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ATOMIC ENERGY
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ÉNERGIE ATOMIQUE
DU CANADA LIMITÉE
Société de Recherche

NUCLEAR FUEL WASTE DISPOSAL IN CANADA
– THE GENERIC RESEARCH PROGRAM

STOCKAGE PERMANENT DES DÉCHETS DE COMBUSTIBLE NUCLÉAIRE
AU CANADA – PROGRAMME DE RECHERCHE GÉNÉRIQUE

K. W. Dormuth, P. A. Gillespie

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RÉSUMÉ

Énergie atomique du Canada limitée (EACL) a élaboré un concept de stockage permanent des déchets de combustible nucléaire canadien et le soumet à l'examen dans le cadre du Processus fédéral d'évaluation et d'examen en matière d'environnement. Au cours de cet examen, EACL montrera que l'enfouissement soigné, contrôlé, dans la roche plutonique du bouclier précambrien canadien à des profondeurs comprises entre 500 et 1 000 m, est une façon sûre et réalisable de stocker de manière permanente les déchets de combustible nucléaire canadien. Le concept a été évalué sans identifier ou évaluer de site particulier. EACL rédige actuellement un rapport complet fondé sur plus de dix ans de recherche et développement.

Énergie atomique du Canada limitée
Établissement de recherches nucléaires de Whiteshell
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ABSTRACT

Atomic Energy of Canada Limited (AECL) has developed a concept for disposing of Canada's nuclear fuel waste and is submitting it for review under the Federal Environmental Assessment and Review Process. During this review, AECL intends to show that careful, controlled burial 500 to 1000 metres deep in plutonic rock of the Canadian Precambrian Shield is a safe and feasible way to dispose of Canada's nuclear fuel waste. The concept has been assessed without identifying or evaluating any particular site for disposal. AECL is now preparing a comprehensive report based on more than 10 years of research and development.

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1. INTRODUCTION

The term "nuclear fuel waste" refers to the highly radioactive waste from the fuel that has been used in a nuclear power reactor. Atomic Energy of Canada Limited (AECL) has developed a concept for disposing of Canada's nuclear fuel waste and is submitting it for review under the Federal Environmental Assessment and Review Process. The concept is to seal the waste in long-lasting containers and bury it 500 to 1000 metres deep in a massive rock body in the Canadian Precambrian Shield.

AECL's objective during the review is to establish that implementing this concept would be a safe and feasible way to dispose of Canada's nuclear fuel waste. The safety and environmental criteria to be used are those established in the regulatory documents of the Atomic Energy Control Board and all other applicable legislation, regulations, and guidelines.

Specifically, AECL intends to show that:

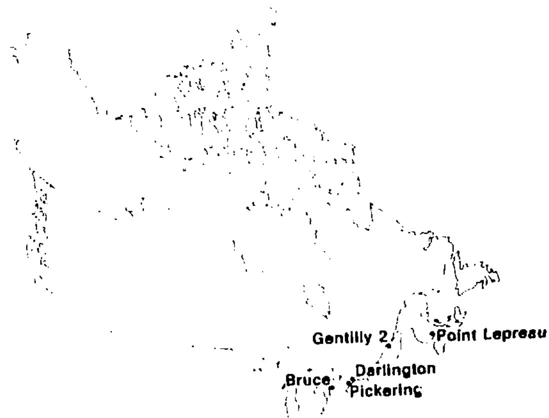
- the technology exists to site, design, construct, and operate a disposal facility that meets the safety and environmental criteria;

- the methodology exists to evaluate the performance of a disposal facility in plutonic rock in terms of the safety and environmental criteria; and

- many potentially suitable sites exist in Canada.

2. NUCLEAR FUEL WASTE

Canada generates more than 15% of its electricity from nuclear power, with 12.5 million kilowatts installed and 3.6 million kilowatts under construction. Quebec and New Brunswick each have one 0.7-million-kilowatt station; the rest of the generating capacity is in Ontario. The utilities that operate nuclear power stations in Canada are Ontario Hydro, Hydro Quebec, and New Brunswick Electric Power Commission.



Nuclear power stations in Canada

All the nuclear-generated electric power in Canada is produced by CANDU[1] reactors. The fuel consists of uranium dioxide pellets, which are stacked and sealed inside metal tubes. As many as 37 of these tubes are welded together to make a fuel bundle. One 25-kilogram bundle can produce as much electricity as 400 tonnes of coal.

Tom Bochsler and Cameco

Inspection of fuel bundles

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1 CANDU (CANada Deuterium Uranium) is a registered trademark of Atomic Energy of Canada Limited.

Inside the reactor, nuclear reactions within the fuel produce heat, which is used to drive steam turbines to produce electricity. The nuclear reactions create new atoms within the fuel, most of which are unstable and change spontaneously into different atoms. This spontaneous change is known as "radioactive decay."

An atomic species[2] produced by radioactive decay is either stable or unstable. If it is stable, it will not change spontaneously. If it is unstable, it will decay to another species, which may also be unstable, and so on. Eventually, however, a stable species will result.

