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HIGH-LEVEL RADIOACTIVE WASTE IN CANADA

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TABLE OF CONTENTS

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HIGH-LEVEL RADIOACTIVE WASTE IN CANADA

INTRODUCTION

The disposal of radioactive waste is one of the most challenging environmental problems facing Canada today. Since the Second World War, when Canadian scientists first started to investigate nuclear reactions, there has been a steady accumulation of such waste. Research reactors built in the early postwar years produced small amounts of radioactive material but the volume grew steadily as the nuclear power reactors constructed during the 1960s and 1970s began to spawn used fuel bundles. Although this radioactive refuse has been safely stored for the short term, no permanent disposal system has yet been fully developed and implemented.

Canada is not alone in this regard. A large number of countries use nuclear power reactors but none has yet put in place a method for the long-term disposal of the radioactive waste. Scientists and engineers throughout the world are investigating different possibilities; however, enormous difficulties remain.

In Canada, used fuel bundles from nuclear reactors are defined as high-level waste; all other waste created at different stages in the nuclear fuel cycle is classified as low-level. Although disposal of low-level waste is an important issue, it is a more tractable problem than the disposal of high-level waste, on which this paper will concentrate. The paper discusses the nuclear fuel waste management program in Canada, where a long-term disposal plan has been under development by scientists and engineers over the past 15 years, but will not be completed for some time. Also discussed are responses to the program by parliamentary committees and aboriginal and environmental groups, and the work in the area being conducted in other countries.

WHAT IS RADIATION?

A brief description of radioactivity, the fission process and how a nuclear reactor works will be helpful to our discussion.

All matter is composed of atoms. Each atom consists of a nucleus, containing virtually all the mass and made up of neutrons and protons, which is surrounded by orbiting electrons. There are the same number of protons (positively charged) as electrons (negatively charged) so that the atom is electrically neutral.

Most atoms are stable; those that are not stable constantly emit energy in order to become so. This energy is radiation and takes the form of alpha, beta or gamma rays. Alpha particles cannot penetrate far and can be stopped by a piece of paper or a few millimetres of air. Beta particles can be halted by several centimetres of wood. Gamma particles, however, are highly penetrating and can be stopped only by a certain thickness of specific material, such as concrete or water.

An element is defined by the number of protons in its nucleus. Every isotope of an element has the same number of protons but a different number of neutrons, and therefore a different mass. Many isotopes are unstable and, by emitting radiation, change spontaneously into different isotopes. The length of time it takes for half of the amount of a particular isotope to transmute into another is known as the "half life."

Uranium is a naturally occurring radioactive element with a half life of over a billion years. It has a number of different isotopes, some of which are susceptible to fission, a process in which the heavy nucleus of a uranium atom absorbs a neutron and splits into a number of smaller fragments, releasing energy in the process. It is this energy, in the form of heat, which is harnessed in a nuclear power reactor to produce electricity.

When a uranium atom splits, a number of radioactive particles are found; these are usually divided into two groups: actinides and fission products. At the same time, neutrons are emitted that break other uranium atoms, thus continuing the heat-producing process. Table 1 lists some of the important isotopes formed during a nuclear reaction and which must later be disposed of as radioactive waste.

Table 1

Actinide Components and Fission Products in One Kilogram of CANDU Spent Fuel

	Radioactive Half-Life*	Type of radiation	Specific Activity (curies/gram)	Mass (grams)
Actinides				
Plutonium 239**	24,390	alpha	6.1×10^{-2}	2.7
Plutonium 241**	14	beta	112	
Plutonium 238	87	alpha	17	
Plutonium 240	6,660	alpha	2.3×10^{-1}	1.1
Plutonium 242	387,000	alpha	4.0×10^{-3}	
Americium 241	458	alpha, gamma	3.2	
Americium 242	0,0018	beta, gamma	8.2×10^{5}	
Americium 243	8,000	alpha	1.9×10^{1}	1.2
Curium 242	0.51	alpha, neutrons	3,320	
Curium 243	32	alpha	47	
Curium 244	17.6	alpha, neutrons	83	
<u>Fission Products</u>	Radioactive half-life <u>(days)</u>			
Iodine 131	8.1	beta, gamma	1.2×10^{5}	
Xenon 133	5.3	beta, gamma	1.9×10^{5}	
Krypton 85	3,944.0	beta, gamma	391	9
Ruthenium 106	368.0	beta	3.35×10^{3}	
Tellurium 127	109.0	beta, gamma	9.43×10^{3}	
Cesium 137	10,957.0	beta, gamma	87	

Source: Ontario, Royal Commission on Electric Power Planning (Arthur Porter, President), *A Race Against Time: Interim Report on Nuclear Power in Ontario*, p. 74-75.

