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ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

PROPOSED APPROACH FOR BEDROCK CHARACTERIZATION AT CHALK RIVER NUCLEAR LABORATORIES FOR WASTE DISPOSAL

Approche proposée pour la caractérisation d'une roche de fond destinée à l'enfouissement de déchets à Chalk River

R.J. HEYSTEE and D.F. DIXON

Paper presented at "Workshop on Geophysical and Related Geoscientific Studies at Chalk River", Ottawa, Ontario, 1983 December 14-15

Chalk River Nuclear Laboratories

Laboratoires nucléaires de Chalk River

Chalk River, Ontario

July 1985 juillet

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Résumé

Des déchets de faible et moyenne activité sont engendrés dans les Laboratoires nucléaires de Chalk River par suite du fonctionnement des réacteurs de recherche et de développement et par suite de la production de radioéléments. Les Laboratoires nucléaires de Chalk River doivent gérer ces déchets ainsi que d'autres déchets de faible et moyenne activité engendrés au Canada par des laboratoires, des universités, des hôpitaux et certaines industries. Tous ces déchets sont actuellement stockés sans danger dans des installations surveillées. C'est un fait reconnu que certains de ces déchets continueront de présenter un risque au-delà de la vie utile des installations de stockage. Les déchets radioactifs à longue période devront être placés dans des sites d'enfouissement ne requérant plus d'intervention de nature sécuritaire.

Une option actuellement envisagée pour le stockage de certains de ces déchets est leur enfouissement dans une cavité peu profonde, au sein d'une roche de fond cristalline fracturée. Pour pouvoir concevoir une telle installation et évaluer sa performance à long terme, il est nécessaire d'avoir des données relatives aux caractéristiques géologiques et hydrogéologiques du site. Il faut, en particulier, faire des études pour obtenir des données qui permettront de localiser les discontinuités pouvant exister dans la roche de fond et d'évaluer leurs propriétés géomécaniques et hydrauliques.

Au cours des récentes années, on a eu recours à diverses méthodes géologiques, géophysiques et/ou hydrogéologiques (dans l'air, à la surface du sol et dans des trous de sonde) afin d'obtenir des données concernant les discontinuités de quelques masses rocheuses à Chalk River. Dans ce rapport, on décrit les techniques les plus prometteuses pour l'acquisition de ces données et on donne les grandes lignes de l'approche proposées pour la caractérisation du site d'enfouissement devant être constitué à Chalk River par une cavité peu profonde dans une roche de fond.

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by

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ABSTRACT

Low- and intermediate-level wastes (L&ILW) are produced at the Chalk River Nuclear Laboratories (CRNL) by the operation of reactors for nuclear research and development and by the production of radioisotopes. CRNL also manages L&ILW produced by Canadian research laboratories, universities, hospitals and some industries. These wastes are currently being safely stored. Surveillance is required during storage and it is recognized that some of these wastes will remain hazardous beyond the useful lifetime of the storage facilities. These longer-lived wastes will require disposal where disposal means emplacement with no further action required for safety.

One option that is being considered for the disposal of some of these wastes is to emplace them in a shallow rock cavity in fractured crystalline bedrock on the CRNL property. To design such a disposal facility and to evaluate its long-term performance, data must be obtained on the geologic and hydrogeologic characteristics of the site. In particular, investigations must obtain data that will help locate discontinuities in the bedrock and evaluate their geomechanical and hydraulic properties.

Over the past several years, a variety of airborne, ground surface and borehole geological, geophysical and/or hydrogeological methods have been used to acquire data on some rock mass discontinuities at CRNL. The techniques which are apparently more useful for acquiring these data are described and a proposed approach to site characterization for a shallow rock cavity at CRNL is outlined.

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PROPOSED APPROACH FOR BEDROCK CHARACTERIZATION AT CHALK RIVER NUCLEAR LABORATORIES FOR WASTE DISPOSAL

by

R.J. Heystee and D.F. Dixon

1. INTRODUCTION AND SCOPE

The disposal of low-level waste (LLW) and intermediate-level waste (ILW) on the Chalk River Nuclear Laboratories (CRNL) property (Figure 1) is currently being evaluated by Atomic Energy of Canada Limited (AECL). Two concepts that are being considered are shallow land burial [1] and disposal in a shallow rock cavity (SRC) [2]. The former facility would be situated in a well-drained sand deposit above the water-table. The latter facility would be located in the fractured Precambrian crystalline rock mass on the CRNL property and is the focus of the following discussion.

The scope of this paper is limited to brief descriptions of the SRC concept, the types of LLW and ILW involved and the geologic data that must be obtained at a potential site in fractured crystalline rock. The most important geologic information required in this type of rock concerns the nature and distribution of the rock mass discontinuities[1]. These largely control the geomechanical and hydraulic properties of the rock mass. Descriptions of site investigation techniques for obtaining these data are based on experiences gained in the investigation of the bedrock at the CRNL property. The overall objective of this paper is to outline an approach to choosing a potentially suitable location for a SRC and to characterizing the geologic and hydrogeologic conditions at that location.

2. DESCRIPTION OF LOW- AND INTERMEDIATE-LEVEL WASTES

Radioactive waste at CRNL is currently being stored in a variety of facilities which are described by Morrison [3] and Feraday [1]. The 80 000 m^3 of stored waste accumulated by 1982 is categorized as being about 80 percent LLW, 15 percent ILW and about 5 percent high-level waste (HLW). The LLW consists mainly of trash arising from the operation and maintenance

[1] Discontinuity is a general term for any break in a rock mass across which there is zero or low tensile strength.