Radioactive decay is always accompanied by the release of energy in the form of radiation. Radiation can damage tissue, and such damage can lead to serious health effects in humans. The potential for damage depends on the intensity and type of radiation, and on the duration of exposure. The three main types of radiation released by radioactive decay in nuclear fuel waste are known as alpha, beta, and gamma radiation.

Alpha radiation[3] does not travel very far through tissue. It can scarcely penetrate the dead outer layer of human skin, so it does not pose an external hazard. In internal, living tissue, however, it can do a lot of damage, because all the energy is absorbed by a single cell or a small group of cells. Thus a substance emitting alpha radiation can pose an internal hazard if it is swallowed or inhaled.

Beta radiation[4] can penetrate one or two centimetres of tissue, but can be stopped by aluminum foil. Thus beta radiation poses an external hazard only to superficial tissue; it is more hazardous when the source is internal to an organism.

Gamma radiation[5] can pass through the human body, so it poses both an internal and external hazard. People can be shielded from sources of gamma radiation by various materials: several millimetres to many centimetres of lead, or greater thicknesses of water or concrete, for example.

In a large group of atoms of a particular radioactive species, 1/2 of them will decay in a certain amount of time, called the "half-life" of the species. Thus, if we start with a large number of atoms of a particular species, after one half-life, 1/2 of them will be left; after another half-life, 1/4 of them will be left; after another half-life, 1/8 of them will be left;

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2 These atomic species differ from one another in the number of protons, the number of neutrons, and the energy content in the atomic nucleus. A particular species is called a "nuclide". An unstable nuclide is called a "radionuclide". Many radionuclides occur naturally, others would be very rare or nonexistent on earth if they were not artificially produced (in nuclear reactors, for example).

3 Alpha radiation results from alpha decay: the nucleus emits an alpha particle, which consists of two protons and two neutrons.

4 Beta radiation results from beta decay: the nucleus emits an electron or a positron (positively charged "electron").

5 Gamma radiation results from gamma decay: the nucleus emits a *photon* (gamma ray), which carries energy but no charge.

and so on. The half-lives vary from less than a second to more than a billion years, depending on the species. A given amount of a species with a longer half-life releases radiation at a lower rate (its radioactivity is lower) than the same amount of a shorter-lived species.

When a fuel bundle is removed from a reactor, it is highly radioactive, but most of the unstable atoms decay very quickly, thereby decreasing the radioactivity. The radioactivity of fuel that has been out of the reactor for 100 years is only about 1% that of fuel that has been out of the reactor for 1 year. Some of the radioactive species, however, will remain in significant quantities for millions of years. Much of the radiation is absorbed by the fuel bundle itself, causing it to heat up. As the radioactivity decreases, so does the heat generated.

Fuel that has been removed from a power reactor is called "used fuel." It is removed because of the buildup of atomic species that hinder the production of heat in the reactor. The used fuel also contains elements that could be used to produce more energy by putting them back into a reactor, that is, by recycling them.

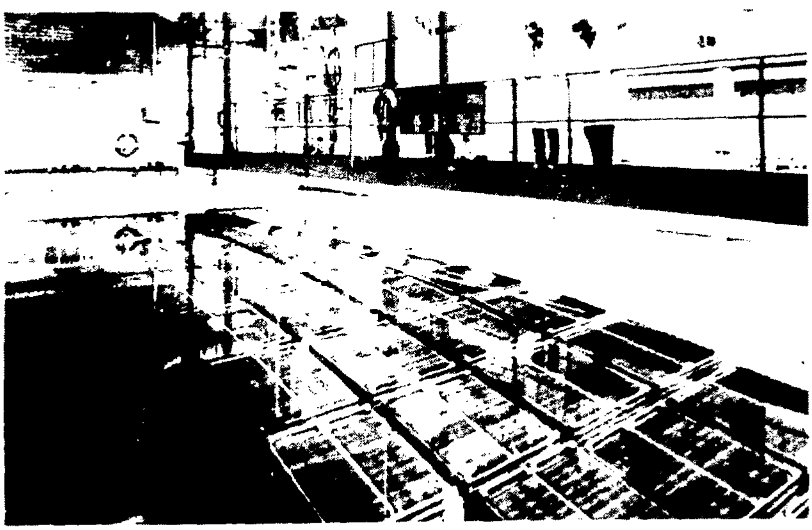
First, however, the used fuel would have to be reprocessed to separate the useful atomic species from the unwanted ones. Currently, it is more economical to use "fresh" uranium than to recycle used CANDU fuel, and it is unlikely that the economics of recycling would become attractive for Canada until well into the next century. At present, there is no recycling of used fuel in Canada. If Canada decides to recycle used fuel, the highly radioactive component of the waste from reprocessing would be incorporated into a solid, such as glass, and then managed in much the same way as the used fuel.

