Regulatory Document

Texte de réglementation

Atomic Energy Control Board

Commission de contrôle de l'énergie atomique

REGULATORY DOCUMENT R-72

Regulatory Guide

GEOLOGICAL CONSIDERATIONS IN SITING A REPOSITORY FOR UNDERGROUND DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTE

Effective date:

September 21, 1987

Canada

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A draft of this document was issued for public comment as a Consultative Document (C-72) on January 24, 1984. On completion of the comment review and text revision process, the content was finalized and made effective on September 21, 1987.

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GEOLOGICAL CONSIDERATIONS IN SITING A REPOSITORY FOR UNDERGROUND DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTE

1. INTRODUCTION

At the present time in Canada, high-level radioactive waste is accumulating in the form of irradiated, used fuel from research reactors and nuclear power generating stations. The used fuel bundles are kept in water-filled bays at each of the reactor sites. Because water is both a radiation barrier and an effective coolant, this system provides a safe means of storage. Used fuel is also safely stored above ground in dry concrete canisters in several Canadian locations.

Both of these methods require surveillance and maintenance in order to ensure their continued safety and can be seriously considered only as temporary management measures. Clearly, some means of disposing of these wastes permanently will be required.

The Atomic Energy Control Board (AECB) is the federal agency responsible for regulating the development, application and use of atomic energy. As such, the AECB must be satisfied that any proposed disposal system will effectively isolate the radioactive waste and will not result in unacceptable risk to humans and to the natural environment, either at the present time or in the future.

At the present time, a research program is being conducted in Canada to obtain scientific information for the assessment of a disposal concept based on the emplacement of radioactive waste in rock, deep below the surface of the earth. In August 1981, the governments of Ontario and Canada announced details of a process called "Concept Assessment" by which the acceptability of the concept would be examined. The announcement also stated that the process is expected to be completed by 1990 and that no siting for a repository would take place until after the concept had been generally accepted.

The disposal concept that is being developed in Canada integrates both engineered and natural components. In essence, the plan involves physical and chemical stabilization of the waste in a resistant package, followed by emplacement in a repository deep within a body of rock that is situated in a geologically stable region.

The information in this document is specifically related to the site selection phase. It is being published now to help identify the geological properties and processes that need to be addressed during site selection. This document should help to identify these geological considerations and to ensure that the concept assessment phase takes them into account in a balanced manner.

2. FUNDAMENTAL OBJECTIVES AND REQUIREMENTS

A general objective of all waste management programs, including programs which deal with radioactive waste, is to protect man and the environment from hazardous or polluting substances. Although the complete isolation of a particularly hazardous material may be desirable, there can be no guarantee that waste components will not eventually return to the environment due to the dynamic character of all natural systems. It is more realistic, therefore, to speak in terms of a rate of return and to take the necessary measures beforehand to ensure that any reintroduction will occur in quantities that can be safely tolerated.

The migration and return of the undesirable material to the accessible biosphere are influenced by natural processes which may sorb, retard, divert, disperse or dilute the waste. In the case of radioactive waste, there exists an additional factor of great importance. Radioactive substances decay at rates that are characteristic of their constituent radionuclides; thus they become less radioactive and correspondingly less hazardous with time.

Therefore, a successful disposal system for radioactive waste which incorporates both man-made and natural components should:

(a) isolate and retain radioactive substances to allow for more complete radioactive decay;

(b) restrict the movement of those radionuclides which may escape from the repository, thus prolonging the time during which further radioactive decay can take place prior to their return to the accessible environment; and

(c) restrict human contact with the waste.

Furthermore, in the development of any radioactive waste disposal concept, the following fundamental requirements must be considered:

(a) The disposal system and its components must be capable of accommodating disturbances due to natural phenomena likely to occur in the vicinity of the repository, so that any increase in risk to the public due to the escape of radionuclides as a result of these disturbances would comply with regulatory requirements.