As the nuclear reaction proceeds, both the number and amount of fission products increase. After a while, these products begin to absorb too many neutrons and the nuclear reaction is slowed.

* The time required for half the atoms of a radioactive substance to disintegrate.

** Fissionable actinide.

The CANDU, Canada's nuclear power reactor, is fuelled by uranium oxide (UO_2), which is refined from natural uranium ore. The oxide is pressed into solid ceramic pellets, which are then sealed inside metal zirconium tubes and welded together to make a fuel bundle. As mentioned above, the fuel bundle can remain in the reactor for only a limited amount of time before it starts to slow the nuclear reaction. In a CANDU reactor, the fuel is removed after approximately 18 months, at which point roughly 2% of the uranium has transmuted into new elements. The used fuel bundle is intensely radioactive and must be stored below at least three metres of water in order to block the radiation.

Most of the radioactive elements in the used fuel decay rapidly to stable elements. One hour after removal from the reactor, the used fuel bundles have lost over 60% of their radioactivity; however, the remaining fission products are still highly penetrating. One year later, a person would still receive a lethal dose of radiation from the used fuel in about ten minutes. After 500 years, the penetrating radiation is no longer a threat but the longer-lived elements still give off radiation that would prove dangerous if ingested. It is for this reason that any disposal system must ensure that these fission products do not contaminate the environment.

Water storage is the main method for storing used fuel bundles in Canada today. It has always been recognized that this is a safe, if temporary, means of storing radioactive waste. Its main problem is that it requires ongoing monitoring and does not remove the waste from the human population at large. For example, waste from the Pickering nuclear reactor west of Toronto is stored on site at the reactor. This is not a satisfactory long-term solution.

CANADA'S NUCLEAR FUEL WASTE DISPOSAL CONCEPT

A. Background

In the early days, waste from the research reactors was stored in nearby water-filled pools. Scientists investigated other possibilities such as converting radioactive waste into aluminosilicate glass hemispheres, which were then buried so that the leaching and migration of buried waste could be studied. But the simplest method, and therefore the one temporarily adopted, was water storage.

By 1975, scientists and engineers had devised a dry storage method whereby used fuel is taken either from the reactor or from wet storage in the pools and placed in primary containment baskets surrounded by a secondary containment steel liner. This is placed inside a large concrete canister that has been reinforced with steel bars. When the canister is full, a shielding plug is welded into place. The life expectancy of the canister is estimated to be 50 to 100 years.

Although both wet and dry storage are acceptable methods of dealing with radioactive waste temporarily, it has long been recognized that a permanent disposal method is essential. In 1977, Energy, Mines and Resources Canada commissioned a study, led by Professor F.K. Hare of the University of Toronto, to determine possible long-term disposal methods. The task force considered a number of options, including firing the waste into deep space or burying it in the seabed; it eventually recommended an investigation into disposal of the nuclear fuel waste deep in the granite rock of the Canadian Shield. This recommendation was endorsed a year later by the Ontario Royal Commission on Electric Power Planning.(1)

In 1978, the governments of Canada and Ontario established the Canadian Nuclear Fuel Waste Management Program. Atomic Energy of Canada Limited (AECL) was asked to assess the concept of disposal of fuel in the Canadian Shield and to develop the necessary associated technologies. The program, described more fully below, is administered by AECL'S Whiteshell Nuclear Research Establishment in Pinawa, Manitoba, and is focusing on the geological, hydro-geological, geotechnical and geophysical aspects of disposal in the granitic rock of the Canadian Shield. Ontario Hydro is responsible for developing interim storage facilities and methods for transportation of the used nuclear fuel.(2)

Early in the program problems over siting the waste disposal facility became apparent. Many communities approached for permission to carry out local geological studies were opposed to such investigations. To help address these concerns, it was announced in 1981 that the program would be modified; a waste disposal concept would be developed first and then the site for

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(1) Robert L. Greyell, “Nuclear Fuel Waste Disposal: Canada's Environmental Review Begins,” p. 307.