Nuclear fuel waste is either used fuel or the highly radioactive waste from reprocessing. In either case it is a solid that would dissolve only very slowly if it were placed deep in the rock of the Canadian Shield. It emits penetrating radiation, so it must be shielded by a material such as water, concrete, or rock; it generates heat, so measures must be taken to ensure it does not get too hot; and it is radiologically toxic, so measures must be taken to prevent harmful amounts entering the biological environment. The radioactivity decreases with time and, consequently, so does the penetrating radiation, the heat generated, and the radiological toxicity.

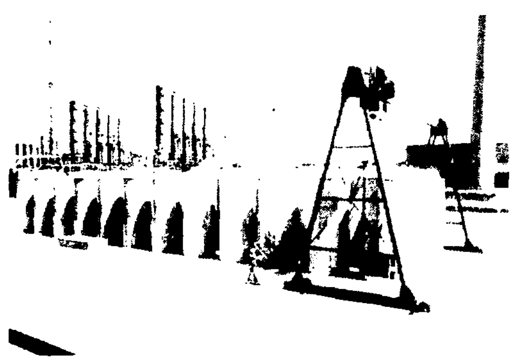
3. THE NEED FOR A DISPOSAL METHOD

In Canada, the used fuel from power reactors is currently stored at the reactor sites. About 14 000 tonnes accumulated by the end of 1989, with about 1800 tonnes produced each year.

When fuel bundles are taken from a power reactor, they are immediately stored in a pool of water adjacent to the reactor. The water in the pool cools the bundles and shields people from penetrating radiation. This type of storage has been used successfully by Canada and other countries for over 40 years. After used fuel has been out of the reactor for several years, the amount of radiation and heat it emits is low enough that it can be transferred to dry storage if desired. Concrete canisters are being used for this purpose at some reactor sites in Canada.



Bundles of used fuel in a water-filled storage pool
at Ontario Hydro's Bruce Nuclear Power Station



Concrete storage canisters, and the overhead crane
used to transfer used fuel to the canisters

Both wet and dry storage are operating technologies that can contain the used fuel safely for decades. They permit easy retrieval of the used fuel while providing the necessary shielding, cooling, and safeguards.[6]

In spite of its excellent safety record, used-fuel storage cannot be considered a permanent means of managing nuclear fuel waste. Storage requires monitoring and maintenance, which will become more demanding as the quantity of used fuel increases. It is wrong to pass on to future generations the burden of monitoring, maintaining, rebuilding, and safeguarding storage facilities. People in the future will not have benefitted directly from the electricity generated, and the structure of society may change in a way that would prevent safe storage of the waste. Thus storage is an interim measure only-- the waste must eventually be disposed of so that future generations need not look after it.

The need for a method of disposal has been affirmed by several notable Canadian commissions, committees, and agencies. In 1977, the Department of Energy, Mines and Resources commissioned an independent expert group, chaired by Professor Kenneth Hare, to review policies for the long-term management of radioactive wastes. This group recommended that wastes not be allowed to accumulate indefinitely in interim storage (Aikin et al. 1977, p. 6).

The Royal Commission on Electric Power Planning, also created in 1977, was directed by the Ontario Government to examine nuclear power issues. The Commission stated that there was "an urgent need to develop ultimate disposal facilities to ensure that [nuclear fuel] wastes are isolated from the world's ecosystems" (Porter 1980, p. 68). Research into the geological and ecological criteria for disposal sites was to be given the highest priority (Porter 1978).

More recently, the federal Standing Committee on Environment and Forestry recognized the need for disposal, stating that "whatever [nuclear energy's] future—the wastes which it produces must be disposed of" (Briscoe 1988, p. 3).

The need for disposal has been asserted also by the federal agency that regulates Canada's nuclear industry. In 1987, after soliciting public comment, the Atomic Energy Control Board issued its regulatory policy R-104 for the disposal of radioactive wastes (Atomic Energy Control Board 1987). It affirmed the international radioactive waste management objectives of protecting human health and the environment and minimizing any burden on future generations. The policy R-104 states that the disposal option chosen should be one "in which there is no intention of retrieval and which, ideally, uses techniques and designs that do not rely for their success on long-term institutional control" (Atomic Energy Control Board 1987, p. 2).

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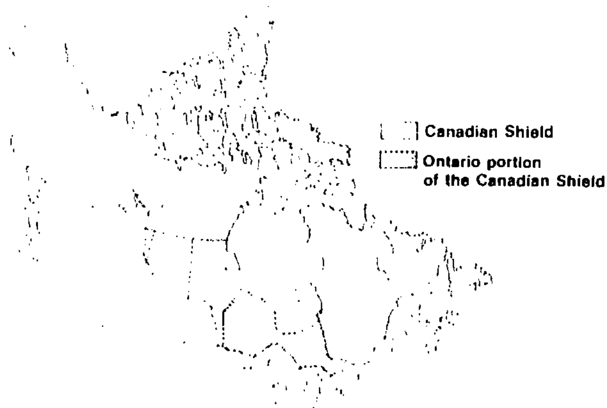
6 Safeguards are the measures taken to ensure that the used fuel is not used for weapons manufacture or other illicit purposes

4. THE MANDATE OF THE CANADIAN RESEARCH PROGRAM

The Hare Commission considered various options for disposing of nuclear fuel waste, including burial in arctic ice sheets, disposal in outer space, nuclear treatment of the waste to render it nonradioactive (transmutation), and geological disposal. It concluded that burial in plutonic rock was the most promising option (Aikin et al. 1977, p. 6), noting that "The Precambrian Shield of Canada ... contains large amounts of such rock .... The fact that the Shield has been stable for hundreds of millions of years is a sure indication that it will continue to remain stable for further millions of years. We can say this with confidence for it takes millions of years for the geologic regime to change from stable to active" (pp. 41-42). It further suggested that "Since Ontario will be the main producer of radioactive wastes, the first repository should be in that province" (p. 46).



