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ENERGY POLICY SECTOR

THE MANAGEMENT OF CANADA'S NUCLEAR WASTES

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Minister of Energy, Mines and Resources

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FOREWORD

This report was commissioned by the Department of Energy, Mines and Resources to provide the government and the public of Canada with the views of an independent expert group on the subject of nuclear waste disposal. The authors have produced a well-written and readable document on a very complex issue and have made a number of recommendations to the government. It is my hope that the report will prove useful in focussing comment and discussion on this subject so that we can move with dispatch towards the evolution of a sound plan for coping safely and sensibly with nuclear reactor wastes.

HONOURABLE ALASTAIR GILLESPIE

Minister of Energy, Mines and Resources

CONTENTS

4 months is not long enough to study this complicated Q, unless you separate the technical from moral, & deal w/ the former in a kind of shallow way.

INTRODUCTION

The urgency of the national energy question, the importance of nuclear-powered electricity generation as a contribution to Canada's future energy supply and the increasing public concern regarding the overall safety of nuclear power, have made it essential for the Government of Canada to formulate policies for the long-range management of the radioactive products of nuclear-powered generating stations.

As a contribution to the development of such policy, and in particular, as a means of ensuring the input of advice and opinion from the private sector and the general public, the Department of Energy, Mines and Resources established in April 1977, a study group whose terms of references were to:

- Carry out a study on the safe long-term storage of radioactive waste and to submit a report that would contain information of a quality and scope sufficient to serve as a general document for wide distribution, both within government and to the public, in order to facilitate a better understanding of the waste disposal problem. The report should contain sufficient information to form the basis of a subsequent Green Paper.

Storage or disposal?

The study was specifically limited to radioactive material emanating from nuclear power stations and did not cover other aspects of the nuclear fuel cycle (i.e. mining, milling and refining). The time available to us was less than four months. ✓

On the basis of these terms of reference and on discussions that we had with officials in the Department, we have undertaken:

- to assess the types and quantities of nuclear waste that will be generated by the operation of nuclear powered generating stations in the foreseeable future,
- to describe the alternative options open to Canada for disposal of these wastes,
- to examine the concerns of the public regarding management of these wastes, and
- to recommend the appropriate option or options to be pursued by Canada to ensure that nuclear energy can make its appropriate contribution to the supply mix required to meet future Canadian energy needs.

didn't study the alternative of no nuke energy as a method of dealing w/ nuke wastes

We have examined many reports, scientific papers and documents relating to the subject of nuclear waste management and have also reviewed the histories of recent incidents such as that at Port Hope, that have caused a marked increase in public awareness of nuclear matters and the special problems associated with radioactivity.

which ones?

Discussions have been held with citizen's groups, technical experts and the various Canadian public bodies having responsibilities or interests in the area of nuclear power, notably the Atomic Energy Control Board, Ontario Hydro, Atomic Energy of Canada Limited, the National Research Council, the

Science Council and the Canadian Environmental Advisory Council. We have also visited the Ontario Royal Commission on Electric Power Planning and had access to its files. Members of the group visited the nuclear waste managing and regulating authorities in the United Kingdom, Sweden, Germany, France and the United States and, in some cases, inspected field facilities. In every instance, we were given a helpful and cooperative reception. As a result, we feel that despite the very short time available to us—too short to permit detailed study of all technical aspects—we have, nevertheless, been able to put forward significant recommendations.

✓

not imp. if it's morality that you're dealing with (or social-political)

In preparing the report, we were faced with the fact that the technological language is often not understood by the uninitiated reader. We have not been able to avoid the use of technical terminology—particularly in the main body of the text—but we have tried, as far as possible, to frame, in non-technical language, those parts of the report (i.e. statement of the problem, discussion, conclusions and recommendations) that are likely to be of primary interest to the general reader. We have also included, at the end of the document, a glossary of technical terms, scientific units and acronyms.

We wish to acknowledge the comments of Dr. E. G. Letourneau of the Radiation Protection Branch, Department of National Health and Welfare. Many of his suggestions have been incorporated in the report.

Some Definitions

IMMOBILIZATION. The process whereby radioactive material is encased in a solid material such as glass, ceramic, bitumen or metal to provide protection against dissolution by water.

STORAGE. The emplacement of radioactive material in a safe location with the intention of retrieving it.

DISPOSAL. The planned permanent placement of radioactive material with no intention of recovery.

REPOSITORY. An engineered site designed for disposal of radioactive material.

Chapter 1. THE PROBLEM

In company with over 20 other countries, Canada has put into operation electrical power generating stations whose primary source of energy is the fission of uranium. The CANDU system, which Canada has pioneered, differs from the light water reactor systems (LWR's) employed in the United States and many other countries in that it uses uranium in its natural form, while LWR systems require that their uranium fuel be enriched to contain a higher proportion of its fissile component—the isotope uranium-235.

Present day nuclear generating stations, regardless of whether or not their fuel is enriched, produce—in addition to the heat output for which they are designed—waste products that are highly radioactive and hence potentially hazardous to human beings and to living things in general.

The term 'waste product' needs to be used here with some reservation because one of the products, plutonium, is fissile and, if separated out from the other waste products, can be re-used as fuel in the reactor. Canada is not at present reprocessing irradiated fuel to obtain plutonium, but in future years, when uranium supplies become seriously depleted, it may be appropriate to do so. This is an important factor that is discussed later in this text.

During the early years of nuclear power generation in Canada, techniques for handling and storing radioactive wastes at power station sites were developed sufficiently to assure that these wastes could be stored safely. They are stored on site in water-filled bays, concrete bunkers or, in the case of wastes having low radioactivity, in shallow concrete-lined trenches above the water table.

for 20-50 years

These storage methods are reliable and safe and have been approved by the Atomic Energy Control Board who are responsible for issuing licenses for their continued operation. For irradiated fuel and other wastes having high levels of radioactivity, however, such methods are only temporary (perhaps 20 to 50 years) and in view of the anticipated growth of nuclear powered electricity generation—possibly 75,000 megawatts of installed power by the turn of the century—the day is fast approaching when there will have to be arrangements made for ultimate disposal.

why

In contrast to the waste products stemming from coal-fired generating stations, the waste products of nuclear power are small in bulk. The problem is that they contain highly radioactive components, some of which remain radioactive for thousands of years.

These radioactive products are basically of two kinds; irradiated fuel (i.e. fuel bundles that have been used in the reactor and withdrawn from it) and reactor wastes, which are all other radioactive materials resulting from normal operation and maintenance of the nuclear generating station.

The irradiated fuel contains highly radioactive components including plutonium—to which we have previously referred—and contains over 99 per cent of the total radioactivity in the waste products of the complete system.

Should the predicted power level of 75,000 megawatts be achieved, the rate of production of such irradiated fuel will be about 10,000 tonnes per year.

The remaining radioactivity—less than 1 per cent—is contained in the reactor wastes which are accumulated in filters, special devices, mops, swabs and other maintenance equipment. Their radioactivity is lower than that of irradiated fuel, but they nevertheless constitute a potential hazard.

Our main task has been to review the quantity of radioactive material now in existence and likely to be produced in future years and to reach conclusions as to how its ultimate disposal can be safely managed. To do this we have studied the wastes themselves and made ourselves conversant with the properties of the various constituents. We have examined the storage methods now in use and taken note of the extent to which existing storage will need to be increased to handle future anticipated amounts of irradiated fuel and reactor wastes.

Many methods of ultimate disposal have been suggested by authorities in Canada and other countries. We have reviewed the literature on them and concluded that deep disposal in rock is the most appropriate for detailed investigation in Canada. We have consequently given particular emphasis in our study to the geological factors involved.

We have reviewed the hazards that radioactive materials present to human beings and to the natural environment and, because we view deep geological emplacement as the best disposal option, we have given special attention to the environmental factors associated with such a method.

The fact that we have been limited to discussion of the management of radioactive wastes produced by reactors means that we have dealt with only part of the problem. We are strongly of the opinion that the other parts of the cycle are just as significant from a waste management point of view and we recommend that they be studied also.

We have not had a medical expert on our team to contribute definitive views on the health hazards of radioactive materials. However Dr. E. G. Letourneau of the Radiation Protection Branch, Department of National Health and Welfare has read the report and has made valuable comments.

disclaimer

Finally, we note that our background is scientific and technical and we claim no special knowledge in the social and political aspects of our subject.

Chapter 2. CONCLUSIONS AND RECOMMENDATIONS

A national plan for nuclear waste management and disposal

Canada urgently needs a national plan for the management and disposal of nuclear wastes. Such a plan should cover not only the radioactive materials that are the subject of this report—irradiated fuel and reactor wastes—but all aspects of the nuclear fuel cycle, including mining, refining, fuel fabrication and the operation of nuclear powered generating stations. It should also cover the radioactive wastes from other industries, from hospitals and from universities.

The existing Canadian policies that govern the handling of irradiated fuel and reactor wastes from nuclear powered generating stations have been established largely through the cooperative action of AECL and Ontario Hydro, with the concurrence of the appropriate ministers. These policies, and the programs based on them, have come into being with little public visibility and in the absence of a number of pertinent governmental decisions that have yet to be taken.

The federal government should develop a draft plan that can be submitted for federal provincial discussions leading to its adoption as a national plan. In so doing it should seek advice from the industry, from the scientific and technical communities and from citizen's groups.

A much more open approach towards public discussion of nuclear energy policies is required. A national plan must be sanctioned by all governments concerned but it must not be simply a working agreement between officials. Mechanisms are needed for an effective interchange of information and ideas between the public, the industry and the department of government concerned.

The country needs a consolidated plan for the management of radioactive wastes now: a piecemeal, hesitant approach to this challenge will not be in the national interest. We list below a series of formal recommendations that offer the rudiments of such a plan. They are incomplete because our terms of reference limited us to only a part of the problem, but they will at least provide a framework on which a more complete plan could be constructed.

We have identified certain key target dates that we consider should be set as a guide for programs of research, development and construction. We are not the right group to determine a critical path chart, but we feel that these targets are important.

1978—Declaration of a National Plan to deal with nuclear wastes.

—Acceleration of the research and development programs.

1983—Choose at least two hard-rock sites in Ontario to be developed for geological disposal.

1985—Have shafts sunk and testing underway in the hard-rock sites.

1988—Start construction of irradiated fuel handling facilities at one site.

1990—Start test disposal of immobilized irradiated fuel and immobilized reactor wastes.

1995—2000—Have an operating repository capable of receiving the Canadian annual output of irradiated fuel.

It is essential that the licensing and regulatory processes remain well ahead of these dates.

Formal conclusions and recommendations

cf. recommendation #10

1. There are good prospects for the safe, permanent disposal of reactor wastes and irradiated fuel, and we see no reason why the disposal problem need delay the country's nuclear power program, provided that the government proceeds immediately to the program of research and development in the following recommendations.
2. The objective of the waste management program must be the protection of the health and safety of the Canadian public. Economic expediency must not stand in the way of this objective.
3. Radioactive wastes and irradiated fuel are now accumulating at generating stations. The mass and volume of these materials are not large and they present no immediate hazard. Their total radioactivity is, however, great and they cannot be allowed to accumulate indefinitely in interim storage.
4. Ways and means exist today for safe surface or shallow subsurface storage of irradiated fuel and reactor wastes. Engineering studies on such techniques are now in progress and are on the right lines.
5. Of the various options for disposal of reactor wastes and irradiated fuel, we consider underground disposal in geological formations to be the most promising within Canada. Igneous rocks are preferred and two sites within differing igneous rocks should be investigated.
6. The repository chosen—initially one will suffice—should be regarded as a central, national facility, and should be located in Ontario. It should be federally owned and operated and be available to all provincial utilities.
7. The cost of building and operating central storage and disposal facilities should be recovered through charges against the organizations producing and supplying the radioactive waste.
8. AECB is the appropriate body to establish the criteria for siting and operating all waste management facilities and should publish the criteria at an early date.
9. AECB is also the logical body to determine the long-term monitoring that will be required at the repositories.
10. Fuel processing is not necessary for safe disposal. Either irradiated fuel or immobilized wastes or both can be disposed of in the same repository. However, no commercial fuel processing plant should be approved in Canada until, inter alia, fully satisfactory methods for dealing with the associated radioactive wastes have been developed.

11. The Government of Canada should finance all the cost of developing the technology for safe storage and disposal of radioactive wastes.
12. The overall Canadian program of research and development is well conceived, but has received much too little financial support and priority. A large increase will be needed in the scale of geological, geophysical, geochemical and engineering research directed towards the investigation of disposal sites and the task of rendering them operational as repositories.
13. Critical aspects on which this research and development program must focus are the capability of the chosen repository or repositories as regards, (i) dispersion of heat, (ii) containment or control of water flow, and (iii) the rate of movement of the radionuclides in relation to the water flow.
14. More research and development is needed into immobilization technology, especially as regards the disposal of irradiated fuel.
15. We expect no environmental or health impacts once the wastes and irradiated fuel have been emplaced in the repository. The slight risks will be associated with the preparation, transportation and emplacement functions.
16. If unforeseen groundwater movement invades the repository, radionuclides may be carried outwards, but at rates very much slower than the groundwater movement itself, with the possible exception of iodine-129 and technetium-99. So ?
17. From a carefully selected repository, with suitable immobilization techniques, it will be at least many centuries before such released radionuclides would reach the surface, and then in great dilution.
18. If, nevertheless, radionuclides do reach the surface, they will be incorporated into soil, water, streams and lakes. They will run through the ecosystems like other soluble nutrients and may be locally reconcentrated by organisms. However, the dilution will be so great that they will not enter food chains in any appreciable quantities. But they will do so for thousands of years.
19. The theft of a significant quantity of irradiated fuel is extremely unlikely.