(2) B. Gray and G. Underdown, “Perspectives of the Proponent and Initiating Department on the Federal Environmental Review of the Canadian Nuclear Fuel Waste Management Program,” Atomic Energy of Canada Limited, Whiteshell Nuclear Research Establishment, Manitoba, n.d. p. 2.

the facility would be chosen. Furthermore, public hearings would be held to ensure widespread participation in the process.(3) The form and extent of this public review will be discussed below.

B. Description

In Canada, as we have seen, the proposed method of disposal is to bury the radioactive waste deep in the rock of the Canadian Shield. This rock formation was chosen for a number of reasons. The Canadian Shield has been stable for at least 600 million years and most of it has not experienced major orogenic (or "mountain-building") activity for 2.5 billion years; it is therefore likely to remain stable for the lifetime of a disposal vault. Furthermore, the topographic gradients within the Shield are low, which means that the natural driving force for groundwater flow deep in the rock should be weak.(4)

The possibility of groundwater mobility is further diminished by the low porosity and permeability of the large volumes of plutonic rock believed to exist in the Shield.(5) Placing the disposal vault within this type of rock would limit groundwater access and inhibit the movement of contaminants through the rock. Furthermore, minerals in plutonic rock are known to interact with many of the radionuclides in nuclear fuel waste and this plan would also decrease their mobility.

A final significant advantage of the Canadian Shield as a storage facility is that it covers an enormous area of land so that there would be a wide choice of sites.(6) Given this flexibility, and because a siting decision will inevitably bring about a great deal of controversy, AECL is developing a generic proposal whereby its disposal facility could be located anywhere in the Canadian Shield. Once this concept has been accepted, the difficult problem of precise location will be addressed.

The proposed disposal vault would resemble a mine. At a depth of between 500 and 1,000 metres, it would occupy an area of approximately four square kilometres and consist of 480 disposal rooms. This design would allow for the disposal of about 190,000 tonnes of used fuel.(7)

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(3) *Ibid*., p. 3.

(4) K. Nuttall and D.F. Torgerson, "Developments in the Canadian Concept for Disposing of Nuclear Fuel Waste," presented at the 1991 Joint International Waste Management Conference, 21-24 October 1991, p. 1.

(5) Plutonic rock is rock formed as igneous rock by solidification below the surface of the earth.

(6) Nuttall and Torgerson (1991), p. 1.

(7) *Ibid*., p. 2.

The used fuel would be sealed inside corrosion-resistant containers made from titanium and large enough to hold 72 CANDU fuel bundles. Inside, free space would be packed with glass beads to provide mechanical support against external pressures in the vault. The aim is to keep groundwater from reaching the used fuel for at least 500 years.

Once the fuel was sealed in containers, each would be placed in a hole drilled in the floor of a disposal room and surrounded by buffer material. The lower portion of the room would be backfilled by a mixture of clay and crushed granite and topped with a mixture of bentonite and sand. Concrete bulkheads would secure the room entrances and grouting material would be used to ensure they were sealed. Finally, the vault would also be closed by backfilling the access tunnels in the same way as the rooms. Even the shafts leading to the access tunnels would be packed with crushed granite and compacted clay.(8)

C. Safety

In disposing of nuclear fuel waste, a difficulty is to develop a system that will be secure for thousands of years. Although it is impossible to guarantee continuing safety, it is possible to develop models that provide a "convincing and indirect demonstration that the proposed disposal system provides a sufficient level of safety to both current and future generations."(9)

Since it is impossible to test the disposal system over the time period necessary, mathematical models have been developed to simulate how it will respond to possible future events, in both normal and abnormal operating conditions. The models were developed by using information obtained in defining the waste disposal concept. To test reliability, their predictions are compared with field and laboratory observations of certain processes (for example, the behaviour of natural uranium deposits) and with the results of independently developed models.(10)

To assess how the system would perform after closure, the system is divided into three components: the vault, the geosphere and the biosphere. The vault includes the waste and its container, the buffer material surrounding the container, and the materials used to backfill and seal the vault. A model estimates the flow of contaminants from the vault into the surrounding

(8) *Ibid*.