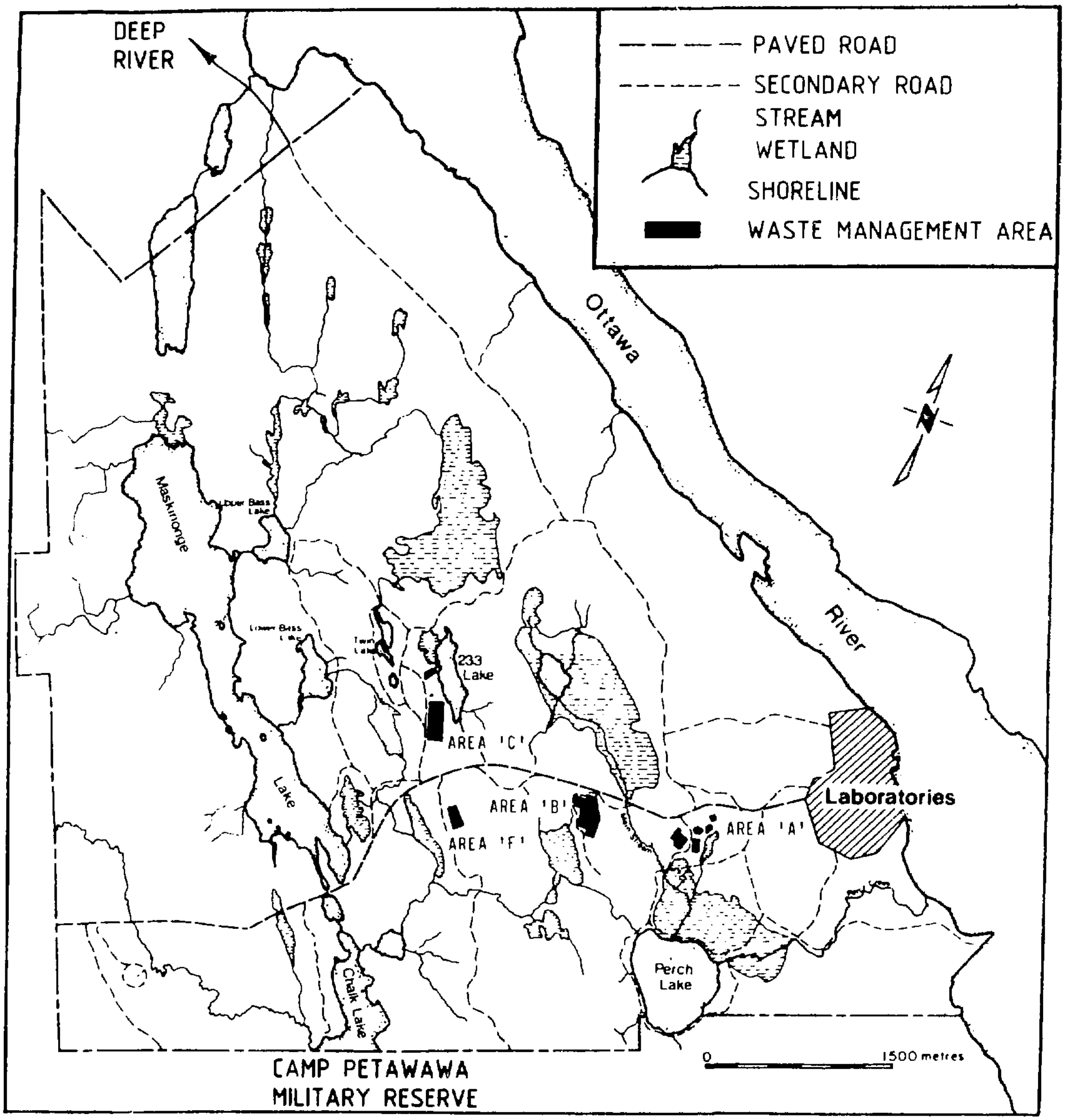

Figure 1. Location of Chalk River Nuclear Laboratories and the waste management areas.

of nuclear facilities. Typically, it contains discarded protective clothing and cleaning materials (e.g. mops and rags), worn out and outdated equipment and tools, contaminated scrap metal and other miscellaneous materials. The ILW includes ion exchange resins, filters, ^{60}Co sources, residues from radioisotope production and some redundant reactor components. The small quantity of HLW is mainly irradiated experimental fuel and in-core reactor components containing long-lived activation products. Up to 1982, about 3000 m^3 of space had been used annually to store the waste. Since that time, a new Waste Treatment Centre has become partially operational with the prospect of eventually decreasing the volume of waste requiring disposal to about 1500 m^3 each year [4, 5, 6].

3. THE CRNL SHALLOW ROCK CAVITY DISPOSAL CONCEPT

Preliminary engineering design studies have been conducted for the SRC concept primarily to estimate the cost of disposal by this method [7]. The studies were generic; they did not take into account any geologic or hydrogeologic data specific to the bedrock at the CRNL property.

Multi-level and single-level repository layouts were evaluated. A single-level layout is shown in Figure 2. All the layouts are based on the modular principle where the waste emplacement room is the basic unit (Figure 3). The emplacement rooms vary in size depending on the concept but could have volumes ranging from 7500 m^3 to 38 000 m^3, cross-sectional areas no larger than 600 m^2 and maximum widths of 20 m. The emplacement rooms are positioned off secondary haulage ways, which in turn are connected to the main haulage ways. The main haulage ways are joined to the ground surface by a shaft, ramp or adit. The areal dimensions of a single-level repository at CRNL would be in the order of 200 m by 200 m.

Before emplacement, the waste material would be reduced in volume, when appropriate, and immobilized (e.g. in bitumen or concrete). After the emplacement room is filled it would be backfilled with a suitable buffer material. Once the entire repository is filled, the haulage ways and entrance would be backfilled and sealed.

4. GEOLOGIC SETTING AND SEISMICITY

Brown [8] has provided a description of the geologic conditions at the CRNL property. The property is within the Ontario Gneiss belt of the Grenville Province of the Canadian Shield and is underlain by three main rock types: paragneiss, monzonitic gneiss and a diabase. The diabase is located spatially along the paragneiss-monzonitic gneiss contact. In some locations the diabase has been altered to chlorite such as, for example, in