Chapter 3. THE NATURE OF THE WASTES

How reactors function

All matter is made up of atoms of elements. These atoms consist of a nucleus, containing virtually all the mass, surrounded by orbiting electrons. The nucleus is composed of one or more protons, each of unit mass and having a unit positive charge, together with one or more uncharged neutrons, also of unit mass. The particular element is determined by the number of protons or positive charges in the nucleus. The number of orbital negatively charged electrons is equal to the number of protons, and the total charge in the atom is hence neutral.

put this in Radiation chapter

The number of protons is called the atomic number. Each element can have different numbers of neutrons that give rise to isotopes of the same element with different total mass. All the isotopes of all the elements are called nuclides.

Many nuclides are unstable and change spontaneously into other nuclides by the emission of atomic particles and energy in the form of electromagnetic radiation (very energetic X-rays called gamma rays). The only naturally occurring radioactive elements are those that have decayed very slowly, i.e. those with a long half-life (the time it takes for one half of the nuclei to change spontaneously). Thus uranium and thorium, both of which are radioactive, have survived since the creation of the earth because their half lives are over a billion years.

yes ?

The heat in a nuclear-powered generating station is produced by the fission process that occurs when a neutron is absorbed by certain heavy elements, such as uranium-235 or plutonium-239. This heating occurs within the nuclear fuel bundle. Each bundle contains approximately 20 kg of natural uranium in the form of high density uranium dioxide ceramic pellets inside zirconium alloy tubes about 0.5 m long, arranged in a circular array 0.1 m in diameter. The heat is removed by liquid heavy water flowing over the fuel. This heavy water coolant passes through boilers, transferring the heat to ordinary water to produce steam. The cooled heavy water is then pumped through the reactor again in a closed loop. The steam from the boilers is used to drive a turbine-generator set in the same manner as in a coal or oil-fired generating station.

and the ordinary water gets pumped back into the lake, 10°C warmer.

During the fission process a heavy atom splits to form two lighter atoms, known as fission products, but not always in exactly the same manner. A spectrum of fission product nuclides are formed, many of which are unstable and decay radioactively. The fission process also releases about 2.3 neutrons per fission on the average. One of these neutrons is absorbed by a fissile atom to keep the nuclear process going. The others are absorbed by the materials in the fuel and the reactor core, the principal neutron absorption occurring in uranium-238. This forms uranium-239, which by radioactive decay, becomes plutonium-239. This plutonium-239 is fissile and so, on absorbing a neutron, it also gives off heat, fission products and more neutrons.

In the CANDU reactor, close to one-half the heat produced comes from the fission of the plutonium formed in situ. As the fission process proceeds in a reactor, the concentration of fission products builds up and other nuclides such as plutonium-239 reach an equilibrium where their rate of formation approaches their rate of destruction or decay. Ultimately the neutron absorption capacity of the fission products becomes so large that their presence in the reactor core begins to bring about a reduction in the nuclear reaction. At this stage the fuel is removed, not because all the fissile material is gone, but because the fission products are absorbing too many neutrons. The idea behind chemical processing of the irradiated fuel is to recover the unused fissile material which, in the case of CANDU fuel, is mainly plutonium.

add to ch. 2

There is also a build-up of isotopes of heavy elements. These are generally classified as the actinides, as they all are elements with atomic numbers higher than the element actinium. They are formed through a series of neutron absorption reactions and radioactive decays. A listing of these actinides as well as the longer-lived fission product nuclides is given in Table 3-1.

TABLE 3-1

Some Nuclides Important in Waste Management

Element	Nuclide	Radioactive half-life	Principal radiation
Hydrogen	H-3	12.5y	beta
Carbon	C-14	5x10^{3}y	beta
Argon	Ar-41	1.8h	beta and gamma
Krypton	Kr-85	10.8y	beta and gamma
Strontium	Sr-90	27.7y	beta
Zirconium	Zi-95	65.5d	beta and gamma
Miobium	Nb-95	35.0d	beta and gamma
Technetium	Te-99	2.1X10^{6}y	beta
Ruthenium	Ru-103	39.5d	beta and gamma
	Ru-106	368d	beta
Tellurium	Te-127m	109d	beta and gamma
Iodine	I-129	1.7x10^{7}y	beta and gamma
	I-131	8.1d	beta and gamma
Xenon	Xe-131m	12.0d	gamma
	Xe-133	5.3d	beta and gamma
Cesium	Cs-135	2x10^{6}y	beta
	Cs-137	30.0y	beta and gamma
Neptunium	Np-237	2.1x10^{6}y	alpha
Plutonium	Pu-238	86.4y	alpha
	Pu-239	2.4x10^{4}y	alpha
	Pu-240	6.6x10^{3}y	alpha
	Pu-241	13.2y	beta
	Pu-242	3.8x10^{5}y	alpha
Americium	Am-241	458y	alpha and gamma
	Am-243	8x10^{3}y	alpha
Curium	Cm-242	163d	alpha and neutron
	Cm-244	17.6y	alpha and neutron

Thus the fuel, on removal from the reactor, contains the unused uranium (about 1 per cent is destroyed by fission), the fission products and the actinides, of which plutonium is the most important. The half-lives of the fission products vary from fractions of a second to tens of years. All the actinides are radioactive, generally with long half-lives.

This irradiated fuel is highly radioactive, giving off both particle and penetrating radiations. These radiations are actually a form of energy and, on absorption, become heat. The radioactivity decreases rapidly at first, but the rate of decrease also changes with time. Figures 3-1 and 3-2 show the variation of dose rate and heat output with time. There is, of course, much more information available on the characteristics of this irradiated fuel, and excellent reports have been issued by AECL and Ontario Hydro. Suffice it here to note that virtually all the radioactive fission products decay in about 600 years, the principal exception being iodine-129 with a half-life of 17 million years. After 600 years it is the actinides that determine the radioactive properties.

Irradiated fuel is the principal waste from a nuclear power plant. Since it contains plutonium, a fissile material, it can be regarded not as a waste but as a source of future nuclear fuel. For this reason, many people believe that the irradiated fuel should be stored in a safe but readily retrievable manner for possible future use. In any case, it must be safely stored until either it is processed or the decision is made to dispose of it as a waste in geological repositories; but, as discussed later, such repositories will not be available for 15 to 25 years. In the meantime, the irradiated fuel will continue to accumulate.

Reactor wastes

As mentioned earlier, in addition to the absorption of the fission neutrons in the fuel to produce plutonium and other actinides, many of the neutrons are absorbed in the other materials in the reactor core. Even the heavy water, though it is used because it absorbs so few neutrons, does, in fact, absorb some, and small amounts of deuterium are changed to tritium.* This makes the heavy water radioactive, which adds to the importance of preventing leaks, an importance that is already high due to the high cost of heavy water.

The metal structure of the reactor also becomes radioactive through neutron absorption or activation reactions, though materials are selected to minimize this. From the radioactive waste production viewpoint, the important neutron activation occurs in the small amount of corrosion products carried through the reactor by the hot water coolant. This coolant is kept as pure as possible and the materials containing it are selected to be very corrosion-resistant. Some corrosion does occur, however, and these corrosion products are carried through the reactor, becoming radioactive. They are deposited throughout the piping system, in the boilers and pumps, thus causing radiation fields around this equipment. The principal radioactive nuclides formed in this way are cobalt-60, iron-59 and manganese-54. Of these, Co-60 has the longest half-life—5.26 years.

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* Hydrogen of mass two is called deuterium and is stable. Hydrogen of mass three, one proton and two neutrons, is called tritium and is radioactive with a half-life of 12.26 years.

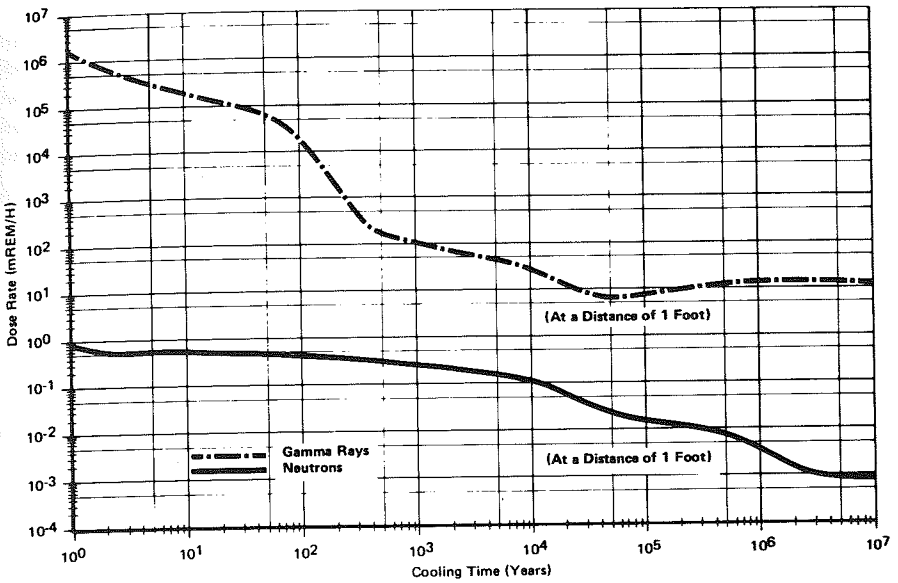

Figure 3-1. External radiation dose rate from Pickering reference irradiated fuel bundle (average exit burnup of 7,500 MWd/MgU).

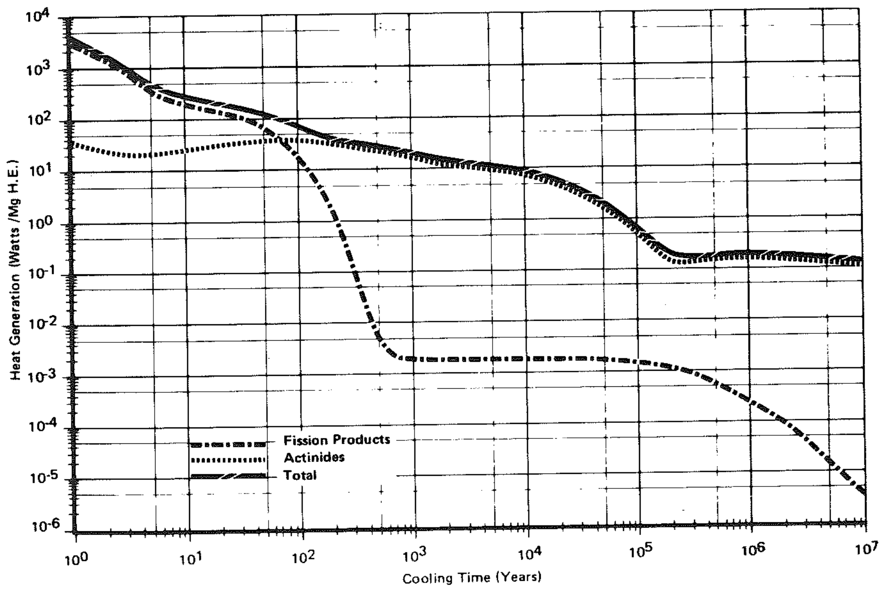

Figure 3-2. Decay heat generation—Pickering reference irradiated fuel (average exit burnup of 750 MWd/MgU)

In addition to the radioactivity due to these activated corrosion products, some fission products can, on rare occasions, be embodied into the coolant circuit through a small hole in the fuel cladding. Such cladding defects are rare and the fuel is removed from the reactor very soon after such defects are detected; but the fission product contamination of the coolant circuit remains.

During operation, the radiation fields around the piping and other equipment are not a problem, since they are located behind shielding. Like all such systems, however, occasional maintenance is required, and station personnel must enter these areas and work on items such as pumps and valves. During the maintenance procedures, gloves, clothes, rags, papers and other such items become contaminated radioactively. The clothes are generally laundered at the plant, giving rise to potentially radioactive solutions. The gloves, rags, paper, etc., are bagged and become solid radioactive waste. Any replaced equipment, such as valve packings and pump seals, are also bagged or wrapped in plastic for disposal.

To keep the radiation fields around equipment down to tolerable levels, the radioactive materials are continuously removed from the coolant circuit. This is done by passing a side stream through filters and ion exchange resins. These filters and resins eventually are replaced and the old ones, which by then are very radioactive, become another form of solid waste.

Some radioactive gases are also formed. Any heavy water that escapes from the process areas in the form of water vapor carries tritium with it. Also in some CANDU designs air is present in the reactor core and this gives rise to the production of carbon-14 and argon-41. Leaks from defective fuel could release krypton-85.

Thus an operating CANDU power station produces radioactive wastes completely apart from the irradiated fuel. These waste products have been variously called low or intermediate level waste. We prefer that all these wastes be called "reactor wastes".