(b) The disposal should be passive; that is, it should be designed to minimize the obligation imposed on future generations to oversee the continued safe isolation of the waste.

3. CHARACTERISTICS OF A GEOLOGICALLY ACCEPTABLE SITE

The properties of the natural barriers will be unique to the site chosen. In addition, it is very difficult to quantify the anticipated performance of the natural barriers. Great care must therefore be taken to properly assess the geological properties of the host rock and the region in which it is located, to ensure that sufficient confidence is achieved in the predicted overall system performance. Careful consideration must be given to geological processes and events which might compromise the performance of either the natural or engineered barriers. These studies should assess the uncertainty associated with any prediction of the performance of geological systems which are a part of an overall disposal system.

The geological system refers to subsystems affecting groundwater flow, rock mineralogy and structure, the location and properties of discontinuities and geochemical processes.

The five geological criteria which follow have been formulated taking the preceding considerations into account. In each case, a brief summary of the rationale is presented for the purpose of explaining the intent and scope of the stated criterion. It must be stressed that, since it is the overall performance of the complex array of man-made and natural barriers which must be considered during the siting and other design and engineering phases, a single aspect of the geological system may not be critical. Therefore a balanced assessment is required which places all geological properties and processes into their proper overall context.

The host rock and geological system should have properties such that their combined effect significantly retards the movement or release of radioactive material.

Aside from deliberate or accidental human intrusion into the repository, groundwater movement would be the principal mechanism by which radioactive material could be transported to the surface environment in geologically stable areas. The groundwater transport of radionuclides will be limited by some combination of the following circumstances.

(a) Limiting releases at source

Radionuclides can enter the groundwater system only as a result of corrosion or mechanical failure of the containers and subsequent diffusion or leaching of radioactive material from the waste medium. The proper choice of container materials will inhibit corrosion and leaching or dissolution of the used fuel. The corrosion however must take account of the chemistry of the groundwater and therefore some sites may contain groundwater with more favourable properties than others.

(b) Low groundwater flux

A low groundwater flux or flow ensures that even where contaminants are freely available deep in the vault, they can only enter the accessible environment slowly. Low flux occurs at sites where the recharge to the groundwater system is very low. Low regional hydraulic gradients will have a similar effect.

(c) Retardation or retention of migrating radionuclides

The mobility of radionuclides migrating with the groundwater flow may be limited by processes in which, for example, the dissolved waste is sorbed by minerals that occur along fissures in the rock and in the buffer material surrounding the container, or is precipitated as insoluble compounds, or is dissipated by diffusion into the rock matrix.

The host rock, together with the geological system, should have properties that promote the physical and chemical processes described above. In this way, any radioactive waste released will be dispersed so that it re-enters the environment in dilute concentrations far in the future after considerable radioactive decay has occurred.

There should be little likelihood that the host rock will be exploited as a natural resource.

If it is suspected that the host rock contains a commercially valuable commodity such as gold, oil, salt or potash, or a strategically important material, it is likely that the rock's potential as a resource will eventually be evaluated.

Exploratory drill holes which penetrate the host rock could impair its effectiveness as a natural barrier to the release of radioactive material and could alter the groundwater system. It is also conceivable that the repository itself could be breached. Efforts to exploit any resource present would only compound the damage. It is therefore important to avoid areas with a history of natural resource production, such as old mining districts. These areas are subject to recurring exploration and evaluation.

As broad a perspective as possible should be brought to bear on this question. Technologies change and with them, the value of commodities. However, commercial interest is not likely to be focused on the host rock itself if it is composed of common minerals and if it is a type of rock that is not only abundant in the area of the repository site but is also widely distributed throughout Canada.

> *The repository site should be located in a region that is geologically stable and likely to remain stable.*

All parts of the earth's crust are undergoing geologic changes of one kind or another, but there are wide variations in the degree of instability. Where significant crustal instability does exist, it may manifest itself in ways that would seriously reduce the effectiveness of a repository. It is important that a repository not be located in such a region. The discussion which follows will illustrate the kinds of crustal instability that may lead to situations that could compromise the integrity of a repository.