Extent of the Canadian Precambrian Shield

Plutonic rock was formed deep within the earth's crust by crystallization from the molten state or by chemical alteration. It is sometimes called intrusive igneous rock or, more loosely, crystalline rock. Many large bodies of this rock, known as plutons, are exposed at the surface today because of erosion of overlying rock and uplift over hundreds of millions of years. Some of these bodies are hundreds of square kilometres in area and several kilometres deep. Most of them are granite. Plutonic rock is not limited to the Precambrian Shield: there is some in all provinces except Prince Edward Island.

In 1978, the Government of Canada and the Government of Ontario established a joint program of research and development on radioactive waste management (Joint Statement 1978). AECL, as an agency of the federal government, was made responsible for verifying the safety of disposal of nuclear fuel waste in plutonic rock. Ontario Hydro was made responsible for developing and demonstrating the technology for storage of the nuclear fuel waste, and for transportation of the waste from reactor sites. Another Joint Statement (1981) imposed the restriction that the disposal concept had to be assessed, reviewed, and accepted before a site could be selected.

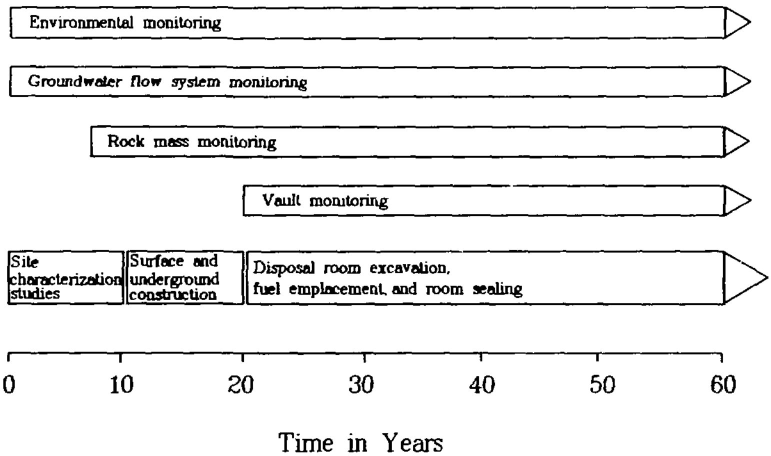
5. THE CANADIAN DISPOSAL CONCEPT

AECL proposes that nuclear fuel waste be placed in long-lasting containers and buried in a mined excavation (vault) 500 to 1000 metres deep in plutonic rock of the Canadian Shield. The waste would be isolated from people and the surface environment, and it would be kept cool by the conduction of heat outward into the rock. The principal concern is that groundwater, which exists even deep within the rock, could penetrate the containers and allow the waste material to move slowly toward the surface. Therefore, each container would be packed in a clay "buffer," designed to impede the flow of water and any movement of radioactive material away from the container. Further, all excavated openings (shafts, tunnels, and rooms) would be filled with mixtures of clay and other geological material and sealed to slow any movement of water, keep the containers securely in place, and keep people away from the waste.

Thus the disposal concept would employ multiple barriers to protect people and the surface environment. While the container is intact, it would prevent groundwater from getting to the waste and would lock in the radioactive material. It would last hundreds to thousands of years, depending on its design and on conditions in the disposal vault. Should the container fail, the waste would resist dissolution in the water so that most of the radioactive material would be released to the water only very slowly. The buffer, surrounding the container, would impede movement of water and the movement of materials away from the container into the surrounding rock. The rock would protect the waste, container, and buffer; it would keep people and the surface environment out of contact with the emplaced waste; and it would impede the movement of radioactive material to the surface should it pass through the buffer. The filling material and seals would complete the envelope of protection afforded by the rock by filling and sealing the excavated openings.

As a contingency measure, the disposal concept incorporates methods for retrieval of the waste containers before the tunnels and shafts are filled and sealed. Once sealed, the vault would be a completely passive system: it would not require monitoring, maintenance, or control. Retrieval would still be possible, with some added difficulty and expense, for at least several hundred years while the containers remain substantially intact.

It would take more than 50 years to construct the surface facilities, excavate the vault, emplace the waste, and seal the vault. Before, during, and after these activities, the biological environment (biosphere), the rock and groundwater system (geosphere), and the vault would be carefully monitored. For example, air, surface water, plants, and animals would be sampled and analyzed; groundwater pressure, temperature, and chemistry would be determined by instruments in boreholes drilled into the rock; radioactivity would be measured in and around the surface and underground facilities; and rock characteristics would be monitored by devices installed from the excavated openings.