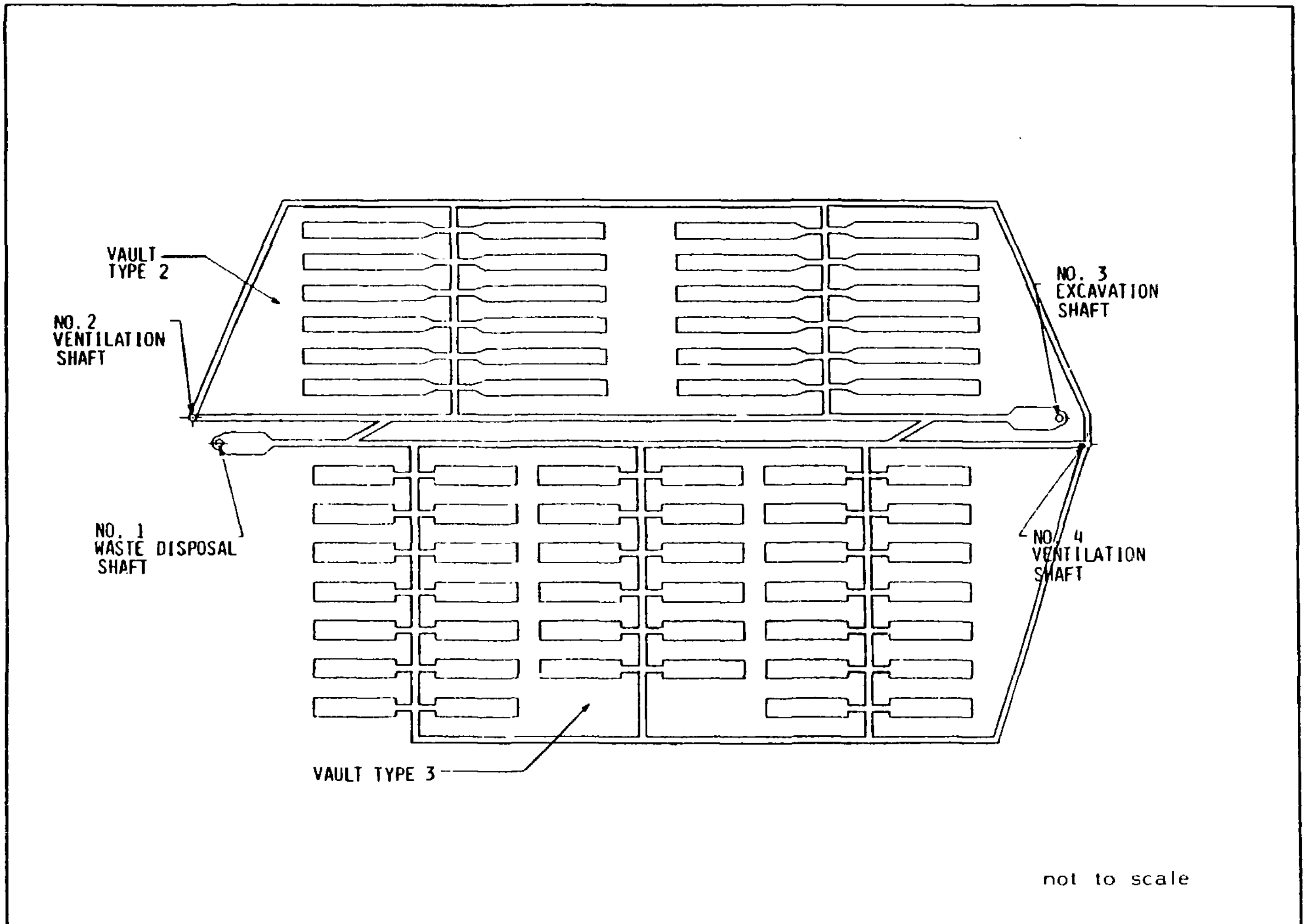

Figure 2. Conceptual layout drawing of a shallow rock cavity disposal facility (from Reference [7]).

