayres, 1995).

are the main instrumentation locations. Each instrumentation site contains eight thermal conductivity sensors, eight TDR probes, two thermistor strings, and two neutron probe access tubes. Figure 4 is a photograph of the NSMS including its data acquisition system. The weather station was installed next to the NSMS. The location of the Bowen Ratio station will alternate between the NSMS and TMS locations. All of the above mentioned instrumentation, except for the two access tubes next to the NSMS, were installed during the summer of 1995. Additional neutron probe access tubes were installed in the tailings in order to provide greater coverage of the moisture conditions in the TMA.

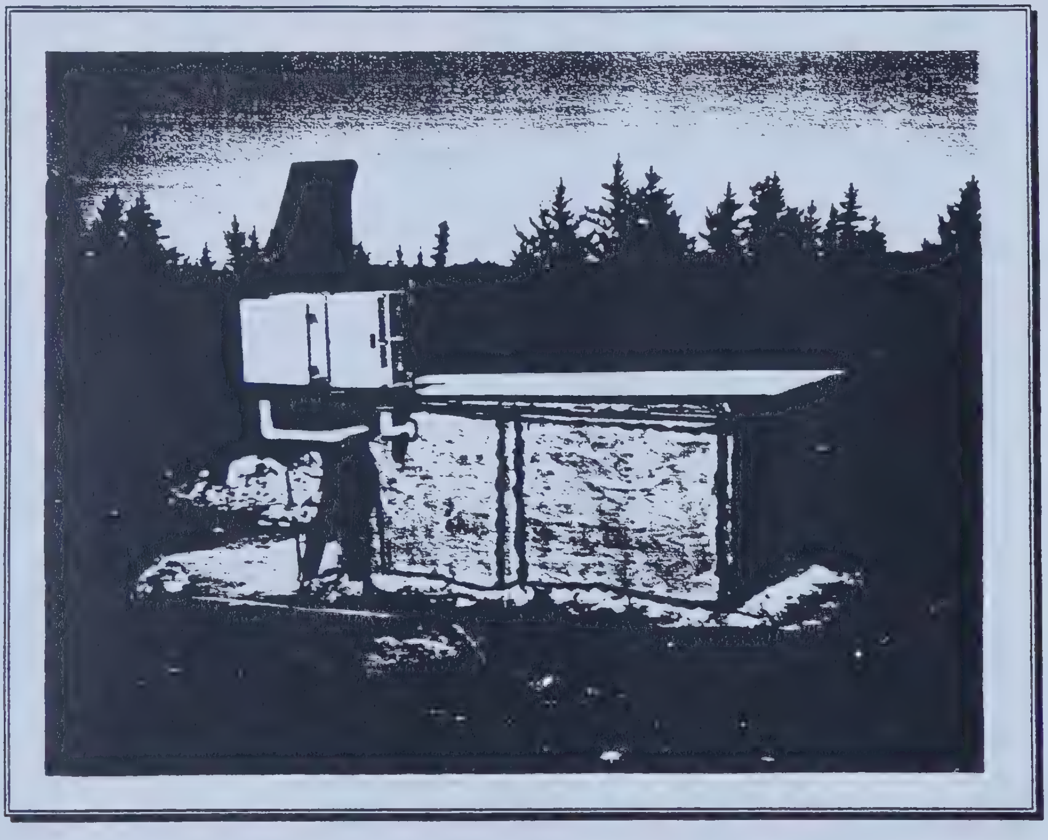

Figure 4. Photograph of the access box culvert and data acquisition systems at the natural soils monitoring site (after Ayres, 1995).

The installation of the thermal conductivity sensors, TDR probes, thermistor strings, and neutron probe access tubes are discussed in more detail below.