Monitoring and disposal schedule

Before any waste is emplaced, the information from monitoring would be used to prepare environmental impact assessments and document baseline conditions for future reference. Thereafter, the information would be used to confirm that the disposal system is performing as it was designed to do. Monitoring would be continued as long as the operators, the regulators, and the public require assurance.

The purpose of the disposal system as a whole is to prevent any waste material from reaching the surface in harmful amounts. This task is made easier because the material is decaying with time. The behaviour of this material in the surface environment and its effects on people are the basis for evaluating the safety of the system.

The disposal concept permits a choice of methods, materials, and designs for many of the components of the disposal system. Choices could be made on the basis of performance, availability, cost, or practicality. Several such choices would have to be made, for example,

- the form of the waste: bundles of used fuel or a solid, such as glass, containing the highly radioactive waste from reprocessing;
- the disposal container material: titanium alloy, copper, or other durable materials;
- the container design;
- the composition of materials used for the buffer, backfill, and seals;
- the depth of the vault and the number of levels of the vault;
- the excavation method: blasting or boring;

- the size and shape of the excavated openings; and

- the location of the waste containers: within a disposal room or in boreholes in the floor of the room.

Of major importance would be the selection of the disposal site. Because the characteristics of the site would be vital to the performance of the entire disposal system, the site would have to be technically suitable for the purpose. Given the large number of sites in the Canadian Shield that are potentially suitable on technical grounds, it is likely that social, political, and economic factors would also play a major role in the selection. The disposal system would be designed specifically for the site eventually selected.

6. THE SCOPE OF THE CANADIAN RESEARCH PROGRAM

6.1 OVERVIEW

The 1978 Joint Statement resulted in the launching of the Canadian Nuclear Fuel Waste Management Program. For more than 10 years, both AECL and Ontario Hydro have been conducting research on the disposal concept at research areas in the Canadian Shield, in AECL and Ontario Hydro facilities, at universities, and at private consulting firms. This diverse research involves geology, environmental sciences, physics, chemistry, mathematics, metallurgy, engineering, and the social sciences. AECL is conducting programs to inform the public about the research, and to identify public concerns so they can be addressed within the research program.

Because the 1981 Joint Statement imposed the restriction that no site could be selected prior to a review of the concept, we are not assessing the suitability of a specific site. Instead, we are conducting research at a variety of sites, and using the information to develop the disposal technology, design a hypothetical disposal facility, and assess the safety and feasibility of the hypothetical facility. Because the research is not site-specific, it is often referred to as "generic."

The research is focussed on the concept of burial deep in the plutonic rock of the Canadian Precambrian Shield. The consideration of other disposal media is addressed by monitoring the research programs of other countries and by reviewing existing information on salt and sedimentary formations in Canada.

6.2 SITING TECHNOLOGY

AECL is developing siting technology to identify a technically suitable site, that is, one at which nuclear fuel waste could be safely disposed of by using available methods. We are developing and evaluating methods for:

- site screening, which is the identification of a small number of potentially suitable areas or sites; and

- site characterization, which is the detailed study of a site.

To develop the siting technology, to establish technical criteria for screening and ranking of potential sites, and to evaluate the performance of plutonic rock as a disposal medium, we are investigating geological conditions at several field research areas in the Canadian Shield and at AECL's Underground Research Laboratory. We conduct surface, borehole, and underground investigations, using existing exploration methods and developing new methods as required. Through this research we are developing and demonstrating our ability to acquire, from any potentially suitable site, all the information necessary for environmental and safety assessment and disposal facility design. This information includes:

- the nature of groundwater flow through the rock;

- the physical, chemical, and structural characteristics of the rock;

- the physical and chemical characteristics of the groundwater;

- the interaction of contaminants with the rock and groundwater; and

- the potential influence of a disposal vault on subsurface conditions.

The nature and influence of the near-surface and surface environment is being investigated through environmental research in the Canadian Shield. Factors studied include the discharge of groundwater from deep in the rock; the behaviour of contaminants in lake water, sediments and soil; and the potential sources of food and water.

6.3 ENGINEERED SYSTEMS TECHNOLOGY

The engineered systems are the man-made barriers that would protect people and the surface environment. These barriers would be the waste, the container, the buffer material surrounding the container, and the materials used to backfill and seal the disposal vault. AECL is studying methods and materials for fabricating these barriers and emplacing them in a disposal vault. We are also studying the properties of these barriers so their performance can be predicted.

AECL scientists are studying both types of nuclear fuel waste: bundles of used fuel and solidified highly radioactive waste from reprocessing. Properties of interest include the chemical and physical composition, heat generation, and factors affecting release of materials to groundwater.

AECL specified a minimum lifetime of 500 years for the disposal container. Container designs and materials are being developed and evaluated for their ability to meet this performance requirement under the conditions of pressure, temperature, and chemistry expected in a disposal vault. Because the groundwater at vault depth could be saline, we are assessing a wide range of corrosion-resistant materials. We have built full-scale and half-scale prototypes of several container designs, and tested their performance. We are also studying methods to fabricate, fill, seal, and inspect containers.