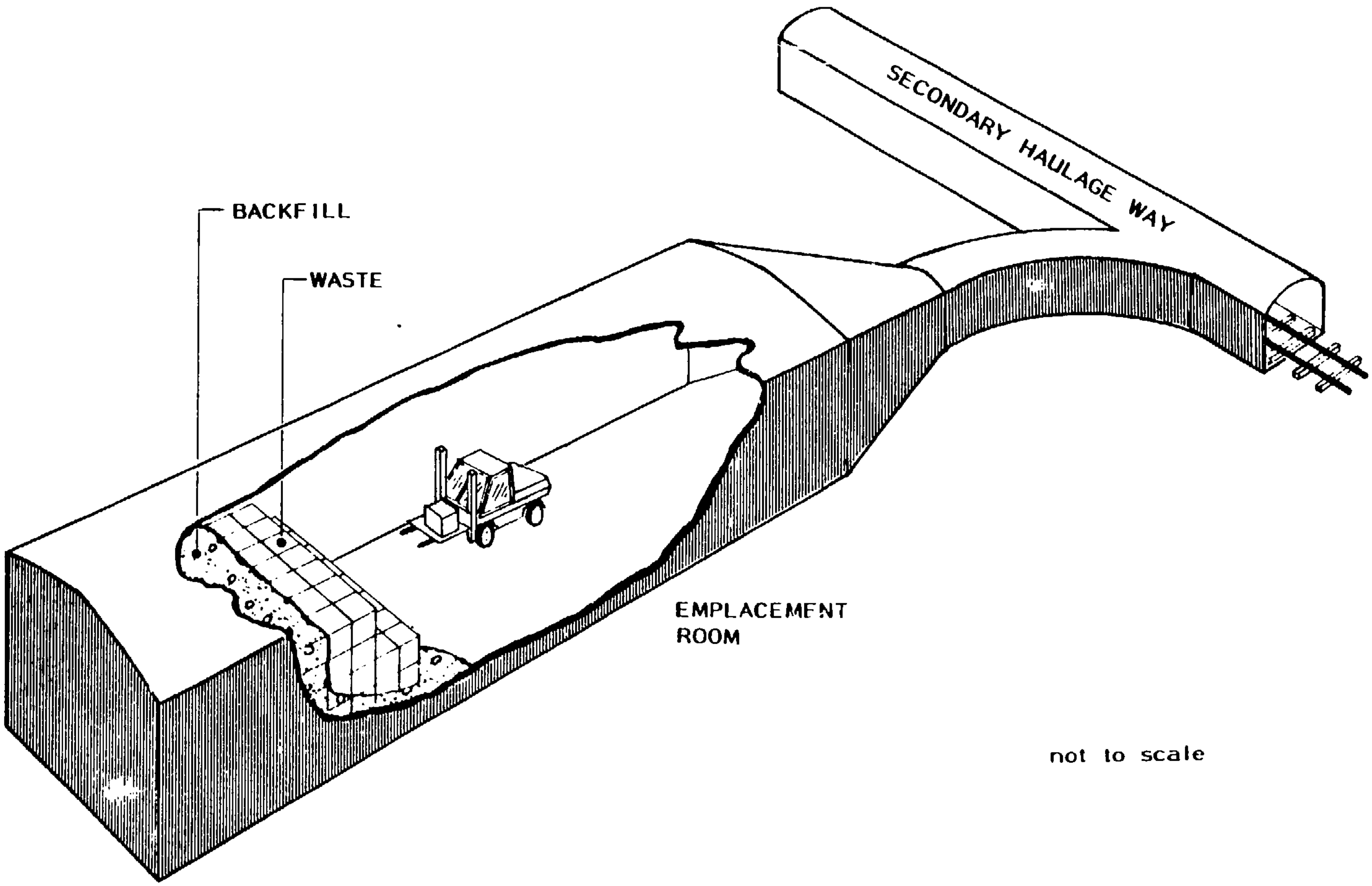

Figure 3. Typical emplacement room in a shallow rock cavity disposal facility (from Reference [7]).

borehole CR6[2] between 209 and 289 m [9, 10]. All three rock units have undergone strong compressional folding and several mylonite zones were created by this process. Many of the discontinuities present in the rock mass are related to this folding. Superimposed upon the discontinuities created by these geologic processes are those related to the creation of the Ottawa-Bonnechere graben. In the area of the CRNL site the Ottawa River fault forms the northern margin of the system of faults associated with the graben. Perpendicular to the Ottawa River fault is a system of later cross faults. In more recent geological times the area was subjected to glacial erosion and uplift. These processes have also created fracturing in the bedrock. In general, the CRNL property has been subjected to several periods of deformation which have resulted in a highly complex fractured bedrock.

The CRNL property is located within the western boundary of a seismically active area known as the Western Quebec Zone (WQZ) [11]. This zone has been delineated on the basis of an apparent clustering of historic earthquake activity in eastern Canada. The WQZ includes a great number of small to moderate, and a few large, historical earthquakes. An earthquake of about Richter magnitude 6 occurred near Montreal in 1732, of Richter magnitude 6.25 at Timiskaming in 1935 and of Richter magnitude 5.6 near Cornwall in 1944. In a circular area with radius of 450 km surrounding the CRNL property, including the WQZ and Eastern background area, there are occurrence reports of some 28 earthquakes with Richter magnitudes greater than 5 since 1661. The tectonic reasons for the concentration of seismic activity in this zone are not yet understood although much research is being undertaken in this direction.

5. DATA REQUIREMENTS FOR THE DESIGN OF A SHALLOW ROCK CAVITY

To design and construct a SRC disposal facility in the bedrock at the CRNL property and to evaluate its long-term safety, the following information must be obtained:

(1) Groundwater Flow Patterns

The control of groundwater flow through the rock mass during the construction and operation of a SRC and following its closure will be an important consideration in its design. In particular, cognizance must be taken of the fact that the potential migration of radionuclides away from the repository will be the result of groundwater inflow and associated leaching of the waste material. Predictions of radionuclide migration will therefore require the determination of groundwater flow pathways through the system of rock mass discontinuities.

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[2] CR6 - Chalk River borehole number 6

Figure 4 depicts the important role that large-scale discontinuities, such as fracture zones, faults and shear zones, may have in controlling groundwater flow patterns [12, 13]. The large-scale discontinuities may be either permeable or impermeable and will thus drain or impede the movement of water from the adjacent rock mass. The flow of water in the rock mass between the large-scale discontinuities will be governed by the location and geometry of the joints and fractures. In particular, it will be the aperture[3] and the interconnectivity of the joints and fractures which govern the rates and direction of water movement through the entire system of joints and fractures [13, 14]. Since flow through a fracture is proportional to the cube of the aperture [15], it is expected that flow through a rock mass is dominated by a series of interconnected joints and fractures having the larger apertures.

Thus, a site characterization program is required to define the geometry of the discontinuity network to determine groundwater flow patterns.

(2) Location of Major Weak Zones

Faults, shear zones and zones of highly fractured rock should be avoided during the construction of an underground opening. In addition to acting as potential conduits for groundwater flow, these features may create rock instability problems. Therefore, it will be necessary to locate these potentially weak zones prior to construction and then to situate a SRC between them in relatively unfractured rock.

(3) Rock Mass Quality

Between the major zones of weakness, the rock mass deformation will be controlled by the system of joints and fractures. The joints and fractures of varying orientations, spacing and persistence often intersect and bound blocks of unfractured rock. The size of the blocks, the interblock strength, the discontinuity pore pressure and in situ stress field will determine the mechanical response of a rock mass to the presence of an underground opening [16].

The accurate prediction of the mechanical behaviour of a rock mass is not currently, and may never be, possible [17]. This is due mainly to an inability to locate and describe all discontinuities in a rock mass. Also, an incomplete understanding of the complex mechanical behaviour of fractured rock masses does not permit predictions of deformation. To overcome this problem, design decisions on configuration and rock support for the underground openings are made on the basis of past experiences in similar rock types. The conditions at one site are related to another by

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[3] See Table 1 for definition.