(9) Organisation for Economic Co-operation and Development, *Disposal of Radioactive Waste: Can Long-term Safety be Evaluated*?, Paris, 1991, p. 11.

(10) K.W. Dormuth and P.A. Gillespie, "Nuclear Fuel Waste Disposal in Canada -- The Generic Research Program," AECL-10183, May 1990, p. 20.

geosphere, simulating the corrosion of the containers, the release of contaminants from the waste and their passage through the buffer and backfill.(11)

The geosphere comprises the rock mass and its groundwater flow system. The model simulates the movement of groundwater through the rock surrounding the vault, the transportation of contaminants in the groundwater and the discharge of contaminants at locations in the surface environment.(12)

Finally, the biosphere model simulates the transport of contaminants within the biosphere through surface water, soil, air, plants and animals. It also examines the amount of exposure to radiation that people might experience.(13)

Though it is not possible to predict safety with absolute certainty, the models provide a technical basis on which to decide whether the proposed system would operate at a safety level satisfactory for both current and future generations.

D. Program Evaluation

To evaluate the extent and quality of the technical program under development by the scientists and engineers at AECL, the company established a Technical Advisory Committee (TAC), whose members were selected from a list of nominees submitted by the major scientific and engineering societies in Canada.(14) The TAC acts as an independent review which advises AECL on the research carried out for the Nuclear Fuel Waste Management Program. This independent, peer-review committee examines proposed research projects and suggests alternatives and additions when necessary, looks at scientific methods, and reviews program results to ensure that conclusions are valid. Each year, a report is issued on the scientific and technical progress made during the previous 12 months.(15)

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(11) *Ibid*., p. 21.

(12) *Ibid*., p. 22.

(13) *Ibid*., p. 23.

(14) These societies are: Chemical Institute of Canada, Engineering Institute of Canada, Canadian Geoscience Council, Canadian Institute of Mining and Metallurgy, Canadian Association of Physicists, Canadian Federation of Biological Societies, Biological Council of Canada, Canadian Information Processing Society.

(15) For copies of these reports, Annual Reports TAC-1 through TAC-12, Technical Advisory Committee on the Nuclear Fuel Waste Management Program, contact Professor L.W. Shemilt, Technical Advisory Committee Chairman, 1980-91, McMaster University, Hamilton, Ontario, L8S 4K1. .

At present, the TAC has 16 members, each appointed for a three-year term. It meets as a full committee but also has four subcommittees (Geoscience, Engineered Barriers, Bioscience, and Systems Analysis). To maintain continuity, the membership of four sub-committees overlaps and the terms of individuals can be renewed.(16) The Committee reports to the Vice-President, Environmental Sciences and Waste Management, at AECL. Its autonomy is maintained by having its members nominated by scientific societies, by having its reports open for public consultation and by inviting public participation.

The TAC is able to provide a necessary scientific and technical review of the Nuclear Fuel Waste Management Program. It was recognized early on, however, that public input is essential to ensure future acceptance of the proposed disposal concept. It is for this reason that the public has been asked to participate a number of times during the review process.

In October 1989, the Minister of the Environment appointed a review panel to examine the nuclear fuel waste management concept. Under the chairmanship of Mr. Blair Seaborn, former Deputy Minister at Environment Canada, the panel was made up of eight members with a wide range of technical, social and economic expertise. A Scientific Review Group was also set up to help in evaluating scientific and technical matters.(17)

The general manner in which an environmental assessment and review is carried out is defined by the Environmental and Assessment Review Process (EARP) Guidelines Order but each panel must define the details of its particular review. In this case, the first steps taken were to hold information gathering ("scoping") sessions and public hearings, where groups presented their views on the disposal concept. This was followed by an opportunity for interested parties to review and comment on guidelines for the preparation of an Environmental Impact Statement (EIS). The panel has held hearings in different communities in the five provinces with a direct interest in the nuclear industry: Saskatchewan, Manitoba, Ontario, Quebec, and New Brunswick.(18)

Throughout 1990, open houses provided the public with information on both the disposal concept and the ongoing review process. A total of 130 groups participated in the scoping meetings and were thus able to comment on the Environmental Impact Statement. As will be seen below, many groups found much to criticize in both the disposal concept and the review process.