Potential buffer, backfill, and sealing materials are being investigated to understand how they would perform in a disposal vault. At our Underground Research Laboratory we are doing large-scale studies on how to emplace the containers, buffer, backfill, and sealing materials.

We are investigating a number of design options for the disposal vault layout and operations. For example, containers could be placed on the floor of a disposal room or in boreholes in the floor; disposal rooms could be located at one or more than one level. We are evaluating these options to determine their relative merits in terms of safety, cost, and practicality.

6.4 USED-FUEL DISPOSAL CENTRE CONCEPTUAL DESIGN

A conceptual engineering design for a used-fuel disposal centre (UFDC) has been produced to assess the engineering feasibility, costs, safety, and potential environmental impact of a disposal facility. The design is based on hypothetical site conditions derived from information obtained at several field research areas in the Canadian Shield. It is also based on the use of present technology or its easily achievable extensions.

This design should be viewed as a realistic "case study" only. The details of the design of any facility built in the future could be quite different, particularly in those specifics that depend strongly on site conditions (rock structure, groundwater chemistry, surface features, etc.). Further, the specifications for the design were produced in 1985, and the design of a future facility would no doubt change to take advantage of knowledge gained since then.

Several assumptions were made in preparing the design: the waste is disposed of in the form of used-fuel bundles; the capacity of the vault is 190 000 tonnes (10.1 million bundles); disposal of waste begins in 2020 and the vault is filled to capacity in 2060; the bundles are stored at the reactor sites for 10 years before being transported to a disposal facility.

The surface facilities include a container fabrication plant, used-fuel packaging plant, concrete plant, rock-crushing plant, and disposal vault head frames. They also include auxiliary facilities, such as a service building, administration building, powerhouse, warehouse, fire hall and security building, and facilities for managing both radioactive and nonradioactive secondary waste.[7] The surface facilities are located on a site 5.2 kilometres long and 3.0 kilometres wide.

Granite was chosen as the reference disposal medium because it is the most abundant type of pluton in the Canadian Shield. Five vertical shafts extend from the surface to a depth of 1000 metres, where a network of horizontal tunnels and disposal rooms is located. This network occupies an area about two kilometres square.

There are 512 disposal rooms, each having up to 282 boreholes drilled into the floor. There are a total of 140 256 boreholes, with one container of waste placed in each. The container is an enclosed cylindrical vessel of titanium alloy, and holds 72 bundles of used fuel. Glass beads are compacted around the fuel bundles inside the container to support the container wall.

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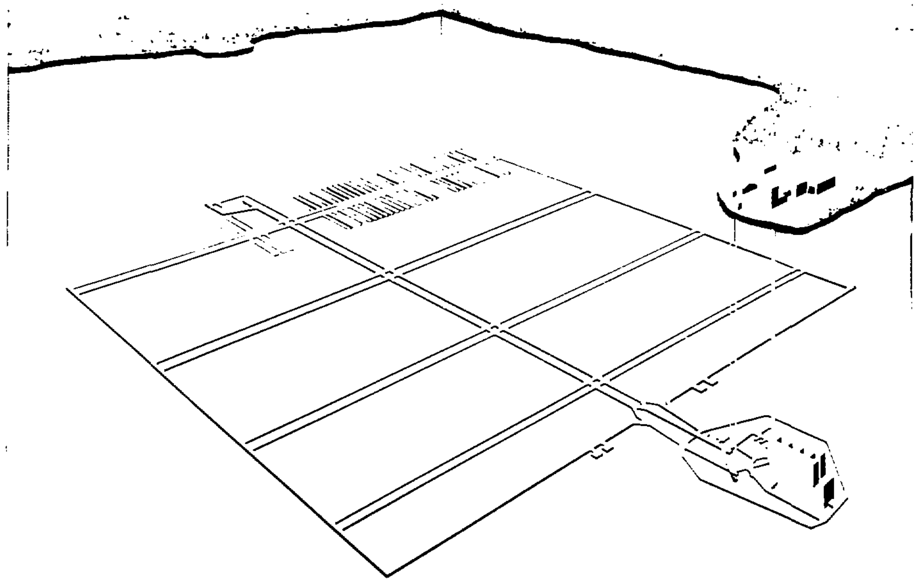
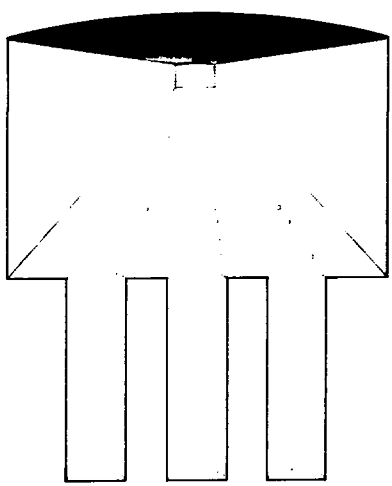
7 Secondary waste is the waste produced in operating the disposal facility itself, as distinct from the primary waste shipped to the facility for disposal