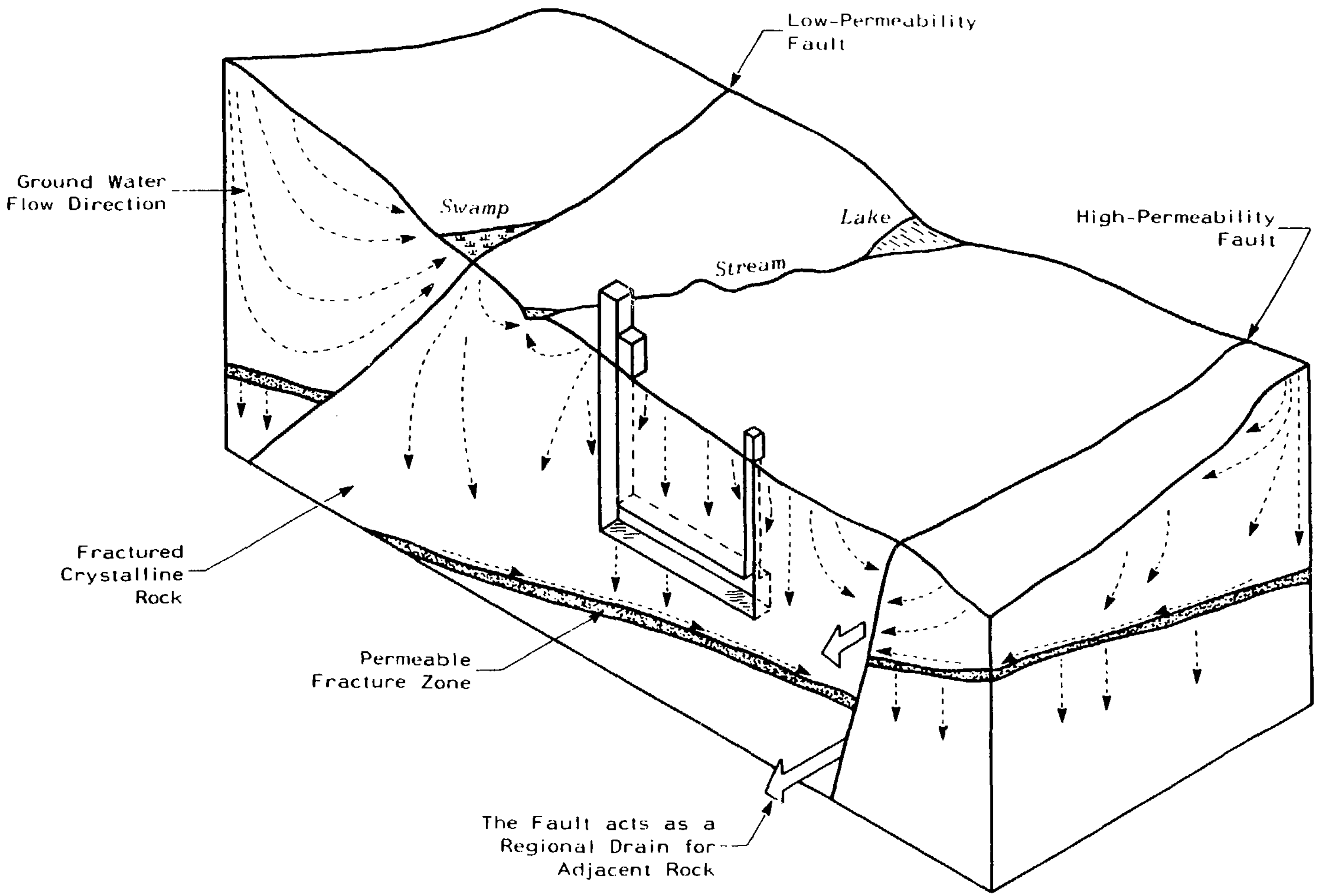

Figure 4. Hypothetical groundwater flow system in a fractured crystalline rock mass (from References [12] and [13]).

using rock mass classification systems (e.g. see [16, 17, 18]). Most of these systems require information on the location, geometry and surface characteristics of the discontinuities. This information may be obtained from the observations on rock core, borehole walls and other rock surface exposures.

(4) Description of Discontinuities

A factor common to all of the above data requirements is the important role of the rock mass discontinuities. Therefore, the collection of data which describe the location and characteristics of discontinuities will be a fundamental requirement of a site investigation in crystalline rock.

Table 1 summarizes the ten parameters which must be obtained for each rock mass discontinuity to obtain a complete description of a system of discontinuities [19]. A variety of site investigation techniques will have to be employed to obtain this information.

(5) Radionuclide Migration Properties

In the event of a radionuclide release from the SRC, the spatial and temporal distribution of radionuclides would be largely controlled by the groundwater flow patterns in the discontinuity network. However, during groundwater transport there would be dilution of radionuclide concentrations by dispersion, diffusion and geochemical radionuclide attenuation processes. Data describing these processes must be obtained to assess the long-term performance of the SRC.

(6) Seismicity

Since the CRNL property is located in a seismically active region, an assessment of the potential effects of seismicity on the SRC ability to contain the radioactive waste material should be evaluated.

6. PAST SITE INVESTIGATION EXPERIENCES AT THE CRNL PROPERTY

Since 1977 the CRNL property has been used as a research area in the Canadian nuclear fuel waste management program [20] and was selected for the purpose of developing techniques to characterize fractured crystalline rock. Investigators from the National Hydrology Research Institute (Environment Canada), Geological Survey of Canada (Energy, Mines and Resources), Earth Physics Branch (Energy, Mines and Resources), and

Table 1. Parameters Which Describe Discontinuities in a Rock Mass [19]

1. Orientation is the attitude of a discontinuity in space.
2. Spacing is the perpendicular distance between discontinuities.
3. Persistence refers to the trace length of a discontinuity as observed in an exposure.
4. Roughness is the inherent surface roughness and waviness relative to the mean plane of a discontinuity.
5. Aperture is the perpendicular distance between adjacent blocks of intact rock.
6. Wall Strength is the compressive strength of the adjacent rock walls.
7. Filling is the material that separates the adjacent rock walls of a discontinuity.
8. Seepage is the observation of groundwater movement through the discontinuity.
9. Number of Sets is the number of joint sets comprising the intersecting joint system.
10. Block Size is the rock block dimensions resulting from the mutual orientation of intersecting joint sets and resulting from the spacing of individual sets.

contracting agencies have used numerous techniques, with varying degrees of success, to characterize lithologies and discontinuities in the CRNL property bedrock (for example, see [21]). These techniques have been used mainly in a small area of the CRNL property centred in the vicinity of Upper and Lower Bass Lakes (Figure 1). Many of these site investigation techniques have been reviewed and the techniques that appear useful for providing SRC design data have been identified. However, this review is neither exhaustive nor unbiased.

Techniques that have been reviewed are divided into three categories based on the vantage point from which they examine the rock mass: i.e., airborne, ground surface and borehole techniques. These are listed in Table 2 and are discussed in more detail below.