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(16) Technical Advisory Committee on the Nuclear Fuel Waste Management Program, Twelfth Annual Report, March 1992, p. 4.

(17) Gray and Underdown, p. 4.

(18) *Ibid*.

In March 1992, the Federal Environmental Assessment Review Panel published the "Final Guidelines for the Preparation of an Environmental Impact Statement on the Nuclear Fuel Waste Management and Disposal Concept." The final Environmental Impact Statement, expected by March 1994, will outline the nuclear waste problem, describe the AECL disposal concept and alternatives, explain how the concept would be implemented and discuss its likely impact.(19)

Public hearings will be held on the Environmental Impact Statement once it has been published. After the necessary changes and possible additions have been made, it is hoped that the panel will be able to submit its report to the government by 1995.

RESPONSES TO CANADA'S PROGRAM

A. Parliamentary Examinations

Two House of Commons Standing Committees have examined the Canadian Nuclear Fuel Waste Management Program in the past decade. In January 1988, the Standing Committee on Environment and Forestry issued a report entitled "High-Level Radioactive Waste in Canada: The Eleventh Hour." The report's most controversial recommendation was for a moratorium on construction of nuclear power plants in Canada until an acceptable solution to the problem of nuclear fuel waste has been found. Other recommendations were for: attempts to reduce both the amount and the volume of waste produced; an independent scientific assessment of the computer models used to test the radioactive waste concept; a public process to determine a site; and a public review if Canada ever considers accepting nuclear waste from other countries.(20)

In August 1988, the Standing Committee on Energy, Mines and Resources held a much broader study of the economics of nuclear power in Canada. Even in this context, the Committee report's first two recommendations related to radioactive waste management. The Committee recommended that the schedule for completion of a high-level radioactive waste repository be advanced and that additional funds be made available to expedite the program.

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(19) Federal Environmental Assessment Review Panel, "Final Guidelines for the Preparation of an Environmental Impact Statement on the Nuclear Fuel Waste Management and Disposal Concept," March 1992.

(20) House of Commons Standing Committee on Environment and Forestry, "High-Level Radioactive Waste: The Eleventh Hour," January 1988, p. 35-37.

Furthermore, it directed the Atomic Energy Control Board to appear before it to present and justify the new schedule.[(21)]

B. Environmental and Aboriginal Groups

During the scoping hearings held by the Environmental Assessment Review Panel, a number of environmental and aboriginal groups discussed their concerns about the proposed nuclear fuel waste management program. Many criticized the terms of reference under which the Panel was operating because they explicitly excluded a number of topics, including the long- range plans for nuclear energy within Canada. It was argued that the question of waste disposal cannot be separated from this larger question.[(22)]

The lack of time and money afforded to the public interest groups was another serious complaint. While AECL, a federal Crown company, had a large budget to draw from, intervenors felt they had insufficient money and time to prepare their briefs. As one participant noted, the lasting impression is that "public participation has been little more than a *pro forma* exercise."[(23)]

Another criticism concerned the possible conflict of interest in having ECL perform the research on the disposal concept. One intervenor argued that it "seems inappropriate to trust AECL with this job of developing the waste disposal plan, when the whole future of the nuclear industry may depend on the outcome of this process."[(24)] Another participant claimed that the scientists and engineers working within the "corporate culture" of AECL, would be unlikely to challenge aspects of the disposal concept, for fear it would hurt their careers.[(25)]

Aboriginal groups from Northern Ontario appearing before the panel were concerned that the waste disposal facility might be placed on their lands,[(26)] and that the

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(21) House of Commons Standing Committee on Energy, Mines and Resources, "Nuclear Energy: Unmasking the Mystery," August 1988, p. 7.

(22) Submission by the Nuclear Awareness Project to the Environmental Assessment Review Panel, 23 October 1990 (available from the Federal Environmental Assessment Review Office).

(23) Environment North, Submission to the Environmental Assessment Review Panel, 29 October 1990.