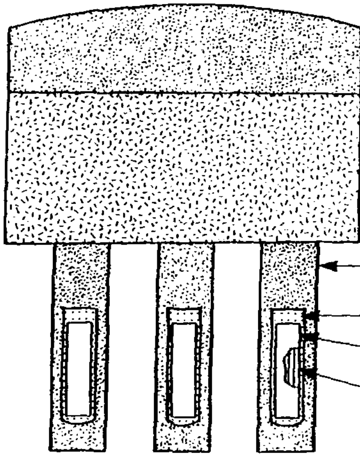


Conceptual design of the vault, showing all the disposal rooms in the first panel and seven rooms in the second panel



A disposal room in the vault, showing the boreholes in the floor of the room

The buffer material is a mixture of 50% by weight sodium bentonite clay and 50% silica sand. It is compacted around each container in its borehole. The shafts and the lower portion of the rooms and tunnels are backfilled with a mixture of 25% by weight glacial lake clay and 75% crushed granite from the vault excavation. The upper portions of the rooms and tunnels are backfilled with the same material used for the buffer.



Cross section through a disposal room

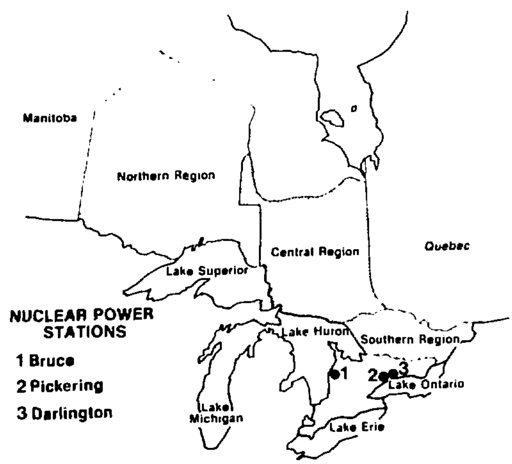
The major operations at the used-fuel disposal centre include the following:

- manufacturing containers;
- receiving bundles of used fuel in transport casks (from the nuclear power stations) and emptying the casks;
- transferring used-fuel bundles into containers, compacting glass beads around them, and sealing and inspecting the containers;
- transferring the containers to the underground facility for disposal;
- emplacing the containers in boreholes;
- sealing the boreholes;
- backfilling and sealing the disposal rooms;
- decommissioning the surface facilities; and
- closing the vault (backfilling and sealing the tunnels and shafts).

6.5 THE PRECLOSURE ENVIRONMENTAL AND SAFETY ASSESSMENT

The preclosure phase of nuclear fuel waste disposal includes transportation of the used fuel to the disposal centre, construction and operation of the centre, decommissioning of the surface facilities, and closure of the vault. The objective of the preclosure environmental and safety assessment is to determine the potential impacts of these activities on human health and safety, on the natural environment, and on the socioeconomic environment. Both normal and abnormal conditions are being assessed.

Because the 1981 Joint Statement required that the disposal concept be assessed, reviewed, and accepted before a site could be chosen, the preclosure assessment is a generic one, that is, no specific site is assumed. Instead, the impacts of implementing the conceptual UFDC are estimated for each of three regions: the southern, central, and northern regions of the Ontario portion of the Canadian Shield. The predominant environmental characteristics of each region are being determined, and potential impacts are being identified.



Southern, central, and northern regions of the Ontario portion of the Canadian Shield

The impacts of transportation are assessed assuming the disposal site is located at the geographical centre of each region. The used fuel is shipped dry in transport casks by road, rail, water and road, or water and rail. Water transport is considered only for the central and northern regions, and it is assumed that the used fuel is transferred to road or rail transport at a specially designed facility on the northern shore of Lake Superior.

The assessment of preclosure activities considers:

- radiological and nonradiological impacts on the public;
- radiological and nonradiological impacts on workers;

- nonradiological impacts on the environment;
- socioeconomic impacts; and
- economic impacts on Ontario and the rest of Canada.

The effectiveness of security and safeguards measures is also being assessed.

6.6 THE POSTCLOSURE ENVIRONMENTAL AND SAFETY ASSESSMENT

The postclosure phase of nuclear fuel waste disposal begins after the vault is closed. The objective of the postclosure assessment is to determine the long-term impacts of the disposal facility, and provide estimates of risk that can be compared with regulatory criteria.

The assessment of long-term impacts requires knowledge of the specific characteristics of the disposal site, and it would be meaningless to perform a generic assessment. Instead, we are estimating the long-term impacts of implementing a reference disposal vault design at a hypothetical site; the characteristics of this site are based on information obtained from one of AECL's research areas (the Whiteshell Research Area). This assessment, then, should be considered as a case study, similar to the conceptual engineering design study. The assessment demonstrates the acquisition of information from the field and laboratory, and its use in assessing impacts.