Thermal Conductivity Sensors and TDR Probes

NSMS - The thermal conductivity sensors and TDR probes were installed laterally into the natural soils as shown in Figure 5. A wooden box culvert installed vertically into the till

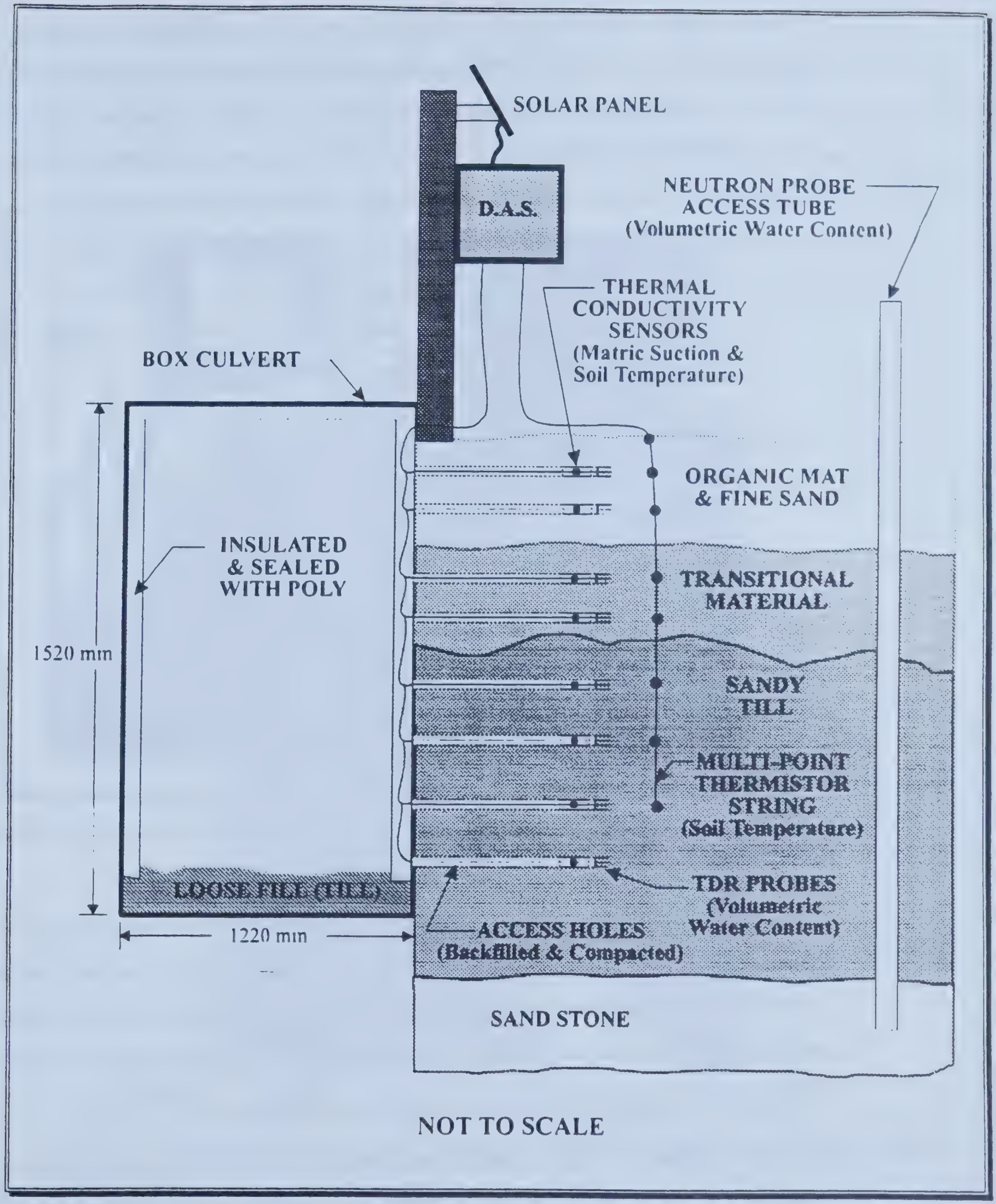

Figure 5. Cross-section of the access box culvert and sensor installations at the natural soils monitoring site (after Ayres, 1995).

provided access to the soil profile. Horizontal excavations of 600 mm were made through holes in the box culvert and into the till material to minimize the influence of the box culvert. Figure 6 is a photograph showing the excavation of an access hole. Separate access holes were required for each thermal conductivity sensor and each TDR probe.