(24) Nuclear Awareness Project, Submission to the Environmental Assessment Review Panel, 23 October 1990.

(25) Energy Probe, Submission to the Environmental Assessment Review Panel, 22 October 1990.

(26) See, for example, Nishnawbe-Aski Nation, Submission to the Environmental Assessment Review Panel, 22 November 1990.

transportation of nuclear waste through Northern Ontario might result in an accident that would contaminate the natural environment.

It remains to be seen how the groups appearing before the Environmental Assessment Review Panel will respond to the Environmental Impact Statement currently being prepared by AECL. Those who do not believe that the disposal facility should be constructed at all, or who dislike AECL's involvement in the process, will likely remain dissatisfied. AECL, however, has at least made an attempt to open up the environmental review process to many who want to be heard.

WORK IN OTHER COUNTRIES

Canada is not alone in facing the enormous problem of radioactive waste disposal. All countries with nuclear power reactors, nuclear weapons, or research programs will eventually have to decide what to do with their waste. Though other governments are also developing disposal programs, none yet has a facility in place and public opposition is common. The United States, for example, which has nuclear waste both from its civilian reactor program and its military program, is a long way from finding a suitable disposal method,(27) though it has conducted investigations into possible kinds of waste disposal for over 30 years. In 1982, the *Nuclear Waste Policy Act* was passed, which set general guidelines, policy and timetables for the disposal of spent fuel and high-level waste. Deadlines have proved difficult to meet, however, especially as there is growing controversy over the siting of the waste disposal facility. The proposed siting at the Yucca Mountains in Nevada has met with vigorous opposition and the scientific and technical difficulties of building the proposed facility are still under investigation.

France, second only to the United States in its production of electricity using nuclear power, is also struggling to a find a means of disposing of its waste. The type of repository to be built depends upon the site, which has yet to be chosen. An announcement in 1987 of four potential

(27) Acres International Limited, *A Review of Various Approaches Being Undertaken by Industrialized Nations for the Management and Disposal of High-level Nuclear Waste*, April 1989, section 8, p. 1-14; Nicholas Lenssen, *Nuclear Waste: The Problem That Won't Go Away*, December 1991, p. 34-37.

sites led to numerous protests. Since then the number of possible locations has been reduced to two, whose whereabouts remain unknown. A final decision has been delayed for 15 years.(28)

Other European countries are at various stages in the development of a nuclear fuel waste disposal concept but no program is yet operating. Here too, much of the controversy surrounds the location of the disposal vault. Canada has avoided this question for the moment, but it is only a matter of time before it must be confronted.

Although western nations are facing enormous scientific and political problems as they try to resolve this dilemma, their difficulties shrink when compared to those faced by countries of the former Soviet Union and Eastern Europe, where stories of poorly constructed reactors, inadequate safety provisions and widespread nuclear contamination over the past four decades are too numerous to cite. To help solve the problem of nuclear waste disposal in these countries, it is clear that the west will have to provide both financial and technical aid.

CONCLUSION

As we approach the next century, Canada, like other countries with nuclear programs, continues to search for answers to a problem that has been growing for nearly half a century. Although methods of disposal have been devised, scientists cannot be certain that these will continue to function for tens of thousands of years.

This lack of certainty about the long-term safety of nuclear waste disposal methods has led some critics to suggest that the high-level waste should remain in storage until scientists have developed better ways of dealing with it effectively. Nevertheless, most countries, Canada included, have decided to proceed with present plans for disposal systems. Canada's proposed method of deep geological burial is the result of many years of scientific and technological research, which is still ongoing. The final form of the disposal system, its site and its possible date for completion are yet to be decided.

In Canada, as in other countries, public consultation on the proposed disposal system has allowed various groups to voice their criticisms of the project. It is hoped that extensive consultation will make public acceptance of the system easier to achieve. So far, Canada has

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(28) Lenssen (1991), p. 37-38.

managed to avoid much of the adverse reaction experienced in other countries by not naming a specific disposal site. It is likely that when this is done there will be considerable discussion and dissension. Despite these future difficulties, the Canadian research program continues to work towards a safe and environmentally acceptable way to dispose of high-level nuclear fuel waste.