Over the years, considerable effort has been invested in finding uses for radioactive wastes. Certainly radiation is useful for certain purposes: for example, the cobalt-60 produced in the control rods of the Pickering reactors is used by Commercial Products of AECL in their radiation therapy units, which are sold to hospitals around the world; it is also used in radiation sterilization units. Practically all the medical sutures used in North America are sterilized by radiation in units supplied by AECL. There have been no economic uses for a significant proportion of the fission products and there is not, as far as we have been able to determine, any requirement to keep these wastes, except perhaps for recovery of the plutonium.

Fuel cycles and the reprocessing of irradiated fuel

The CANDU reactor concept was originally conceived on the basis of using natural uranium, passing it through the reactor core just once, but getting the maximum amount of energy from the fuel by designing the core to absorb the fewest possible neutrons. This accounts for the use of heavy rather than ordinary water as moderator and coolant, since it absorbs many fewer neutrons. This fuel cycle was called "once-through" or "throw-away". There was no economic value assigned to the irradiated fuel, which was to be stored indefinitely but retrievably, in case it was decided to recover the plutonium in the future. All other nuclear power systems were designed on the assumption that the fuel would be processed to recover the plutonium and uranium.

The Magnox reactors, operating in Britain, use natural uranium, but the fuel is uranium metal, clad in a magnesium alloy, and since it is subject to corrosion in water, it cannot be stored for very long and must be processed within a few years of leaving the reactors. Other reactor systems use uranium enriched in the fissile isotope uranium-235. After discharge from the reactor, the irradiated fuel contains significant amounts of unused U-235, as well as considerable plutonium.

The fuel discharged from the light-water reactors (LWR's) which are used in USA, Europe, Japan and other countries, contains about twice as much plutonium as does CANDU fuel and the U-235 content is above that in natural uranium, whereas, in irradiated CANDU fuel, the remaining uranium is of little value as the U-235 content is very low. The incentive to recover fissile material from fuel used in CANDU reactor is therefore less than in the case of LWR's. In any case, recovery only makes sense when there is a market for plutonium, and that can only come from alternative fuel cycles that use plutonium.

The development and use of plutonium fuel cycles will increase the amount of energy that can be obtained from natural uranium. This is important, especially for those industrialized countries that have no uranium resources of their own. In today's nuclear power reactors, only a small fraction of the mined uranium is fissioned—in CANDU's about 0.8 per cent and in LWR's about 0.6 per cent. If the plutonium in the same reactor systems could be recovered and reused with the natural uranium, these percentages could be increased to about 1.8 and 1.1 respectively. In other words, plutonium recycle could cut the uranium demand by a factor of about two for the same electrical power output.

Other cycles are possible that offer considerably more efficient use of uranium. The Fast Breeder Reactor (FBR) could use most of the uranium by efficiently converting the U-238 to plutonium. This reactor concept is under development in many countries, particularly in Europe.

Another possible fuel cycle involves thorium. Large quantities of thorium are available in the world and the development of its use would extend the world's nuclear fuel resources. Thorium occurs in nature as the isotope Th-232, which is not fissile but which can be changed into a fissile material, U-233, through neutron absorption followed by radioactive decay. In the nuclear jargon it is called a fertile nuclide, like U-238, which is converted to fissile Pu-239 in a nuclear reactor. By mixing plutonium with thorium we can produce a fuel that can be used in a CANDU reactor in the same fashion as natural uranium fuel and in which U-233 is produced, rather than Pu-239. The special value of this fuel is that the fission of U-233 produces slightly more neutrons than that of U-235 or Pu-239 and these extra neutrons are used to produce more fissile materials, namely U-233, from the fertile nuclide Th-232. By the use of a Pu-Th cycle in the CANDU reactor, it is possible, at least theoretically, to produce almost as much fissile material as is used. This type of system is called a "near-breeder". It could extend our nuclear resources by at least a factor of ten, but would, of course, involve processing to recover the fissile material (U-233).

The economics and the need for these alternative fuel cycles depends on the price and availability of uranium. In Canada there are indications of uranium ore sufficient to last us at least 25 years—if we do not export at a rate higher than required in current export contracts.

This study did not concern itself with the problems of maintaining adequate nuclear fuel resources for Canadian needs, nor whether Canada will need to introduce plutonium recycle to meet future nuclear fuel requirements.

The need for processing should be easier to predict in 10 to 20 years when the balance—or lack of it—between growth of nuclear power (particularly in Canada) and discovery of new uranium deposits may be clearer than it is today. Canada, however, should take action to be in a position to introduce alternative fuel cycles in 20 years if they are required. For this reason we believe it makes sense to store the irradiated fuel in a safe retrievable manner until at least 1990 and probably longer.

Fuel processing is sometimes cited as desirable to ease the long-term waste management problem. As pointed out earlier, the principal hazard after about 600 years, comes from the actinide elements, mainly plutonium. If the plutonium were recovered and subsequently destroyed by use in power reactors, the remaining wastes would present a smaller long-term hazard. This is correct but, because it is very difficult to recover all the plutonium, and because other actinides such as americium and curium remain with the fission products, the long-term hazard is not eliminated. Fuel processing would therefore ease the problem of long-term storage but would not eliminate it. We do not believe the benefits to waste management justify, on their own, the recovery of plutonium.

Fuel processing would produce radioactive waste in a variety of forms and it is the conversion of these waste streams into concentrated solid forms that makes processing so expensive. The fission products, along with some actinides, come out of the process in acid solution and must be concentrated and incorporated into insoluble solids such as ceramics or glass. The zirconium fuel cladding is not dissolved but comes from the process as highly radioactive metal rings that could be compacted to a small volume, but must also be immobilized. There are many other sources of lower level waste in the processing and these must all be concentrated and immobilized.

It is not within the scope of this report to detail how this waste treatment should be done. We feel strongly, however, that no commercial fuel processing plant should be approved in Canada until, inter alia, fully satisfactory methods for dealing with the radioactive wastes have been developed.

Chapter 4. PRESENT METHODS OF WASTE MANAGEMENT

Management of irradiated fuel

The amount of irradiated fuel produced per unit of electricity is not great, about 130 tonnes per year per 1,000 megawatts of generated electric power. To date, over 1,500 tonnes have been produced in Canadian power reactors and this is stored in water-filled, double-walled concrete tanks at the various stations. The storage volume needed is about two cubic metres per tonne of fuel. The 2,000 megawatt Pickering GS-A generating station produces about 260 tonnes of irradiated fuel each year and all the irradiated fuel produced in its reactors by the year 2000 could be stored in a water-filled, concrete tank 160 metres long by 10 metres wide and 8 metres deep.

Recent EMR estimates of the growth of nuclear power in Canada indicate that there could be up to 75,000 MWe installed within the next 25 years. This would correspond to a production rate of 10,000 tonnes of irradiated fuel per year at that time. The accumulated amount at the end of the 25-year period would be close to 50,000 tonnes and, if stored under water in tanks 10 metres wide and 8 metres deep, would require a total length of about 1,250 metres with an extra length of 250 metres needed each year. This volume of tank storage is not available today and would have to be built, but the area required would obviously not be exceedingly large.

The storage of irradiated fuel in water-filled "bays" is the method used world-wide. There is thus considerable accumulated experience and the designs of the facilities are now such that little hazard is associated with this method (see Figure 4-1).

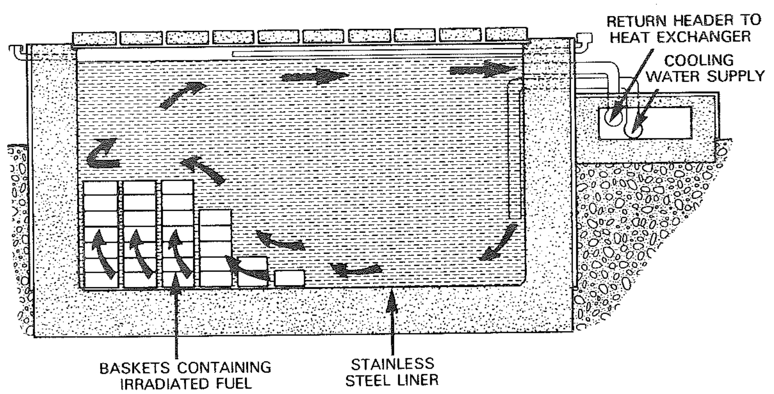

Figure 4-1. Water pool concept.

The storage capacity in the bays at Pickering GS-A is slightly greater than 80,000 bundles (about 1,600 tonnes U) and that at Bruce GS-A will hold about 30,000 bundles (600 tonnes). Auxiliary bays are under construction at both stations to provide additional storage capacity.

Beginning in about 1986 further additional storage will be needed for Pickering fuel, while the bays at Bruce will be full by 1989. The fuel storage bays at the 600 MWe CANDU plants under construction at Gentilly, Quebec and Point Lepreau, New Brunswick, will have storage capacity for 10 years production of irradiated fuel.

Since it is unlikely that Canada will be in a position to start commercial processing of fuel or to have a geological disposal site ready within the next 15 to 25 years, additional interim fuel storage capacity will clearly be needed, even if no new nuclear power plants are built.

In anticipation of this need, AECL set up a committee in 1972 to study the storage alternatives. This Committee for Assessing Fuel Storage (CAFS) included members from AECL, Ontario Hydro and Hydro-Québec. After examination of many possible systems, the committee concluded that water-filled pools were a safe and acceptable method of storing irradiated fuel for an interim period and that a concept based on concrete canisters was the best prospect as an alternative method. Unfortunately their report was not made public.

As a result of this study, AECL and Ontario Hydro agreed on a joint program involving further development of chosen concepts. AECL is developing and testing concrete canisters and Ontario Hydro is studying the engineering and economic aspects of the concepts. These and other decisions have led to the establishment of a task group to review and recommend research and development programs and to recommend action to establish a separate fuel storage site to be in operation by 1985.

The essential purposes of any irradiated fuel storage facility are to remove the heat generated in the fuel by its radioactivity, to provide sufficient shielding that the radiation levels outside the storage are acceptable, and to provide containment of any radioactive materials that might escape from fuel if, due to corrosion or other processes, the fuel cladding should fail.

An excellent detailed description of the storage concepts being considered is given by Ontario Hydro in their report "The Management of Irradiated Fuel in Ontario". The reader is referred to this report for details as only a brief description of the facilities is given here.

A layout of a pool storage facility is shown in Figures 4-1 and 4-2. The design is of a series of modular units consisting of eight concrete tanks in a row set partially above ground. Each tank or bay is an integral, reinforced concrete structure subdivided into six sections by cover support beams and is lined with stainless steel. When filled with fuel, it would be covered first with a metal cover and then with a concrete one. There is a loading cell that moves from bay

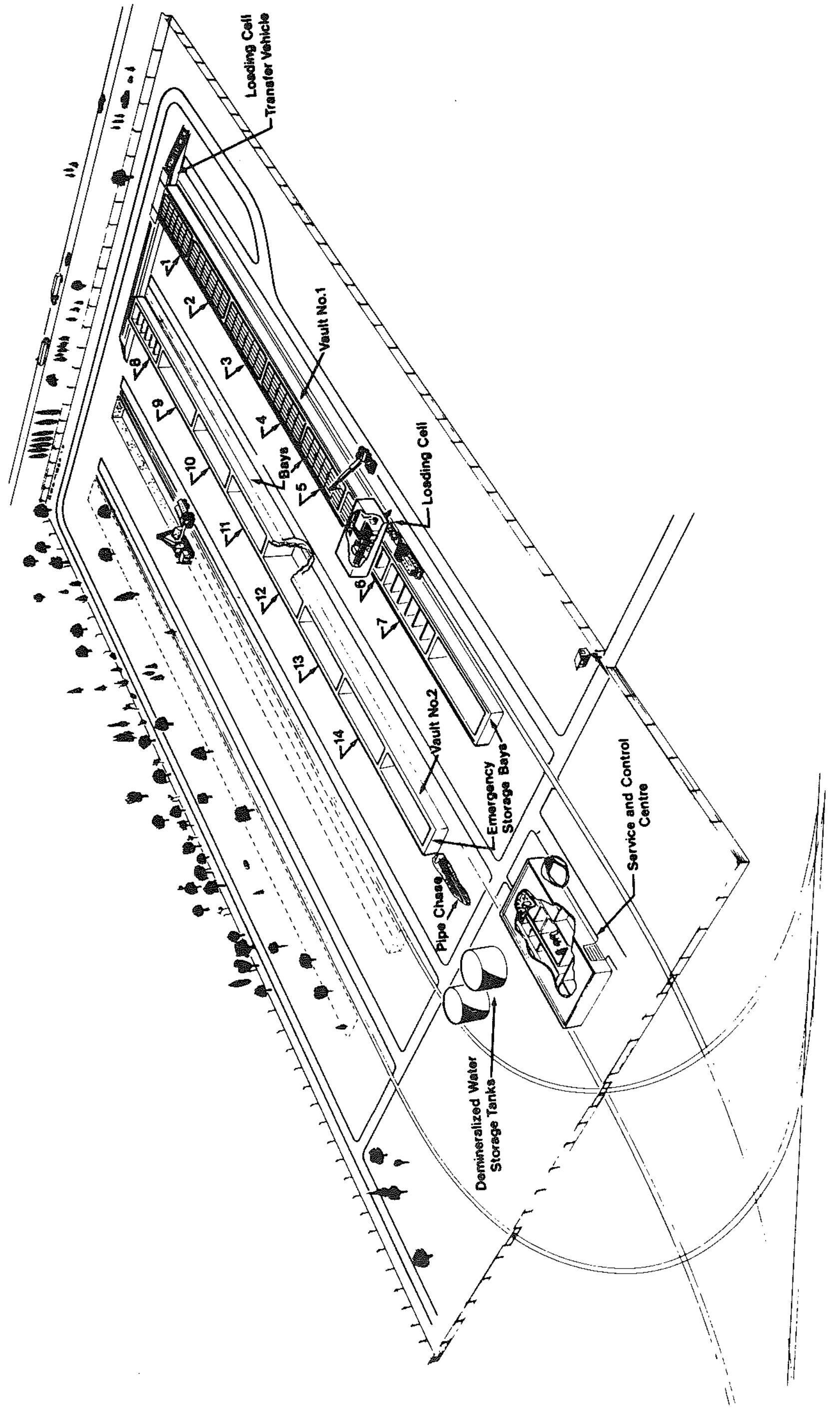

Figure 4-2. Spent fuel storage facility.

to bay and the operation is such that fuel is transferred from the shipping flask under water. At no time during or after filling would the inside of the bays be exposed to the weather. The water would be circulated through coolers to remove the heat and through ion exchange columns to remove any dissolved radioactivity that might have escaped from the fuel. As in storage bays at the power stations, enough water—about 4 metres—is left over the fuel to provide shielding from the radiation.