Table 2. Site Investigation Techniques for Describing Rock Mass Discontinuities

Airborne Techniques:

- Aerial Photography
- Airborne Geophysics
  - aeromagnetic surveys
  - electromagnetic surveys

Ground Surface Techniques:

- Ground Surface Geological Mapping
- Ground Surface Geophysics
  - electromagnetic methods
  - electrical methods
  - seismic methods

Borehole Techniques:

- Analysis of Drill Core
- Borehole Geophysics
- Borehole Television Camera
- Borehole Acoustic Televiewer
- Borehole Hydraulic Testing

7. AIRBORNE TECHNIQUES

7.1 Discussion of Reported Results

Aerial photography and airborne geophysics are the two airborne remote sensing techniques that were used to study the geologic conditions in the vicinity of Upper and Lower Bass Lakes. Brown [8] and Raven [9] have used aerial photographs of the CRNL property to identify topographic lineaments. An example of an airphoto lineament interpretation is shown in Figure 5. Most of the lineaments that were observed on the aerial photographs were valleys or depressions. Many of the lineaments are believed to represent major structural features such as faults and shear zones. However, some of these lineaments may represent zones of selective weathering or areas which were preferentially eroded by glacial ice. In addition, the analysis of airphoto lineaments is partially subjective and different

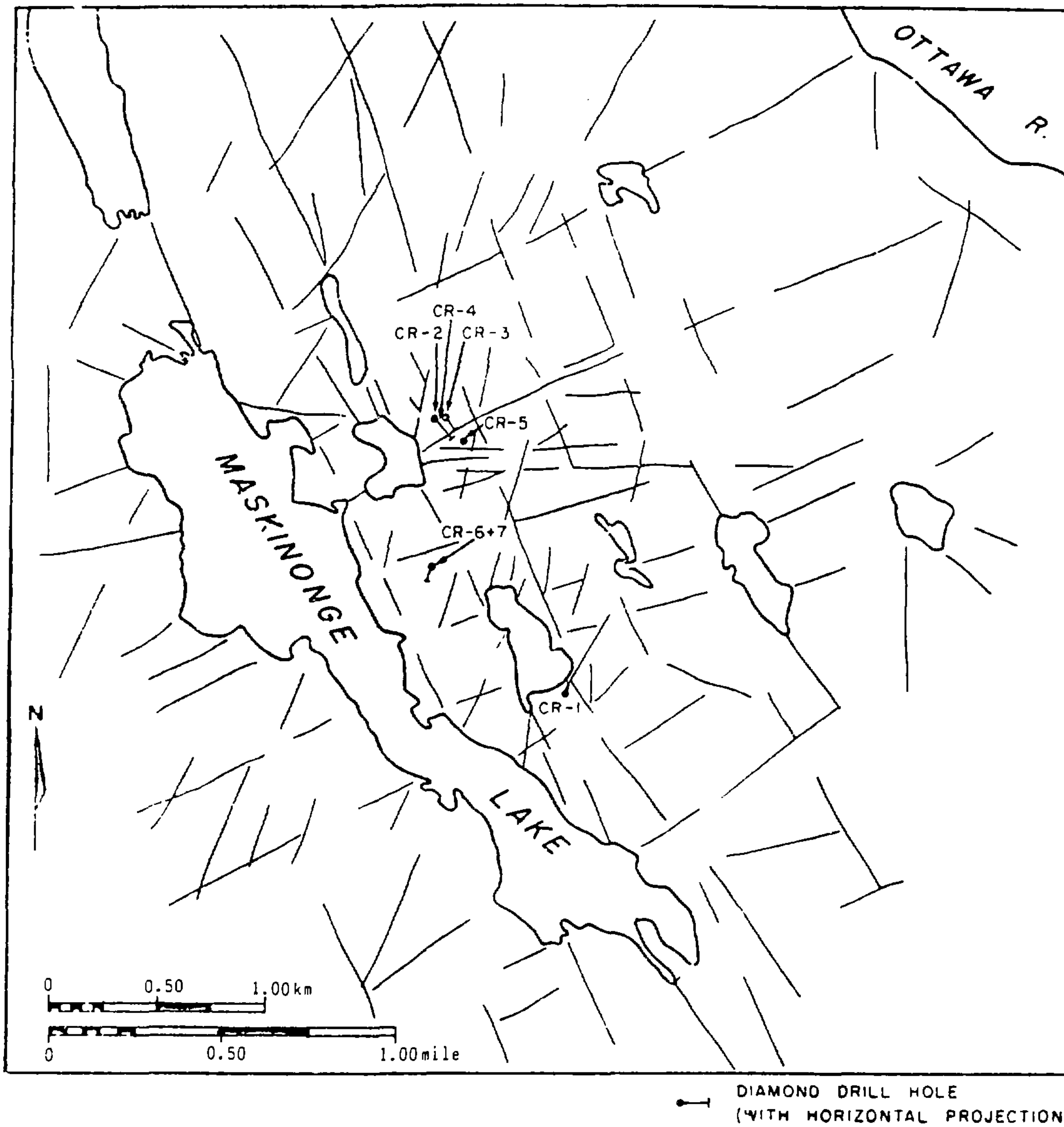

Figure 5. Traces of lineaments identified on 1:4800 scale air photograph (from Reference [9]).

investigators may see different lineaments. Aerial photographs taken under differing conditions also show different lineaments. Thus, several independent lineament surveys should be conducted.

Raven [9] has reported that a combination of airphoto lineament analysis and surface geological mapping was successful in establishing the location and orientation of a major east-west fault zone running through Upper Bass Lake. Raven and Gale [22] (cited in [9]) have shown that similar techniques employed at three Canadian mines were useful in predicting the occurrence of faults and shear zones to depths of 1000 to 1500 m. However, Merritt and Baecher [23] state: "Regional geology or local geology may be of use in projecting faults or large shears to unexplored parts of the rock mass, but poor correlation of the predicted and encountered geology in tunnelling casts doubt on the accuracy with which structural features at the surface can be projected into the rock mass".

Hayles [24] has reported the use of the two types of airborne geophysical techniques on the CRNL property: aeromagnetic (total-field and vertical gradient) and airborne electromagnetic surveys. The aeromagnetic surveys were successful in identifying two parallel east-west striking diabase dykes running across the property. These are part of the Grenville diabase dyke swarm found in the area.