Large-scale crustal forces may result in three broadly defined effects which are not mutually exclusive.

(a) Rocks may crack and break, and a fault will develop if there is movement along a break with a resulting dislocation of one body of rock with respect to an adjacent one. Also pre-existing faults and fractures may be reactivated.

(b) Broad regions may experience upward or downward movement (regional uplift or subsidence).

(c) Steep thermal gradients with associated heat flows may develop, and in extreme cases, volcanic activity may ensue.

Although active faulting in the region of the repository might have several undesirable consequences, perhaps the most important of these is the possibility of creating new fractures or altering existing ones. The groundwater flow pattern could change in an unpredictable manner and groundwater access to radioactive waste might increase. If freer circulation resulted, the movement of radionuclides back to the environment could be facilitated.

Regional uplift would result in accelerated erosion due, at least in part, to an increase in the gradient of streams. The ground surface could erode downward towards the repository, reducing its isolation from the environment.

Heat flows sometimes result in hot springs and geysers. The hot circulating groundwater could speed the dissolution and transport to the surface of radioactive materials.

Although extensive areas of the earth's crust exhibit significant crustal instability of the nature described above and should be avoided as possible locations for a repository site, there are other correspondingly large areas which are relatively dormant. For example, it appears that some of the most geologically stable regions on earth are found within the central part of this country.

Both the host rock and geological system should be capable of withstanding stresses without significant structural deformation, fracturing or breach of the natural barriers.

There are natural stresses in all rocks due, in part, to the weight of overlying materials and to large-scale crustal processes. Besides these natural stresses, the host rock will be subjected to changing stresses, which result from the excavation of the repository and from the heat and ionizing radiation of the radioactive waste. This combination of natural and induced stresses may adversely affect the structural stability of the host rock and surrounding rocks.

In evaluating a site for resistance to stress, consideration should be given to the rock type, its alteration under mechanical and thermal stresses and the overall impact on the suitability of the site. It is not possible to select *a priori* those properties which are inherently desirable. Therefore a broad evaluation is needed and an effort should be made to achieve as satisfactory a combination of host rock properties as possible.

The dimensions of the host rock should be such that the repository can be deep underground and well removed from geological discontinuities.

Placing the repository deep underground is an effective means of isolating and protecting the radioactive waste and the engineered components of the disposal system. It also ensures the preservation of natural barriers between the waste and the environment. Specifically, an adequate depth of burial is necessary in order to:

(a) restrict human access to, and contact with, the radioactive waste;

(b) isolate the repository from the effects of such human endeavours as explosions, excavations, and large construction projects; and

(c) reduce the effects of certain surficial processes such as erosion by wind, water, and glaciation.

It is also important to keep the repository away from geological discontinuities. There are several reasons for this, among them, the following:

(a) Discontinuities are potential zones of weakness. The various stresses induced in the host rock as a result of the presence of the repository diminish with distance. However, if a discontinuity lies within the volume influenced by the repository such that the increase in stress is enough to overcome the natural resistance along the boundary, a rock failure may result which, in turn, could impair the effectiveness of the repository.

(b) Substantial movement of groundwater may take place along discontinuities and these may extend to the surface. Under these circumstances, the shortest distance between the repository and the boundary may become, in effect, the pathway which is of critical interest, especially if groundwater flow along the discontinuity could possibly transport any escaping radionuclides back to the environment in unacceptable concentrations.

(c) Commercially valuable minerals, petroleum resources and other commodities are sometimes found along or near discontinuities.

The effect of any particular geological discontinuity will be site-specific and therefore it is not possible to specify a minimum distance between it and the vault. Thus a detailed study will be necessary to determine a proper distance, and the effect of engineered measures on structural and other less important discontinuities in the host rock. Again it is the overall system performance which is important rather than the performance of any single component within the system.