Another concept under development and being considered for commercial use is the concrete canister. It is shown schematically in Figure 4-3. This is a dry method of storage, consisting of three inner containment cans inside an outer containment can, all within the cylindrical concrete vessel. Lead shot is used to fill the cavities and to increase the radiation shielding provided by the concrete. The heat from the fuel is conducted through the walls of the inner and outer cans, through lead shot and through the concrete canister walls to the outside surface, where natural convection takes the heat away. Any leakage of radioactivity from the fuel would be contained within the double canning.

The canisters are about 2.5 metres in diameter and 5 metres high. When filled they would contain 4.4 tonnes of irradiated fuel and weigh a total of 50 tonnes. They would be stored outside. For most soil conditions, a gravel base would be adequate to carry the load. The present design is planned for fuel that has been stored and cooled for five years in the station storage bays. To store the estimated 50,000 tonnes accumulated over the next 25 years, about 12,000 canisters would be needed.

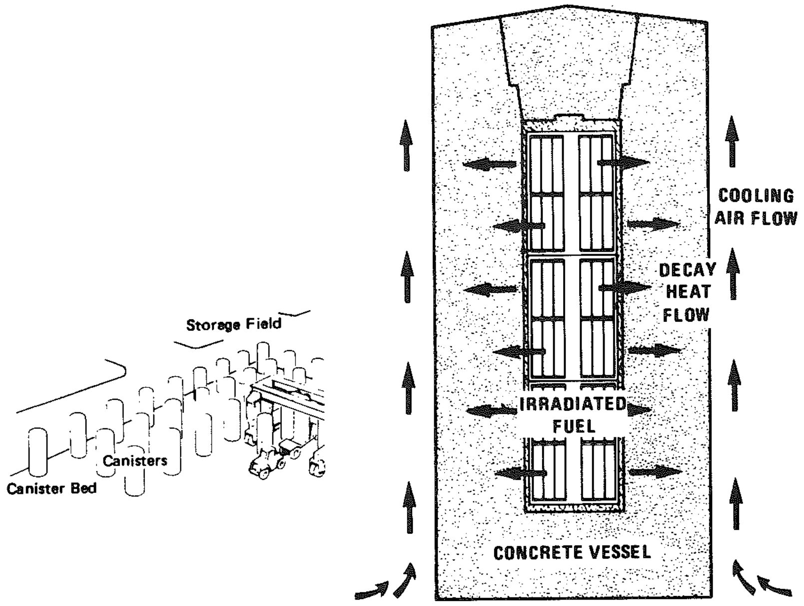

Figure 4-3. Concrete canister concept.

The use of these canisters is being demonstrated by AECL at their Whiteshell Laboratories. Concrete canisters have been built and tested using electric heaters to simulate the heat load and to do tests well above the expected operating levels. A canister has been loaded with irradiated fuel from the Douglas Point Generating Station and the monitoring of this test canister indicated no problems with the method.

Of other methods examined, only one has survived for further study—the convection vault facility. This is shown in Figure 4-4. Four cans, each containing 196 CANDU fuel bundles, are placed inside a long vertical tube about 15 metres high by about 0.6 metre in diameter. The tubes are arranged in a vertical grid inside a concrete vault. Cooling occurs by natural circulation of air through the vault. Containment would be assured by welding closed both the inner can and the vertical tubes. Little experimental work has been done to test this method, but it may require less space and be less costly than the others.

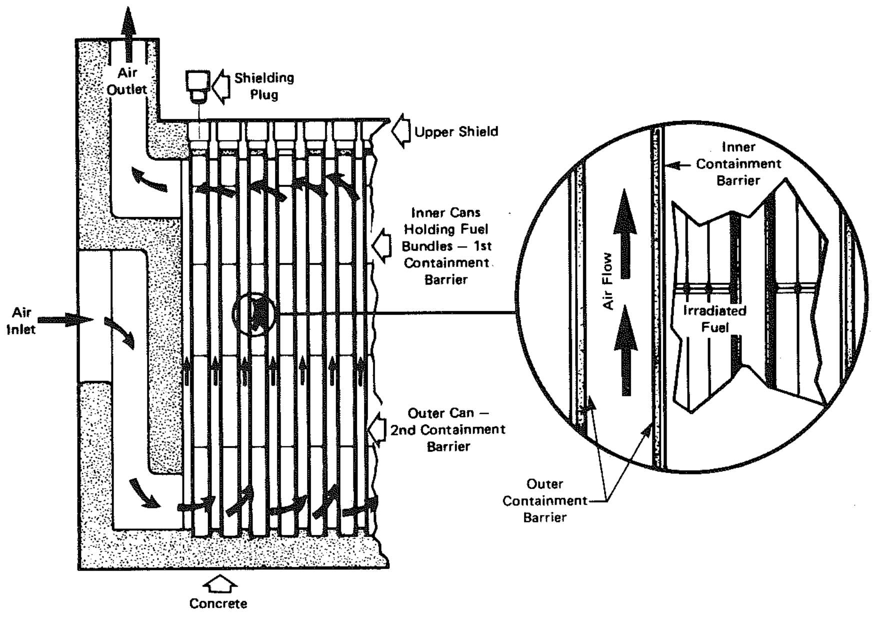

Figure 4-4. Convection vault concept.

Shipping of irradiated fuel

If a central storage site separate from the nuclear power generating stations is to be set up, or if the irradiated fuel is to be processed or disposed of in a geologically acceptable formation, shipment of the fuel will be required. About 500 such shipments have been made in Canada in the past, using very heavy shielded containers called shipping flasks, without any significant problems.

The shipping flasks, typically weighing about 50 tonnes, are 3 metres long by 2 metres in diameter and can hold 3 to 4 tonnes of fuel. They are designed to dissipate the heat produced in the fuel and to provide adequate shielding to reduce the radiation outside the flask to non-dangerous levels. They have been designed to withstand all conceivable accidents—such as train wrecks, truck accidents and fire—without loss of containment. Many thousands of shipments are made in the world each year and good experience has been obtained. The regulations for such shipments have been agreed internationally and are proving to be adequate.

In 25 years, again using the prediction of 75,000 MWe of installed nuclear power in Canada, about 2,500 shipments of irradiated fuel will be made each year or about eight per day. If rail shipments are used, this would not present a big load to the railways. The biggest hazard associated with road shipments would probably be traffic accidents caused by the presence of these very big trucks on the highways. The frequency of these accidents, however, would be too low to present a significant hazard to the public. The subject of the hazards due to transportation is discussed further in the chapter dealing with environmental and health hazards.

Security and safeguards

The term security is used in relation to the loss of any irradiated fuel by any means, including carelessness or theft. By safeguards is meant the procedure used by international agencies, usually the International Atomic Energy Agency of the UN, to ensure that irradiated fuel, or fissile material derived therefrom, is not diverted to military purposes. We are discussing these together as they are closely related and must be considered in any review of irradiated fuel management.

The possibility that irradiated fuel could be stolen and used by terrorists to threaten a population has been raised many times. The safe handling of irradiated fuel requires elaborate and heavy equipment. Even if a well-organized group seized control of a nuclear power station in order to obtain some irradiated fuel, they would need big shielded flasks to ship their loot and this could easily be detected. Similarly, hijacking of a shipment, although possible, would be detected, and elaborate unloading facilities would be needed at the delivery point. The problems involved in stealing a significant quantity of irradiated fuel and doing anything with it that would threaten a population are so great that we conclude that such an occurrence is extremely unlikely.

There is also the possibility that someone might blow up a storage bay with explosives in order to create havoc by spreading radioactivity. Again, such an occurrence, while causing real difficulties for the operating staff, would be very unlikely to result in a significant hazard to the population.

Security, as applied to separated plutonium, is another matter. Even if fuel processing is undertaken, a significant quantity of separated plutonium or other fissile material in pure form should not be allowed to exist in Canada.

Security measures are of course not discussed in public and we have made no attempt to study them. We do not believe, however, that irradiated fuel will present an attractive terrorist device since there are many others much more readily available and potentially as hazardous to public safety.

Safeguards are concerned with accounting for all irradiated fuel. This is an enormous task considering the thousands of fuel bundles that have been and will be irradiated. Techniques have been developed, however, in cooperation with IAEA. Any new storage facility will have to be such that full accountability of the fuel is possible. The storage systems now being considered are being designed with this requirement in mind.

Management of reactor wastes

It is convenient to consider these wastes under their particular state: gas, liquid or solid, since that state primarily determines the treatment method. These methods are either to dilute and disperse the radioactivity or to concentrate and store it. Both methods are used.

Release and dispersal of radioactive materials can only be done within very restricted limits. In a later section of this report we shall introduce the concept, internationally established and recognized by Canada, of control by setting local dose limits, both for individuals and the total population. Interpretation of these dose limits in terms of individual nuclides to be released from a particular site leads to the Derived Release Limit (DRL). These DRL's, which are approved by the AECB, tell each nuclear power plant operator how much of each nuclide it is allowed under law to release from his stations. It is also instructed to ensure that any radioactive releases are as low as practical. In line with this, the Canadian utilities have chosen, as their design and operating target, release rates that do not exceed 1 per cent of the DRL.

Gases

The CANDU reactors are equipped with charcoal beds designed to maintain the quantities of radioactive noble gases (argon, krypton and xenon) released to the atmosphere below 0.6 per cent DRL. The systems are also designed to recover heavy water and deuterium gas from the various streams and this automatically reduces the tritium release. The gaseous effluents from Pickering GS-A during 1974 are given in Table 4-1. The numbers for other years are about the same.

It is these gaseous releases that have been accused on occasion of causing increases in infant mortality near nuclear power plants, of causing cancers, or of shortening the life span of nearby residents. We find no evidence to support these claims. Furthermore, radiation biological research indicates that they

TABLE 4-1

Gaseous and Particulate Effluents from Pickering GS-A — 1974

Category	DRL	Release as average percentage of DRL
Tritium	2.2×10^5 Ci/wk	0.22
Noble gases	4.3×10^4 Ci-Mev/wk	0.20
Iodine	0.4 Ci/wk	0.02
Suspended particulates	1 Ci/wk	0.07

cannot be correct. It is interesting to note that there is often more airborne radioactivity put out by a coal-fired plant than from a nuclear one of equivalent electrical power output, because of the release of the naturally occurring radioactive materials from the coal.

Liquids

All liquids from potentially radioactive areas of the power station are collected in hold-up and dispersal tanks. These liquids come from such operations as decontamination facilities, laundries, reactor and service building floor drains, laboratory rinses and other systems.

When a tank is full it is sampled and analyzed for its radioactive level. A dilution factor is calculated so that the liquid waste can be metered into the turbine condenser cooling water at a rate which maintains effluent concentrations below the release limits.

Table 4-2 indicates the liquid effluent releases from Pickering GS-A in 1974.

Although the release of radioactivity in these liquids has been substantially below the target of 1 per cent of the DRL, studies are underway on processing systems that could remove much of the radioactivity and concentrate it in solid form.

TABLE 4-2

Liquid Effluents from Pickering GS-A in 1974

Category	DRL	Release as average percentage of DRL
Tritium	1.65×10^7 Ci/y	0.09
Other radio-activities	900 Ci/y	0.28

Solids

Because dispersion is not practical, the radioactive solid wastes need storage or disposal depending on their nature. They are categorized as to type based upon their treatment process. Table 4-3 gives the volumes of each type produced at Pickering GS-A and also gives the volumes per electrical megawatt year. Using these numbers, and the estimate of 75,000 MWe in 25 years, the annual volume of solid wastes from nuclear power plants will be about 40,000 cubic metres, a large but not tremendous volume.