7.2 Implications of Results

If all of the lineaments in Figure 5 represent structural features such as faults and shear zones, then it is evident that the CRNL property is comprised of a series of rock blocks with dimensions in the order of hundreds of metres. A suitably large rock block would have to be located to host a SRC and the location and properties of the bounding faults and shear zones determined.

On the CRNL property, the results of airborne electromagnetic surveys would be useful for identifying large-scale water-filled discontinuities in the rock mass. In addition, several airphoto lineament surveys should be conducted to identify possible locations of faults and shear zones. However, detailed information at depth cannot be obtained by using airborne techniques alone.

8. GROUND SURFACE TECHNIQUES

8.1 Discussion of Reported Results

Surface geological mapping of bedrock outcrops and ground surface geophysics were used on the CRNL property to identify discontinuities at the bedrock surface. Several investigators [8, 9, 25] conducted surface fracture mapping surveys of the bedrock outcrops in the vicinity of the east side of Maskinonge Lake. The fracture data recorded during these investigations included some or all of the following: orientation, persistence, aperture, filling and roughness. These data were then further analyzed, in some cases by using computer-aided techniques (e.g. see [25]), to identify fracture sets, mean orientation, lengths, and spacing of the fractures. These studies have shown that within the large-scale rock blocks, the rock is intersected by joints and fractures which have spacings in the order of metres. At least three fracture sets were identified in this highly complex geologic setting.

Of the numerous ground surface geophysical techniques employed on the CRNL site, the electromagnetic and electrical methods appear to have been the most successful in defining the near-surface location of discontinuities. The Very Low Frequency-Electromagnetic (VLF-EM) technique and to a lesser degree the resistivity technique have met with some success in detecting weak conductors created by water-filled fracture zones in the top 100 to 200 m of bedrock [24, 26, 27]. However, Hayles [24] states that the VLF-EM technique responds to all resistivity contrasts in the subsurface including those created by differences in the conductive properties of the overburden and bedrock. This may pose problems in uniquely identifying rock discontinuities by the VLF-EM technique in overburden-covered areas. The interpretation of data produced by these electrical methods is limited to identifying the strike of a vertical to subvertical discontinuity. The depth to the feature and its structural dip are uncertainties due to limitations in these electrical methods.

Ground surface seismic techniques have been used on the CRNL property in an attempt to characterize the discontinuity network in the bedrock. For example, Wright [28] has described seismological experiments (surface and surface-to-borehole seismic velocity measurements) which were able to distinguish zones of different rock mass quality. In one case a seismic velocity minimum was correlated with a fault. Wright has suggested that the measurement of seismic wave velocities would be a useful method for assessing the quality of large blocks of rock.

Gagné [29] conducted a seismic refraction survey on the CRNL property. Data from this survey was limited to depth-to-bedrock values and rock quality at the bedrock surface.

The high resolution reflection seismic technique was employed with little success on the CRNL property [30]. However, experience elsewhere has shown that this method, combined with an exploratory drilling program is a very useful technique for detecting subhorizontal fractures [31, 32]. Other investigations [25] indicate that subhorizontal structural features in the bedrock at the CRNL property are hydraulically significant. Thus, any combination of site investigation techniques that shows some promise of detecting such features should be employed in a search for a suitable disposal site.

8.2 Implications of Results

The purpose of fracture mapping at the bedrock surface is to predict fracture patterns in the subsurface. The usefulness of this approach has been demonstrated [25] at CRNL at least to a depth of 50 m. However, it is unlikely that data on such fracture characteristics as aperture, filling and roughness can be extrapolated to the subsurface because of the effects of bedrock surface weathering and fracture closure by larger compressive stresses at depth. It may also be difficult to accurately predict subsurface fracture patterns or rock mass quality using bedrock surface data beyond a depth of 50 m. This is evident from the rock mass characteristics in the vicinity of CR6 (see Figure 5). The fracture log for this borehole [33] shows the significant increase in fracture density with depth below 50 m. This evidence suggests that a suitable location and design for the SRC must use boreholes to supplement the discontinuity data obtained by the ground surface methods.

9. BOREHOLE TECHNIQUES

9.1 Discussion of Reported Results

Thirty-nine boreholes have been drilled at various locations in the vicinity of Maskinonge Lake since 1977. Twenty-four of these were cored (CR1-12, CR14-22, FS15[4]-17) and 15 of the holes were air percussion drilled (CR13, FS1-14). Several borehole techniques have been used to define the lithologies and discontinuities intersected by these boreholes including the analysis of drill core, borehole geophysical logging, borehole television camera and acoustic televiewer logging, and borehole hydraulic testing.

The principal advantages of obtaining an oriented drill core is that the lithology and the fracture surfaces can be observed directly and the spatial attitude of the fractures and joints can be accurately determined. Direct observation of small-scale fracture surfaces will be useful for obtaining information on fracture surface roughness and wall strength. The drilling process limits the possibility of obtaining accurate data on

[4] FS15 - Chalk River Flow System Study Area borehole number 15.

discontinuity aperture due to disturbances caused by drilling. The direct observation of large-scale discontinuities such as shear zones or fault zones in drill core may be hampered by the fact that the rock core is highly disturbed during the drilling and core removal process [23]. A discontinuity in the rock mass which is filled with a soft clayey material could have this infilling washed out by the drilling process. Having accurate data about such weak zones is important for predicting the geomechanical and hydraulic behaviour of a rock mass.

A possible alternative to the use of drill core for defining lithology and discontinuities is to use percussion drilling techniques and to log the drill hole using borehole geophysical tools, a borehole television camera and/or acoustic televiewer. Davison, et al. [34] have found that the use of multiple borehole geophysical logging techniques (e.g. acoustic velocity, neutron, high-resolution caliper, gamma, resistivity and temperature) produce a set of signatures that contain anomalies. These anomalies could be correlated with the location of large open fractures. However, these techniques have limited resolution and cannot be used to define fracture geometry.