Figure 6. Photograph showing the excavation of an access hole at the natural soils monitoring site (after Ayres, 1995).

A small void was made at the end of the access hole for the installation of each thermal conductivity sensor. This allowed for the installation of the sensors into undisturbed material. All sensors were connected to a multiplexer controlled by a datalogger. The data acquisition system is powered by a solar panel/rechargeable battery. Currently, soil temperature and matric suction measurements are collected every six hours.

In order to obtain accurate moisture measurements with TDR, it was essential that the metal rods of the probe be in tight, intimate contact with the soil. Therefore, the probe rods were inserted directly into the soil to retain bulk density characteristics. The three-wire TDR probes were inserted directly into the upper layer of the till profile by simply pushing on the probes by hand. Insertion of the TDR probes into the till at lower depths, however, was much more difficult. An installation tool was used to create voids for each of the wires on the TDR probe. Figure 7 is a photograph of the installation tool and a TDR probe used in this study. The diameter of the rods on the tool were slightly smaller than the diameter of the wires on the probe, which ensured the probe wires remained in intimate contact with the soil. Figure 8 is a photograph showing a TDR probe installed at the end of an access hole.

Figure 7. Photograph of the TDR installation tool and three-wire TDR probe (after Ayres, 1995).

The inside of the box culvert was insulated with fiberglass insulation and sealed with poly after backfilling and compacting all of the access holes. The objective was to minimize the influence of the atmosphere on the instruments installed laterally from the culvert. In addition, approximately 250 mm of till material was placed over a sheet of poly on the floor of the wooden box. The quality of the seal will be determined by the measurement of the temperature gradient across the wall of the box culvert. A thermistor string was installed inside the box and a second against the outside wall of the box culvert in the soil.

Figure 8. Photograph of a TDR probe installed at the end of an access hole (after Ayres, 1995).

TMS - The only difference between sensor installation at the NSMS and TMS is the fact that no access box culvert was used at the TMS. Instead, a trench was excavated by hand to gain access to the tailings profile. Once all thermal conductivity sensors and TDR probes were installed and access holes backfilled and compacted, the trench itself was backfilled and compacted.

Thermistor Strings

Two thermistor strings were installed next to each of the main instrumentation locations. A six inch diameter post-hole auger was used to excavate material for the insertion of the string. The thermistor string was placed against the edge of the hole (undisturbed material) so that soil temperatures will be representative of actual conditions. A careful attempt was made to backfill the material in the manner it was excavated and the material was compacted to its original insitu density as best as possible. The thermistor strings were connected to a multiplexer which is controlled by the same datalogger that controls the thermal conductivity sensors. Currently, soil temperature is recorded every six hours at eight depths. Figure 9 is an example of recent measurements collected from the NSMS.