TABLE 4-3

Volumes of Solid Radioactive Wastes Produced at Pickering GS-A 1974

Type of waste	Yearly volume produced (m^3)	Volume/unit energy m^3/MW — Y
Combustible	600	0.33
Processable	270	0.14
Non-processable	30	0.02
Ion exchange resins		
Columns	10	0.005
Bulk	36	0.02
Filters	4.5	0.002
Total	950.5	0.52

Combustible wastes are those that could be burned in a special design of incinerator to bring about a large volume reduction. Such an incinerator has been installed and is being tested at the Bruce waste storage site. If successful, it will reduce the volume of stored waste considerably.

Processable wastes are materials that are suitable for compaction, plus those that are nominally combustible, but unsuitable because of high activity content.

Non-processable wastes are miscellaneous pieces of equipment such as valves, piping, etc.

These solid wastes are stored in concrete boxes, trenches or pipes above and below ground. The designs vary depending on the wastes to be stored, but they all are governed by the guidelines established by AECB. All solid wastes from Ontario Hydro nuclear generating stations are shipped to the storage facilities at the Bruce Nuclear Development. The original storage trenches there are now full and a new waste storage area has been built.

All operators of radioactive waste storage facilities must obtain a licence for construction and operation of such facilities from the AECB and are required to submit quarterly and annual reports giving details on quantities and activities of wastes processed and stored, environmental monitoring results, abnormal events and any other information that might be pertinent. In this way the AECB keeps watch on the safety of the storage facilities.

We visited the storage site at Bruce and were satisfied that the wastes stored there did not constitute a hazard to the public. We were concerned, however, regarding the length of time that such wastes should be stored in this manner and, whether some, depending on the time required for complete decay, should not be immobilized and transferred to a geological disposal facility.

Some consideration is being given to this. AECL have a development program aimed at concentrating both solid and liquid wastes and incorporating those that contain nuclides of long half-life into a water insoluble material such as bitumen, which has been successfully used in Europe. The bitumen containing the radioactivity would be disposed of in a geological disposal site.

The concrete surface storage facilities should have a life of 100 years. Thus it could be argued that radioactive wastes that will be completely decayed by that time could be left in such storage.

The problem is to determine which of the wastes contain long-lived nuclides, such as Cs-137, that will still require isolation beyond 100 years. To be safe, then, we believe that any wastes containing radioactivity above dangerous levels should be processed to reduce the volume, immobilized and subsequently put into geological disposal.

Chapter 5. ENVIRONMENTAL AND HEALTH IMPACTS

Types of radioactive emission

The radiation emitted by radioactive materials comprises either alpha particles (fast-moving helium nuclei consisting of two protons and two neutrons) or beta particles (fast-moving electrons or gamma rays). This radiation can cause electrical effects in the materials they pass through, frequently resulting in chemical change. In living tissue, this may affect the behaviour of the constituent cells with resultant possible damage to the organism. When these radiations reach the body surface, the alpha particles are absorbed in the outer layer of skin and have no significant effect; the beta particles, depending on their energy, are capable of penetrating to the more sensitive layers where they are potentially damaging; and the gamma rays can penetrate to irradiate the whole body. When the radioactive nuclides are taken into the body, all types of radiation have access to sensitive tissue.

Impact of radiation on humans

The health hazards arising from exposure to ionizing radiation are well-known. Exposure to intense radiation can kill a person within hours or days and many aspects of bodily failure are involved in such acute cases. Lower levels of radiation may induce cancers and/or genetic damage in a small number of those exposed. These effects have been widely investigated and as the result of these investigations, most countries have adopted internationally-defined standards regulating exposure to ionizing radiation.

The International Commission on Radiological Protection (ICRP) recommends maximum permissible radiation doses and Canadian regulations, set by the Atomic Energy Control Board, generally follow these recommendations. The doses are expressed in "rem", which is a unit of effective energy absorbed from a particular radiation in a biological tissue. The average whole-body dose from natural sources of radiation for the Canadian population is about 0.100 rem per year, or 100 millirem per year. Man-made radiation exposures add an average of 40 millirem per year, 35 of which come from medical diagnostic procedures.

Canadian regulations limit the man-made dose to individual Canadians to 500 millirem per year. The nuclear industry has been operating in such a manner as to contribute no more than 1 per cent of this. To be sure not to exceed this number, the release of radioactive materials must be closely controlled and limited. This leads then to "derived release limits" (DRL's) for each radionuclide and these limits are given in regulations for both atmospheric release and as dissolved in water. Thus some release of certain radioactive materials is allowed, but it is such that no individual will receive a damaging amount of radiation.

The health hazards pertaining to radioactive wastes or irradiated fuel stem from radiation; hence it follows that we must take account of the health effects of not disposing of these materials, as well as their safety once in the repository. There may well be a health risk involved in preparing the materials for disposal, and in transporting them to the repository. But these must be accepted if the much greater risk of leaving radioactive materials in surface storage indefinitely is to be avoided.

Comprehensive studies of the fields of radiological medicine and health physics have been prepared very recently by leading Canadian authorities. These include reviews by H.B. Newcombe and R.E. Jervis, prepared for the Science Council of Canada, together with the Council's overview of the hazards due to ionizing radiation, written by J. Basuk and A. Nichols. Newcombe has also given a shorter but invaluable review in AECL's submission to the Porter Commission. External summaries of great value are those by Sir Edward Pochin for the Nuclear Energy Agency of OECD, and the 1977 report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), especially Annex D on nuclear power production. Finally, Report 6 of the UK Royal Commission on Environmental Pollution (the Flowers Report), Nuclear Power and the Environment, gives an excellent plain-language account of radiobiology and health physics. Accordingly we see no need to include in the present report any detailed restatement of the background information.

One thing all these reports have in common is a downplaying of the health implications of waste or fuel storage. It seems to have been generally assumed that the storage and disposal functions of power station operation pose no health problem. The UNSCEAR document, for example, confines itself to the remarks,

> "... Because the method of treatment of solid wastes is to isolate them as far as possible from man's environment, doses to the public will be very low ... Surface and deep burial of solid wastes carried out under control at suitable sites is expected to give rise to no public exposure."
>
> (UNSCEAR 1977, para. 205)

Pochin's report, based on NEA statistics, and widely held to be an authoritative international analysis, also assigns little importance to the health hazard of the waste storage and disposal functions, though it does attempt a quantification of the overall transportation hazard. He employs as unit the man-rem per megawatt (electric) year. He finds the following figures:

Nuclear function	*Whole body exposure rate (man-rem/MW(e) y)*
Transportation	.03 (occupational); .005 (population)
Waste disposal from reactors (too low for measurement: hence pathway model calculations),	
(a) liquid wastes	.002
(b) gaseous wastes	.1
Waste disposal from reprocessing plants	
(a) liquid wastes	.1
(b) gaseous wastes	.25
Accident (undifferentiated)	.05

He also finds for fatal occupational accidents and diseases, death rates of .02 per 1000 MW(e)y from reactor operation, a similar number for processing operations, and .003 per 1000 MW(e)y from transport.

Figure 5.1 shows Pochin's diagram comparing the average genetically significant dose* rate average over the whole population. It emphasizes that the overall population exposure to radiation from the nuclear industry is small by comparison with that received from natural sources—about 6 per cent of the latter—if power consumption is of the order of 1 kilowatt of nuclear-generated electricity per person (as it may well be in Canada in the 1990's). It is also small by comparison with that received from the use of X-rays and radiological therapy in medicine. He concludes, as regards waste disposal:

> "Most types of waste disposal, including an estimated annual discharge corresponding to possible accidental releases averaged over a period of time, amount to only 0.5 man rem/MW(e)y, but an additional figure of 1.0 man rem/MW(e)y is included in respect of the slow discharge of low activities of radioactive carbon—C-14—which, because of its long persistence in the environment, is likely to cause exposure at very low rates over a very long period."

These results are based on a detailed study of all types of reactor in the member countries of the Nuclear Energy Agency, of which Canada is a member.

Newcombe has tried to estimate the potential consequences of the planned expansion of Canada's nuclear capacity, unfortunately without separate identification of the hazards due to the waste storage and disposal functions. We reproduce here his Table in consolidated form (Table 5.1).

Newcombe applies these estimates to the Canadian population, at a time when their consumption of nuclear electric power will have risen to the 1 kilowatt per person level. He finds that the natural sources of ionizing radiation—cosmic rays, natural radionuclides like potassium-40, radium and others—may seriously affect or kill about 1,600 persons per million. Nuclear power would add perhaps two cases of fatal cancer or hereditary disease and accidents a further one. In short, he concluded, as most other authorities have concluded, that the nuclear power industry poses no large threat to human health. Although he does not say so, it follows that storage and disposal pose an even smaller threat.

In a different sort of analysis Cohen treated solid waste already interred in a deep repository chosen at random; i.e. in the average rock of a continent, as being comparable with the risk posed by the natural distribution of uranium in that rock. He derived an upper limit of 0.01 death per reactor-year. In other words, even if one simply dug a deep hole at random, the wastes from 100 reactors operating continuously would be likely to produce at most one death per annum.

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* i.e., weighted according to the age structure of the population; doses received after parenthood years are genetically insignificant.

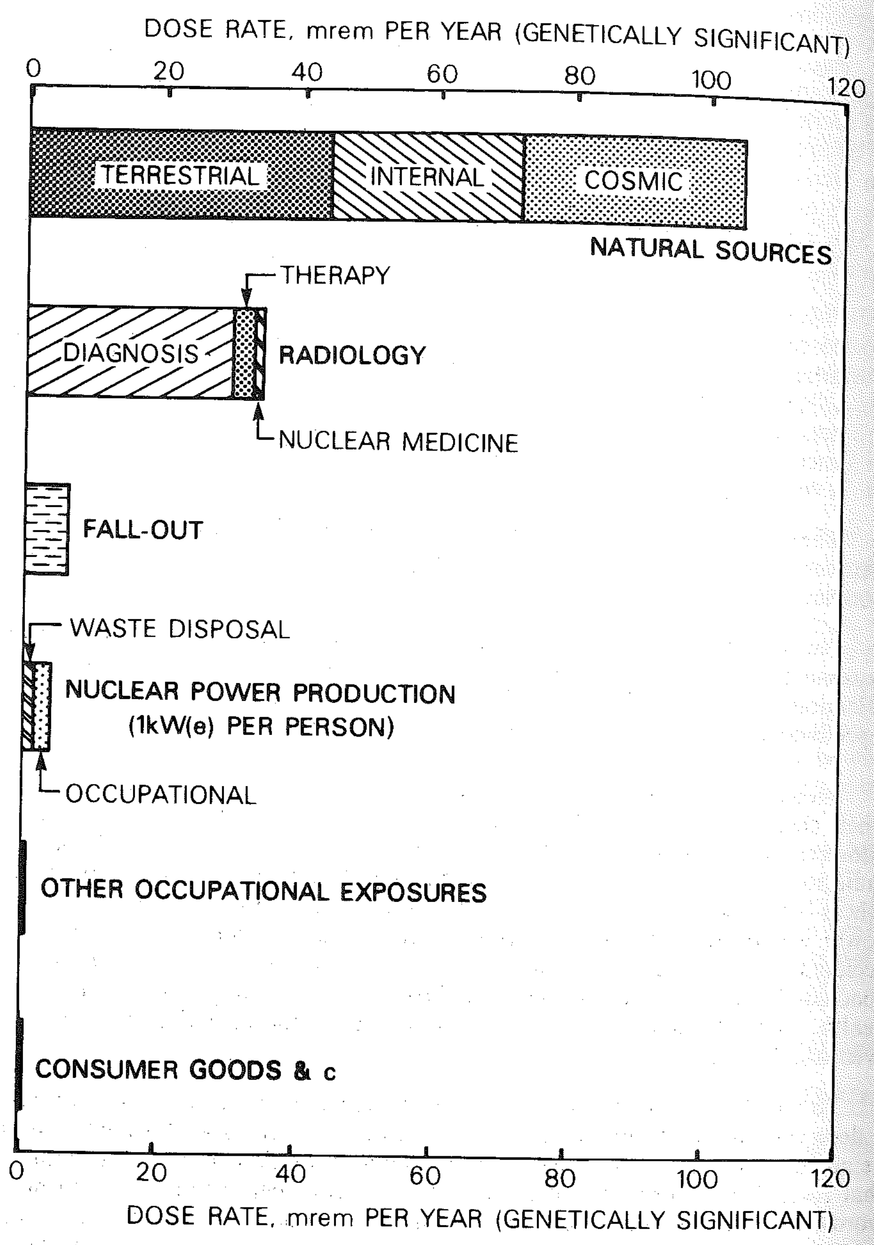

Figure 5-1. Annual genetically significant dose rate, as averaged through whole population.