The acoustic televiewer and borehole television camera have been used extensively in CRNL boreholes to provide fairly accurate data on discontinuity location, orientation, spacing, filling and aperture at the borehole wall. However, neither the acoustic televiewer nor the borehole television camera could accurately identify those discontinuities which are hydraulically significant; that is, there may be many open fractures intersecting the borehole but all of them are not necessarily interconnected with other fractures and are thus not able to transmit water. Davison, et al. [34] state: "At the present state-of-the-art, there is no substitute for hydrologic testing to definitely establish the permeability of fractures in crystalline rock".

Davison [10] conducted numerous borehole hydraulic tests in a group of boreholes in the vicinity of CR6 to define the interconnectivity and aperture of the discontinuities intersected by these boreholes. The most commonly used technique was one which isolated a fracture or group of fractures with straddle packers. Water was injected into these fractures under known pressure gradient and volumetric fluid flow conditions. In the case where the tests were conducted on a group of fractures, it was often not practical to isolate individual fractures to determine their hydraulic properties; therefore, an equivalent aperture was calculated. The tests typically determined the hydraulic characteristics of the fractures in the immediate vicinity of the borehole. This part of the fracture is often damaged by drilling (either plugged or opened). Therefore, testing may have produced poor estimates of fracture aperture if the zone influencing the test was not extended beyond the damaged zone.

The results of these borehole hydraulic tests show that the equivalent rock mass hydraulic conductivity ranges from 5×10^{-6} m/s (a single open fracture with an equivalent aperture = 350 microns) to less than 1×10^{-11} m/s in the intensely fractured and highly altered diabase unit [10]. It is worth noting that this range in hydraulic conductivity is characteristic of the gneiss as well as the diabase. Most of the fractures that have been shown to transmit water are complex rather than single planes [34].

Hydraulic interference and tracer tests were conducted in the group of boreholes in the vicinity of CR6 and FS group of holes [10, 35, 36]. These multiple borehole tests have shown that discrete and permeable fracture zones are interconnected over distances ranging from 10 to 40 m. (These zones were not identified by other borehole techniques or surface geophysical methods.) The tests were also used to determine the equivalent aperture of fractures at a distance from the boreholes which was not attainable by single borehole testing techniques. The multiple borehole test procedures are not routine and are expensive to conduct.

A number of experimental borehole geophysical techniques have been employed in the CRNL property bedrock in an attempt to define the hydraulic characteristics of discontinuities intersected by a borehole. Included in this group are the analysis of seismic tube waves [37], well-tide data [38] and acoustic waveforms [39]. Of these three techniques, the analysis of acoustic waveform data appears to be the most promising method of predicting fracture aperture and permeability. However, Davison, et al. [34] state that this technique is still in the early stages of development and is presently not suitable for routine use.

9.2 Implications of Results

Groundwater flow in rock will most likely be dominated by large discrete discontinuities or sets of discontinuities. Predictions of groundwater flow and radionuclide migration through the rock mass will require that these features be located and characterized by borehole hydraulic testing procedures. To achieve this at a scale which is necessary to predict radionuclide migration from a SRC disposal facility may be an elusive task. In addition, based on tracer test experiences [36] in the fractured crystalline rock, it will be difficult to predict radionuclide migration along well defined discontinuities.

The borehole techniques are the most reliable methods for obtaining data which describe the discontinuities in a rock mass. However, it must be emphasized that they can only provide data in the vicinity of the borehole. Even the combination of borehole data with information from remote sensing and ground surface methods will only give an approximate picture of the complex geologic conditions that exist in the bedrock at the CRNL property. A pilot shaft or adit may have to be constructed at the selected site to confirm that the geologic and hydrogeologic conditions are as predicted. If unfavourable conditions are encountered during these test excavations then design changes may be warranted or a new site may have to be selected.

10. CONCLUDING REMARKS

The construction of a SRC for a LLW and ILW disposal facility will require that site specific investigations be conducced on the CRNL property. The purpose of these investigations will be to find a suitable rock mass for hosting the facility, to obtain the necessary geologic and hydrogeologic data for designing the facility and for the assessment of its long-term performance.

Based on the observations of rock mass discontinuities in the vicinity of Upper and Lower Bass Lakes and on the aforementioned discussion about investigation techniques, the following approach to investigating the entire CRNL property bedrock is proposed. The objective of the site investigations will be to locate a relatively large and unfractured block of rock in which a SRC can be suitably located. A reconnaissance investigation of the entire CRNL property using a combination of airphoto lineament analysis, ground surface geological mapping and ground surface geophysics (in particular the electrical and electromagnetic methods) would be used to locate and assess large-scale vertical to subvertical discontinuities. However, the usefulness of these techniques will be hampered by the presence of overburden. In all locations the orientation and characteristics of large-scale discontinuities would have to be confirmed by drilling.

Large-scale rock blocks which appear to be suitable for hosting a SRC would be further evaluated using a drilling technique to determine rock mass quality. Since drilling can only determine rock mass quality at discrete locations, other methods which can assess larger volumes of rock should be used. The propagation of seismic energy through large volumes of fractured rock using either surface-to-borehole or cross borehole techniques might be a useful method of comparing the overall rock mass quality in potentially suitable large-scale rock blocks. In particular, geophysical cross-hole probing techniques probably hold the most promise for characterizing discontinuities in a volume of rock with dimensions up to 100 m on a side [40]. High-resolution seismic techniques supported with borehole information appears to be the optimum method of obtaining data describing the presence of large-scale horizontal to subhorizontal bedrock discontinuities.

Based on information acquired by the site investigations as well as other siting considerations, a suitable site for the SRC would be selected. At this stage more detailed site-specific information would be obtained regarding the location and characteristics of rock discontinuities and groundwater conditions at the selected site by using a combination of drill core analysis, borehole geophysical logging techniques, borehole television camera and acoustic televiewer logging and borehole hydraulic testing. These activities are costly and would only be used to acquire enough geologic and hydrogeologic information to conduct site-specific design studies and safety assessments for a SRC. For example, the data from these studies would be used to evaluate various configurations for a SRC, types of rock support, potential groundwater inflow quantities, the ability of the rock mass to take grout and potential groundwater flow patterns in the vicinity of a SRC. The ability of a SRC facility to safely contain the LLW and ILW during its hazardous lifetime would be evaluated using the geologic and hydrogeologic information.

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