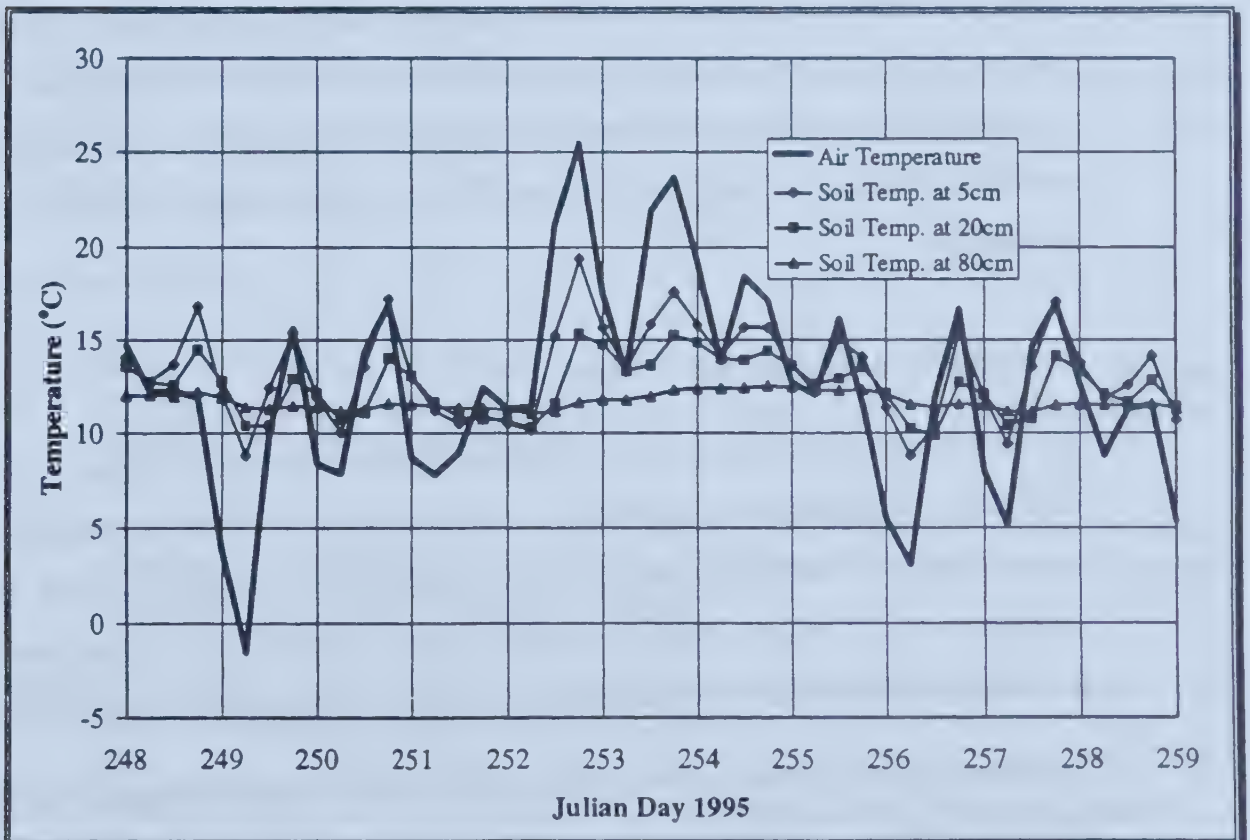

Figure 10. Air and soil temperature data collected at the natural soils monitoring site (after Ayres, 1995).

Neutron Probe Access Tubes

A total of ten aluminum access tubes will be installed at the Cluff Lake Mine. Two access tubes will be installed near each of the main monitoring sites and the remaining access tubes will be installed at other locations in the tailings and till. Water content measurements obtained at the NSMS and TMS will be verified with the matric suction measurements. Water content data from the remaining access tubes will be used to evaluate the soil system on a larger scale. To date, only the access tubes located on the tailings have been installed; the method of installation is described below.

A void was created by drilling a hole in the tailings with a 50 mm diameter auger. The aluminum tubing was placed in the void and pushed with a constant force to a depth of approximately 2000 mm. Care was taken to ensure the proper hole diameter was created. If the diameter is too large the resulting space between the outside wall of the access tube and the soil will allow moisture to migrate along the void. If the diameter is not large enough soil may compress and distort along the sides of the access tube. In both cases the resulting readings from the neutron gauge will not be representative of actual soil moisture conditions.

SUMMARY AND CONCLUSIONS

An overview of a multi-year research program initiated during the summer of 1995 at the Cluff Lake Mine has been presented. The objective of the research program is to develop environmental technologies for the decommissioning of uranium tailings in northern Saskatchewan. The key areas of research involve defining the chemical and hydraulic response of the tailings, as well as the physical characterization of the waste material.

To date, the primary focus of the work has been on the field instrumentation portion of the research program. The main objective of the field monitoring program is to characterize the soil/atmosphere flux boundary conditions of the uranium tailings and natural soils at Cluff Lake Mine. The design of the field program involved selecting robust and low maintenance instruments for the continuous monitoring of climatological and hydrological conditions at the mine site.

Presently, three M.Sc. graduate students and one research engineer are working on the research program. A significant portion of the installation of field instrumentation has been completed. Introductory modelling to evaluate the soil-atmosphere model's ability to simulate fundamental flow processes has been completed. A laboratory program including the design of a diffusion cell has been developed for characterization of the geochemistry of the uranium tailings.

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