TABLE 5-1

Estimates of Cancers and Hereditary Diseases from Ionizing Radiation in Canada (Assuming 1 kW nuclear electrical production per person)

(A) NON-NUCLEAR ENERGY SOURCES

Nature of exposure	Relevant dose (mrem per annum)	Cases per million lifetimes Fatal cancers	Hereditary disease
Natural radiation (e.g. cosmic rays, natural radioactive substances)	100	750	900
Medical exposures (e.g. X-rays; radiotherapy)	35	260	300
Fall-out	6	45	50
Occupational	0.3	2	3
Miscellaneous	0.3	2	3
TOTAL		∿ 1,000	∿ 1,200

(B) NUCLEAR ENERGY SOURCES

	Relevant averaged population dose (mrem per annum)	Cases per million lifetimes
FATAL CANCERS		
Population—		
Whole body exposure	1.5	0.2
Krypton-85 β-radiation to skin	5.0	0.05
Iodine-129 to thyroid	0.5	—
Occupational—		
Whole body exposure	4.2	0.6
Radon to lungs	—	0.05
Partial body, reactor and reprocessing	—	0.1
HEREDITARY DISEASES		
Population—		
Whole body exposure	1.5	0.5
Occupational—		
Whole body exposure	2.7	0.8
TOTAL		
Fatal Cancers		1
Hereditary Diseases		1.3

[Source: Newcombe, 1977]

The US Atomic Energy Commission estimated the risks associated with the transportation of irradiated fuel and wastes. They found, that non-radiological deaths from such movement might be 0.01 per reactor-year. Radiological causes might account for 0.0000001 death per reactor-year. They found, in other words, that accidents having nothing to do with radioactivity would be likely to cause 100,000 times as many fatalities as would the radioactivity.

We have listened to the representations of concerned citizen's groups, and read numerous critiques of the calculations on which the arguments are based. We conclude as follows:

(1) The health hazard posed by disposed-of irradiated fuel or reactor wastes will be virtually nil.

(2) The safe disposal of such fuel and wastes is essential for public health. Any risk incurred in preparing, transporting and interring these materials is a necessary price to pay for the safety of our own and future generations.

Transmission of radioactivity into and through the natural environment

The objective of disposal is to isolate unwanted and dangerous radioactive materials from the natural environment and hence from man himself. A successful disposal system will have little or no environmental impact.

Environmental considerations in nuclear matters have usually been concerned with human exposure to ionizing radiation, and the work of the international agencies that establish norms for such exposure is mainly concerned with the protection of human beings, with little attention being given to other organisms, or to the functioning of ecosystems.

Given the nature of the hazards involved, such a concentration on human welfare is understandable, but consideration should be given to the impact of ionizing radiation on Canada's fauna and flora. In any considerations bearing on the location of a waste storage or disposal site, the radiological impacts on natural ecosystems must be considered in addition to the impacts on human health and safety.

There are four distinct periods during which an individual radionuclide might escape from containment and enter the natural environment:

- during preparation for storage or disposal,
- during transportation,
- during emplacement in a disposal site,
- subsequent to final emplacement.

We shall examine each of these situations.

During preparation for storage or disposal

The immobilization of wastes or irradiated fuel, whether at the reactor or at the disposal sites, will involve the handling of radioactive materials. There will hence be some occupational exposure to ionizing radiation, on a scale resembling those experienced now in other aspects of reactor operation. Some controlled escape to the environment, in liquid or gaseous form, is also possible.

We have not seen estimates of either health or environmental impacts likely to be associated with immobilization technology, but believe these to be small.

During transportation

Transportation of irradiated fuel or wastes from power stations to disposal sites provides opportunity for escape of radioactive materials into the environment. However, as we have already observed in an earlier section, Canada already has considerable experience in the transport of irradiated fuel, and the methods and equipment that have been developed provide such a high degree of protection and safety that, in our opinion, there is negligible probability of any public harm from such activity.

During emplacement in a disposal site

At the disposal sites themselves the environmental impacts will include those associated with extensive industrial operations, such as are commonplace in Canada. For reasons of security, monitoring and possible future expansion, it will be necessary to locate the disposal facilities in a reserve having an area much greater than that actually occupied by the facilities themselves.

We expect that management of these sites will require the same care in isolating radioactive materials as is now mandatory at all reactor sites. In its licencing, the AECB will presumably impose such requirements. It should be possible to maintain radiation levels at close to background levels over most of the reserve area, and certainly along the entire perimeter (including stream and groundwater discharge from the site).

In sum, after examination of the techniques involved, we believe that the routine operations needed to prepare, transport and emplace the wastes, or irradiated fuel, in disposal sites should create no significant environmental hazard.

Subsequent to final emplacement

The main question then arising is clearly this: can one dispose safely of high-level, long-lived wastes or irradiated fuel so as to isolate them from the environment for very long periods? How secure, in other words, will be the radioactive materials committed to the disposal sites?

As we have seen, these materials will contain a wide variety of radionuclides. Though they will have lost their most intense radioactivity while in storage at the power stations, they will still be "hot" in both senses: (1) they will still emit ionizing radiation which, (2) on absorption, will heat the surrounding media. The fission products will have lost most of their activity after about 600 years, but the plutonium and other actinides will continue to emit chiefly alpha particles for a much longer period. After many millennia activity will have subsided to that characteristic of natural uranium ores. The wastes and irradiated fuels thus pose a threat for a period greater than the time that has elapsed since man's first steps towards civilization.

We shall, in the next chapter, discuss the emplacement of the wastes in largely impermeable rock at a depth of about 1,000 metres, with ultimate backfilling so that they become incorporated in the upper crust of the earth. Such sites can be found where the risk of physical disruption by earthquakes, glacial downwarping or catastrophic faulting is vanishingly small. From such stable sites, the only obvious pathway whereby radionuclides might find their way back to the biosphere would be via solution or suspension in circulating groundwater. The problem, therefore, becomes one of estimating the probable consequences of such groundwater movement, and whether the radionuclides move with it.

A study has recently been made by ERDA (through the Battelle Pacific Northwest Laboratories) to predict how radionuclides might migrate under such groundwater circulation. The rate at which such nuclides might escape to surface water-bodies of soils will depend on the following controls:

(a) The rate at which the immobilized wastes dissolve in the circulating waters. This rate will itself be very low provided the temperature of the wastes is not allowed to rise above about 150°C.

Measurements of solution of vitrified waste at Chalk River over an 18-year period confirm what the chemistry of glasses suggests: that vitrified wastes will dissolve extremely slowly provided the temperature is kept low. In the case of irradiated fuels, immobilization will be required to ensure that dissolution is slow.

(b) The rate of circulation of the groundwater itself, which is unlikely to exceed 1 metre per day even in highly permeable aquifers, will be much less than this in the low-permeability rocks preferred here.

(c) The "sorption" capacity of the rock, which means its capacity to remove from the groundwater the dissolved or entrained nuclides. The term sorption covers a variety of physical processes, such as ion exchange, colloid filtration, mineralization and adsorption. It is desirable to select rocks with very high sorption capacity since the effect of this will generally be to make the nuclides move much more slowly than the groundwater—perhaps as little as one ten-thousandth or hundred-thousandth as fast. Different nuclides are likely to have different sorption characteristics, as are different rocks. A few of the fission products, notably technetium and iodine, are poorly sorbed, and will hence move closer to the rate of the water itself.

These processes have been incorporated by ERDA into a complex computer model that predicts the rate at which the various nuclides may reach the biosphere. The model depends, however, on laboratory determination of sorption characteristics of the various rock-types. These data are incomplete (and may conceivably be inapplicable to the very dilute solutions likely to occur in any real case). They can be tested in situ, though at considerable cost.

Thus far we have considered the probable path of radionuclides that may escape from confinement in the repository, to be incorporated into migrating groundwater. To make good this escape they will have had to be dissolved out of the immobilized waste form; to have passed through the retentive barriers, if any, with which they were clad before disposal; and then to have passed through the rock surrounding the repository, either via the pore spaces, or through fractures and fissures in the rock's structure. Each barrier is formidable, so that the rate at which the radionuclides ultimately escape to the earth's surface is likely to be exceedingly small.

Obviously the key question is "how small?" A quantitative answer is hard to arrive at, because it is difficult to imagine the pathway to be followed by the migrating waters. Will they rise vertically? Or will they flow quasi-horizontally, parallel to the water table, as they do in aquifers?

A recent rough calculation by Cohen, for example, assumes that the actual pathway is gently sloping and that 100 km separates the repository from the point of escape into surface waters or soil. If the rate of flow were 0.3 m per day, such a journey would take 1,000 years. Even for un-sorbed fission products, much of the radioactivity would hence have disappeared en route. Strontium-90, which is poorly sorbed, and which moves at about 1 per cent of the groundwater rate, would take 100,000 years to reach the surface, by which time it will have decayed to a non-radioactive nuclide. Strongly sorbed materials, like plutonium and most of the actinides, would take much longer. Such results are reassuring, but they will be misleading if the groundwater moves directly upwards, as it is believed to do in poorly permeable but fractured rocks.

A group of French scientists modelled the case of vertical movement mathematically, providing more data than did Cohen. Their prime concern was with the very long-lived radionuclides that occur in high-level liquid wastes, i.e. neptunium-237 (half-life 2.13 million years) and plutonium (24,400 years), plus iodine-129 (17 million years). They also allowed for the eventual breakdown of the glass in which the wastes were embedded. The considered five hypothetical rocks, ranging from poorly confining to highly confining characteristics.

Their major conclusion was that the key property in slowing the escape of the radionuclides to the surface was the sorption capacity of the rock. "Neither the thickness of the geologic formation", they wrote, "nor its low permeability (very rarely null in nature) are major factors in the confining of radionuclides with very long half-lives." Even a highly impermeable rock will allow the escape of such nuclides as iodine-129 and plutonium-239 if there is no sorption—with contamination of surface wastes beginning with a few thousand years. With good sorption capacity, even a poor rock formation provides "enough confinement to retain plutonium so that no significant amount is released to the environment: the duration of transfer is so long that the radioactive decay of plutonium eliminates the waste naturally."

There is scattered evidence that natural containment of radionuclides can be indeed excellent. At Oklo, in Gabon, a rich uranium orebody being worked by a French mining company was found to contain the daughter nuclides of fission products. The uranium-235 in the ores was less than its normal value of 0.72 per cent of the total uranium. It soon became apparent that a natural reactor had existed within the rock body (largely sandstones and clays) that simulated the processes we now create in modern reactors. The natural reactor worked for about 100,000 years, about 1.7 billion years ago. It created fission products and radioactive actinides, including plutonium-239, as do modern reactors. Its operation presupposes the presence of water (as a moderator), so that this was not a dry site.

The fission products have, of course, decayed to stable isotopes. But, at least half of these are still present in the surrounding rock. Only the very soluble or poorly sorbed elements have escaped. Most interesting is the fact that the daughter products of plutonium-239 are still present. Apparently the original plutonium did not move at all: it was fully sorbed by the local rock. Hence the evidence is that the permeable, water-impregnated rocks acted as efficient containers of most of the products of the reaction, especially plutonium.

It is vitally necessary to test the sorption characteristics of the rock for all the radionuclides that will be confined in a specific repository. This is one reason why test boring of the sites is necessary—to establish the geochemical characteristics of the confining rock. The answer to the question posed above—how small will be the rate at which the radionuclides ultimately escape to the earth's surface? —depends above all on this capacity of the rock to act as a chemical filter, and this requires field testing. But the rate will be small. Even if the sorptive capacity is low, it can be considerably enhanced by artificial means.

Existing knowledge of Canadian igneous rocks suggests that many of them will act as excellent filters for a wide range of radionuclides, in the absence of open fractures—which we do not expect at these depths, and in any case should be avoided in site selection. Even if groundwater moves vertically through them to the surface, the radionuclides will be largely or entirely filtered out. Those that are poorly sorbed, like iodine and technetium, will move most rapidly—at rates close to those of the groundwater itself. For these elements it is clear that a high level of immobilization in the wastes is the best protection.

Nevertheless, even if it is a very unlikely occurrence, we should examine the consequences of some radionuclides reaching the surface, and entering soils, streams, lakes and the foodchains. Here there is far more experience on which to base a judgment.

There has been extensive observation, experiment and modelling directed at the travel of radionuclides in sub-soils, soils, waterbodies and organisms. This work has been undertaken in connection with fallout from airborne nuclear testing; with airborne or liquid leaks from power stations or research reactors; and with the performance of shallow sub-surface storage sites. In Canada there have been nearly three decades of such study at CRNL, with a shorter program at WNRE. Surface storage sites at Suffield (DRB), Gentilly (Hydro-Québec) and Bruce (Ontario Hydro) have been monitored for some years. There are substantial programs of environmental research at AECL, at Ontario Hydro and in certain universities, especially in the University of Waterloo. Canada is able to draw on extensive international experience in this question.

At these shallow sites, experiments and observations have confirmed that some of the radionuclides are much more mobile than others. Strontium-90 and Cesium-137, both long-lived fission products, are present in many of these wastes. Experiments at CRNL, whereby substantial quantities of these two nuclides were added deliberately to a sandy, unconfined aquifer, showed that strontium-90 moved at less than 3 per cent of the rate of water movement, and cesium-137 much more slowly. In fine-grained material such as silts or clays, the movements of each would be much slower. The rates of movement of other fission products or actinides should be far slower.