The reference disposal vault design is similar to the UFDC conceptual design, but there are some differences. For example, the depth of the vault is taken to be 500 metres, rather than 1000 metres, because the estimated risk for the shallower vault will tend to be higher. An assumption such as this, which would tend to overpredict the impact, is known as a "conservative assumption." Many conservative assumptions are made in the assessment.

Our approach has been to understand the features of a disposal system, the processes that are important to its safety, and potential future events that could adversely affect it. Based on this understanding, we develop mathematical models of the system, which are used to estimate impacts far into the future. Field and laboratory studies are used to obtain realistic and valid information for the models and to test the validity of the model results.

Potential impacts are evaluated for scenarios that include normal operation as well as abnormal events and processes (for example, failure of shaft seals). The uncertainties in the estimates are also evaluated to give a perspective on the range of impacts that are possible and the likelihood of encountering them.[8]

It is necessary to use mathematical models because we cannot observe the performance of the disposal system over the very long time for which we must assess the impacts (at least 10 000 years). Instead, we must estimate the long-term impacts of the system from information available before and during the preclosure phase. For this concept assessment, the reliability of the models is established by comparing

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8 The assessment relies heavily on the so-called probabilistic method of analysis to estimate the uncertainties; that is, much of the information used in the assessment is given in terms of probability distributions rather than single values, and these probability distributions are carried through the calculation to estimate a corresponding probability distribution of results.

calculations with field and laboratory observations of important processes—including observations of natural systems such as uranium deposits—and by intercomparing calculations made using different, independently developed models. Several model intercomparisons have been organized internationally, so there is a very broad range of expertise applied to establishing confidence in the models.

If and when a disposal facility is actually constructed, the models and data used will be refined over the entire preclosure life of the disposal facility (more than 50 years). They will be adjusted continuously as information is obtained from the monitoring systems prior to construction, during construction, and during operation. By the time the vault is ready to be closed, the reliability and accuracy of the models will have been thoroughly established.

To perform the postclosure assessment, we divided the disposal system into three components: the vault, the geosphere, and the biosphere. The vault comprises the engineered barriers, which include the waste, the container, the buffer material surrounding the container, and the materials used to backfill and seal the disposal vault. The geosphere consists of the rock mass and its groundwater flow system. The biosphere consists of the surface and near-surface environment, including the soil, water, air, people, and other organisms.

For each of these components, a model is being developed by scientists who are experts in the processes important to the behaviour of that component. These models are briefly discussed in the next three sections.

6.7 THE VAULT MODEL

The vault model is used to estimate the flow of contaminants from the vault into the surrounding geosphere. This model simulates:

- corrosion of the containers;
- release of contaminants from the waste; and
- transport of the contaminants through the buffer and backfill.

The information used to develop the vault model is obtained primarily from the engineered systems technology research described in Section 6.3.

6.8 THE GEOSPHERE MODEL

The geosphere model is used to estimate the flow of contaminants from the vault to the biosphere. This site-specific model simulates:

- movement of groundwater through the rock surrounding the vault;
- transport of contaminants in the groundwater; and
- discharge of contaminants at locations in the surface and near-surface environment.

The information used to develop the geosphere model is obtained primarily from the siting technology research described in Section 6.2.

6.9 THE BIOSPHERE MODEL

The biosphere model is used to estimate concentrations of contaminants in the environment, and to estimate the radiological impact on the people most affected because of their location and lifestyle (diet, source of food, source of drinking water, etc.). This model simulates:

- transport of contaminants within the biosphere, that is, through surface water, soil, air, plants, and animals; and
- exposure of people to internal radiation (from the food, water, and soil they swallow and the air they breathe) and to external radiation (from soil, air, water, and buildings).

The information used to develop the biosphere model is obtained from the siting technology research described in Section 6.2 and from other studies that focus on:

- the dispersion of contaminants in air;
- the uptake of contaminants by plants from soil and air;
- the transfer of contaminants to animals; and
- the transfer of contaminants to people.

7. DOCUMENTATION

The research performed as part of the Canadian Nuclear Fuel Waste Management Program has been documented in AECL Reports, AECL Technical Records, Ontario Hydro Reports, and papers published in scientific journals and conference proceedings. More than 1000 such publications exist.

We are now preparing a comprehensive report about the work we have done. An overview for a general technical audience will describe the characteristics of used fuel, the need for a disposal method, regulations governing disposal, the disposal concept developed by AECL, technical siting methods, the assessment methods and results, and alternatives to the proposed disposal concept. The overview will also contain conclusions and recommendations. A summary of the overview is being written for those with non-technical backgrounds. The bulk of the report will describe in detail the research briefly discussed in Sections 6.2 to 6.9. This detailed description is intended for readers who wish to familiarize themselves thoroughly with the technical and scientific aspects of the proposed disposal concept.

AECL expects that this comprehensive report will provide a large part of the information that will be required for the review of the disposal concept.

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The research has been independently reviewed and assessed, on a continuing basis, by the Technical Advisory Committee to AECL on the Nuclear Fuel Waste Management Program. This committee, which consists of eminent scientists and engineers nominated by Canadian learned societies, has made an invaluable contribution to the quality and direction of the research.

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