The evidence that the actinides move very slowly is not, however, all favorable. It has been reported from Maxey Flats, Kentucky, that plutonium from a shallow low-level waste burial site in fractured sedimentary rock has moved tens or hundreds of metres in less than a decade. Possibly this was because the circulating waters are acid and the plutonium was complexed. Moreover, the rock is fractured, and groundwater moves very rapidly at the site. We are informed that deep groundwater at Canadian sites is characteristically neutral or alkaline, not acid.

Once, if at all, the radionuclides have entered surface waters they are subject to rapid transport, and also to ingestion by living organisms, some of which have the ability to reconcentrate certain nuclides. A much-studied instance arose from the discharge of low-level liquid wastes from the Windscale reprocessing works of British Nuclear Fuels, Ltd., into the Irish sea. Fish caught in that sea are sources of radiation exposure to a small population, though the dilution of the wastes is great enough to make swimming in the waters perfectly acceptable. However, a seaweed used in South Wales in the manufacture of a local delicacy called laverbread was found to reconcentrate the fission product ruthenium-106. This case illustrated three fundamental factors that underlie the environmental impacts of radionuclides: (i) that there are certain critical pathways whereby movement of a nuclide through natural ecosystems can reach man; (ii) that there are usually certain critical groups within the human population that are vulnerable targets for specific nuclides and pathways; and (iii) that plants or animals may reconcentrate solutions of the nuclides that had previously been very dilute. These factors are recognized and taken into account in setting allowable release limits.

Within Canada there have been many studies of the migration of radionuclides through surface waters (and lake sediments) and their absorption into plants and animals. The Biology and Health Physics Division of CRNL has made a detailed study of the Perch Lake basin on the CRNL reserve, particularly as regards the pathways used by the critically important radionuclide strontium-90 (which resembles calcium and hence tends rather easily to be incorporated into bone tissues).

Environmental impact analysis

We have examined the documents submitted by AECL and Ontario Hydro to the Porter Commission and they confirm our impression that little emphasis has yet been given to the sort of impact analysis that will be required before repositories can be constructed. Moreover, the Atomic Energy Control Board has not yet published, even in preliminary form, licencing guidelines for repositories.

We cannot at this stage spell out in detail what the environmental impact analysis should cover, but it must clearly be comprehensive and should include analysis of the impact on plants, animals, ecosystems, natural amenities and natural resource development.

It will be necessary, as part of the environmental impact analysis, to conduct exhaustive field studies in and around each repository and storage site. It will be essential to establish, before there is any possible contamination from the deposited wastes, the background levels of the major radionuclides throughout the drainage basin—including the plant and animal populations within the area. It will be necessary to understand thoroughly the surface and groundwater hydrology, the characteristics of the soil, and many other items. Only if these are firmly established before wastes are deposited will it be possible at a later time to distinguish any increased radionuclide levels due to unexpected leaks of the repository system.

At the core of such an analysis must be a comprehensive study of all aspects of the hydrologic cycle for the drainage basins within which repositories are to be constructed. As was shown above, if radionuclides should escape into the biosphere from the repositories, it is virtually certain to arise from groundwater movement to the surface, with subsequent possible movement through soils, plants and animals into human food and drink.

The techniques employed will include the critical pathway methods already widely developed. These are demanding in manpower and equipment. AECL's Biology and Health Physics Division has the methodology and experience to conduct the analyses, but it is unlikely to have the manpower. Presumably it will be necessary to contract out much of the actual study to consultants.

As we said above, if the repositories function as planned, there will be virtually no escape of radioactivity at the surface.

The environmental impact analysis should aim at impact on the natural environment itself, and not solely on the environment as a pathway to man. Canada's plants and animal have a value of their own. Moreover, one cannot accurately predict pathways to man in the absence of a full understanding of natural ecosystem functions, including the cycles of water, nutrients and gaseous exchanges with the atmosphere.

Chapter 6. FINAL DISPOSAL METHODS

This part of our report is concerned with the ultimate disposal of irradiated fuel and the emplacement of these materials in a site or sites where there is no intention of ever retrieving them.

The objective is to remove the wastes from the zone of life on earth and to dispose of them in such a manner that the likelihood of dangerous materials reaching the biosphere is exceedingly small.

Whether irradiated fuel or the wastes from fuel processing is being considered, the problem of ultimate safe disposal is the same. Irradiated fuel will generate more heat and have larger amounts of long-lived radioactive actinides, so that if the disposal is safe for irradiated fuel, it is safe for processing wastes also.

Several methods of disposal have been suggested. These include:

a) Placing in sealed canisters and leaving on the surface of the earth in designated locations where they can be monitored for as long as considered necessary.

b) Transporting the wastes in suitable containers to the Antarctic or to Greenland where they are buried in the great ice sheets.

c) Loading them into rockets and firing them to another planet or to the sun.

d) Depositing the wastes, suitably contained, in the deep abyssal plains of the oceans, either on the sea floor, or buried in the sediments and rocks beneath.

e) Geological containment on land—

    i) Burial in rock salt, either where the beds have been deformed into domes, or in thickly bedded strata of salt.

    ii) Burial in crystalline rocks of igneous origin.

    iii) Burial in shaly rocks of a kind normally associated with limestones and other sedimentary deposits.

    iv) Burial in rocks formed from volcanic ash (tuff).

    v) Burial in other rock types which may be found to be suitable because of particular characteristics.

Each of these will be discussed in turn, with primary emphasis given to discussion of deep burial in geological formations on land.

Surface disposal

Some people consider practical the ultimate disposal of irradiated fuel, whether processed or not, by placing it in suitable containers and leaving them on the surface where they can be suitably monitored for all time and remedial action taken if there are signs of failure. We consider that surface disposal is unsuitable because it leaves to future generations of man the duty to keep watch on the dangerous substances that we have left behind. Furthermore, surface disposal, even if it is well managed, will always be more vulnerable to man-made hazards such as wars, revolutions and the breakdown of organized society, than disposal deep underground.

Antarctic or Greenland ice sheets

At first glance this seems to be a logical method for disposal. Material would be isolated from mankind. The ice is 3,000 metres or more thick. The heat generated within the canisters used to contain the waste would be sufficient that, given a start, they would sink to the bottom of the ice sheet. Questions have been raised about the stability of Antarctic and of Greenland ice over long periods of time. However, the flaws of most immediate significance in this proposal are: (1) the use of the Antarctic is covered by an international treaty and (2) neither the Antarctic or Greenland are Canadian territory. Canadian glaciers are too small for serious consideration.

Disposal in outer space

Although it is clearly possible to send rockets with a substantial payload to outer space, the possibility of accidents is much too high for this to be seriously considered in our present state of knowledge. The cost of disposal by this method also seems likely to be excessively high for the dubious advantage of extra-terrestrial disposal.

Disposal on or in ocean plains

It has been suggested that wastes in appropriate canisters could be simply dumped onto the ocean bottom and left. The canisters would obviously be attacked by sea water but corrosion would be slow due to the low temperatures on the bottom of the sea (about 2°C), as would be the solution of the materials once the covers were breached. In any case, the canisters would not be breached until the radioactivity had decayed substantially, and the solution rate of the radionuclides would be so slow that their diffusion through the ocean would be an effective means of disposal. This method is a possibility, but much more work needs to be done and a better understanding obtained of the movements of waters in the ocean.

As a refinement of this procedure, it has been suggested that high-level wastes, in suitable containers, could be buried in the sea floor of the ocean deeps and thereby ensure an even slower rate of incursion of sea water, and slower migration of nuclides due to the overlying clays. The difficulties of drilling holes in the deep ocean of a size necessary to accept these wastes and the difficulties of relocating over the hole in case of severe storms, suggest that such a procedure has too many hazards and is needlessly costly for serious consideration now. The Conference on the Law of the Sea may rule out disposal both on and in the ocean bottom. There is already a convention, to which Canada is a signator, that prohibits disposal of high-level wastes in the

sea. Nevertheless, several nations are investigating, burial in the deep-sea bed, and Canada should at least keep abreast of developments.

Geological containment on land

This concept includes burial in salt, crystalline rock, shales, volcanic ashes (tuffs), and others. It is assumed that the wastes would be buried deep below the surface of the earth. Depths ranging to 1,000 metres have been considered, depending to some degree on the type of rock under study, but chiefly because at depths below about 600 metres the pressures are such that the smaller fractures that might permit the relatively easy movement of groundwater are normally closed.

In general terms, the following characteristics of potential rock sites are considered important:

1. The rock type should be homogeneous and sufficiently large to ensure isolation of the disposal site from any externally imposed changes in environmental conditions.
2. Thermal conductivity must be high enough to permit dissipation of heat generated by the wastes at a rate that will prevent over-heating in the disposal site, that could possibly weaken the containing rock, permitting ingress of circulating water.
3. The containing rock should not show undesirable characteristics—fracturing, overheating, structural weaknesses—due to irradiation from the contained wastes.
4. The chemical characteristics of the containing formation should favor a measure of chemical containment in the unlikely event of escape of waste material.
5. Groundwater circulation, or penetration by surface water through fissure flow or granular movement, or both, should be low.
6. The site must be in an area sufficiently removed from fault zones that earthquakes are unlikely ever to affect the wastes.
7. Jointing and other characteristics favoring a possible ingress of water should be at a minimum.
8. Areas containing nearby mineral or other resources should be avoided.
9. The formation must be sufficiently deep that the wastes can be buried where they will not be affected by rising or falling sea level, by glacial scouring or deposition, or by major climatic changes such as excessive rain or dryness.
10. Sites should be well removed from types of human activity that can generate crustal instability, such as deep mining or large dams.

We consider that, whatever the method of disposal selected, the wastes should be immobilized in material with long-term structural stability and extremely low solubility in water at temperatures likely to be reached in the disposal site. Incorporation of the fission produced wastes into glass is a method commonly proposed for immobilization. Experimental testing of such glasses have shown that they can be very insoluble and the release of contained nuclides very low at normal temperatures. However, the tests give little information on the solubilities at the temperature in a repository. All glasses become more soluble with increasing temperature and some kinds are known to be dissolved by water at temperatures over 250°C. Thus, we have some question that glass is entirely suitable for immobilization at the conditions possible in a repository. Ceramic materials might be better. In any event, considerably more research is needed.

We now consider the various rock types that might be used for ultimate disposal of irradiated fuel and reactor wastes.

Salt formations

Almost no research has been carried out on disposal in salt in Canada. Large programs have been mounted in the Federal Republic of Germany and in the United States of America. In both these countries, investigations have been underway for 10 years or more and we have been told by officials in the USA that they expect to have the first disposal site selected and ready to accept nuclear wastes in about five years. Scientists in the FRG, on the other hand, believe that it will be a decade or more before there will be a site there ready to accept waste from the processing of irradiated fuel. It is worth pointing out, however, that the FRG has already adopted a policy of burying toxic materials in salt. These include such chemicals as PVC's, mercurides and arsenic, as well as reactor wastes.

The US National Academy of Sciences has had three different studies made on disposal in salt beds and has concluded in each that solid nuclear wastes of all kinds can safely be disposed of in salt formations. Canadian scientists have been and are being provided with detailed results from all investigations carried out by their counterparts in USA and FRG. They should also participate to the extent practical in these programs.

Studies of available information on Canadian salt deposits indicate that there are sites in Canada at least as suitable as those available to other countries. A minimum of further investigation could determine whether or not they are as satisfactory as they appear to be (see Figure 6-1).

Briefly, the advantages of salt are:

a) Its presence is evidence of the fact that the area has not been subjected to groundwater activity for a very long time.

b) It has a very important characteristic in that, under pressure, it tends to flow and is therefore self-sealing at depths of about 600 metres. Thus wastes emplaced in salt would not be much affected by earthquakes or other natural cataclysms.

c) It conducts heat well, so that the build-up of temperatures where the waste is emplaced could not conceivably be high enough to be dangerous.

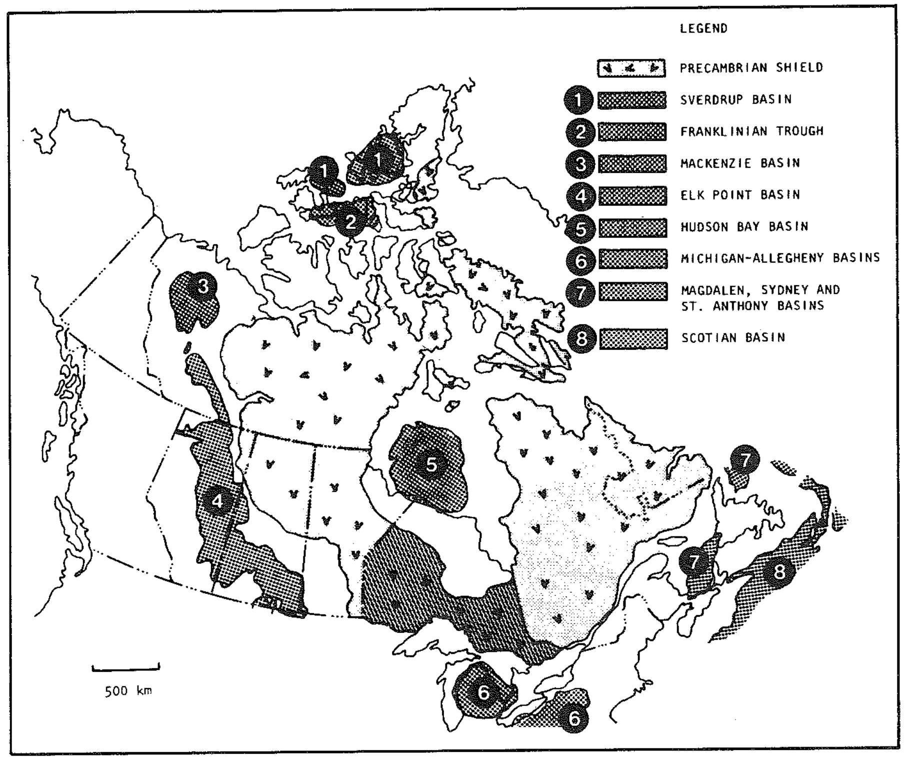

Figure 6-1. The Canadian Shield (showing area of immediate interest for radioactive waste disposal by oblique hatching) and salt basins of Canada.

The investigations so far undertaken concerning salt suggest that deposits that have been geologically deformed into domes might be better than those that occur in thick beds, essentially horizontal. Ontario has little salt that has been deformed: it is mostly of the bedded variety, but is sufficiently thick to be a potential repository. Other places in Canada, notably Nova Scotia, have dome salt formations that could also be sites for the emplacement of radioactive wastes.

The principal drawback to salt lies in the fact that it is an indicator of geological conditions that may lead to the discovery of other useful materials such as petroleum. It is, furthermore, potentially valuable in itself. Thus, there is a remote possibility that a waste disposal site might be intersected by exploratory drilling in generations to come. Nevertheless, salt is the preferred medium for disposal in some other countries and should be Canada's second choice.

Crystalline rocks

The crystalline rocks here referred to are of igneous origin—that is they have crystallized deep in the earth. The Precambrian Shield of Canada (Figure 6-1) contains large amounts of such rock and has remained stable for hundreds of millions of years, except for relatively minor vertical movements and earthquake zones that are delineated (Figure 6-2). 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.

Scattered throughout the Shield are small igneous intrusions commonly called "plutons". These are not in any way related to plutonium. The term "pluton" refers to the origin of these rocks deep in the earth. In Ontario alone about 1,500 such plutons, with a minimum diameter of three miles, not crossed by obvious fractures or joints and not penetrated or bounded by obvious potential faults, have been identified on geological maps, aerial photographs and satellite images. Preliminary investigations in the field will identify those that have the best characteristics and merit follow-up investigations.

Perhaps as many as 40 or 50 of these plutons may merit such detailed investigation, but an AECL/EMR team has proposed that eight or nine be studied in the field. Undoubtedly some will be eliminated because the rock is not sufficiently strong, does not conduct heat properly, is not homogeneous or for a variety of other reasons. It is expected, however, that this sample, if it does not yield a possible disposal site, will enable the scientists and engineers to select, with a greater chance of success, other plutons that could potentially be used as disposal sites.

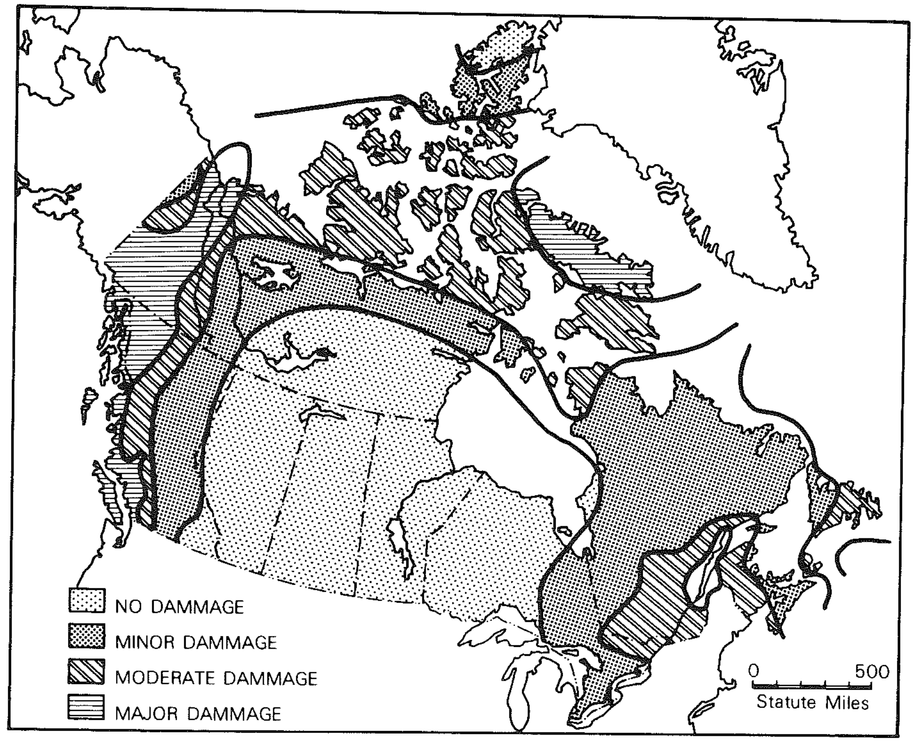

Figure 6-2. Seismic zoning map (1970).

Before a definitive judgment can be made on the potential suitability of a particular body of rock, many tests will have to be undertaken, especially at the approximate depths at which nuclear waste might be placed. Assuming the results are satisfactory over several years, it would then be possible to designate a disposal site. Monitoring could be continued for an appropriate time to ensure that the scientific interpretations were correct.

Although some authorities feel that a depth of 300 metres from the surface would be satisfactory for the repository, we are inclined to feel that a greater depth would be surer, perhaps 800 to 1,000 metres, which is the depth being now considered in Canada. Circulating groundwater is the principal agent that could carry nuclides to the surface and the rate of movement is certain to be very much less at depths of 1,000 metres than at 300. However, at depths greater than about 1,200 metres, there is an increasing danger of rock bursting into the disposal site cavity due to pressure.

Some authorities suggest that open fissures could reach from the surface to the depths being considered for a repository. This seems unlikely in essentially homogeneous rock.

Shale

Thick shale formations, or homogeneous rock capped by thick shale formations, are another possibility. Shale is an excellent barrier to water and to oil, as illustrated by the presence of many oil fields throughout the world that are capped or contained by shaly layers, and by the many aquifers—underground sources of water—that lie beneath shaly horizons. Such potential sites could be determined from geological maps already in existence, although a more detailed study would be required, including drilling, before it would be possible to determine whether or not such a site would be suitable for the disposal of nuclear wastes. Investigations along these lines are already underway in Belgium, Italy and USA. The attractive feature, from the Ontario point of view, is that such formations lie directly beneath most of the nuclear generating stations already in existence. If safe disposal of the irradiated wastes could be made directly underneath the station that generates them, the question of disposal sites would be solved relatively easily. However, it is far from certain that a multiplicity of disposal sites is better than a single site for Canada.

One of the particular advantages of shaly formations, in addition to their relative impermeability, is that, being made of clay, they have excellent sorption characteristics. If a solution containing actinides moved through shale, it would tend to give up dissolved material to the shale through ion exchange, thereby preventing the movement of the radioactive materials, except at extremely slow rates.

Tuffaceous rocks

These rocks are formed from the ash thrown out of volcanoes. Ash-falls of great thickness have occurred here and there in the world, and there may be examples of these rocks that merit investigation as waste disposal sites. In the Canadian Shield such volcanoes have, of course, been extinct for many hundreds of millions of years, and the tuffs are now highly crystalline. The USA is investigating tuffaceous rocks in the western states, particularly Nevada, where they have special characteristics—rather porous and with an excellent ion exchange capacity.

Such rock, overlying a burial site, would almost certainly prevent any escape of radioactive wastes should water begin to move through the tuffs towards the surface. Rocks having suitable characteristics of this nature are likely to be found in Canada only in British Columbia and the Yukon and it is suggested that, for the present at least, only a watch be maintained on the activities of other agencies that may be investigating this material.

Other potential sites

Here and there are thick layers of clays that were deposited at the conclusion of the last ice age (10-20,000 years) and there have been suggestions that these might make suitable repositories. The fact that they have been formed so recently suggests that the long-term stability is much less than rocks of the Canadian Shield, or even of much younger consolidated rocks. Moreover, the wastes would be relatively close to the surface and changes in climate could drastically change the character of the containing medium.

Summary

We feel that several different kinds of rock could profitably be studied but that resources ought not be spread too thinly. We suggest that primary effort be given to the crystalline rocks of plutonic origin (i.e. deep in the earth), but that careful attention be paid to the work of other scientists in other countries on different rock types.

Research requirements

We are pleased to note that experiments are now being conducted in deep rock exposed by mining. We do not consider, however, that an abandoned mine would be a good disposal area for wastes. They are open to the surface, invariably flooded and may have man-made fractures and openings not on record. Hence the containment of wastes will be difficult.

We need to be sure on the basis of experimental evidence that what is believed to be true regarding the characteristics of the various rocks in association with radioactive waste is actually the case. Among other things, research is needed to ensure that the repository is geophysically stable, that the effect on the rocks of radiation and of the development of heat in the nuclear wastes is acceptable for containment, that emplacement can be safely effected, and that the effects of groundwater will be minimal. Research is also needed on the possibility of artificially enhancing the sorptive characteristics of the containing rocks.

The EMR/AECL team now making preliminary studies of these matters has suggested that a minimum of five years of testing and experimentation is needed before a particular site or sites could be chosen for experimental purposes. This calculation is based on the assumption that sufficient men and money can be made available for the study. Therefore, if a start is made in 1978, recommendations on an experimental site could be made by 1983.

Once a site has been chosen for full examination, there will need to be a detailed and instrumented study of the rock characteristics before wastes can be disposed of. Some wastes might be buried as an experiment during this period, but they would have to be recoverable in case the experiments showed the site to be unacceptable. A possible repository is sketched in Figure 6-3.

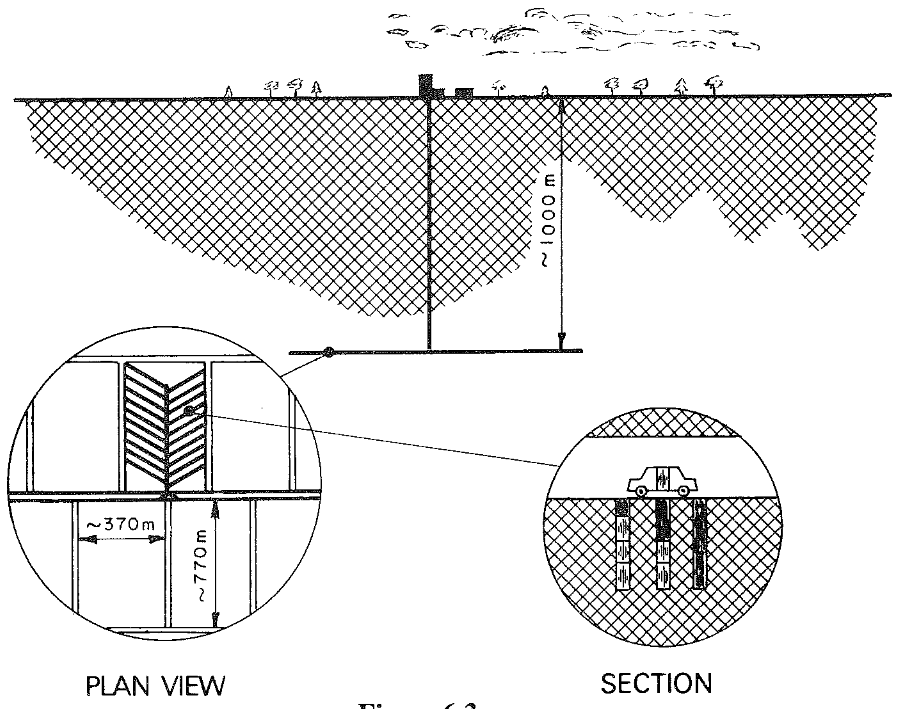

Figure 6-3

Based on the inadequate, empirical knowledge now available, we estimate that about 10 years of experiments will be needed to establish the acceptability of a disposal site. Thus, even with an all-out effort beginning in 1978, it will be 1983 before a site can be selected as potentially safe for disposal of nuclear wastes, and 1993 before such disposal can be experimentally demonstrated. By that time, if present forecasts are realized, the amount of nuclear waste being generated by nuclear stations in Canada may exceed 5,000 tonnes a year. It is important that Canada begin seriously to investigate potential waste disposal sites.

Preferred options for waste disposal

In summary, after reviewing all the options that appear to be available for the disposal of high-level, radioactive waste from the operation of nuclear reactors, we have concluded that the best potential is burial in geological formations of igneous origin in Precambrian rocks. Since Ontario will be the main producer of radioactive wastes, the first repository should be in that province.

Much investigation remains to be done before a specific site or sites can be selected, but on the balance, we are inclined to believe that the best potential is in plutons about 5 km in diameter and which are, so far as can be determined from present data, not intersected by faults (loci of earthquakes), that are substantially homogeneous, that have no obvious linearity, or fractures, and which are "dry" or as nearly so as is likely to be achieved. These rocks should be of a character that can sorb nuclides should they escape from their container. On the basis of present information, this would seem to limit the search to rocks that are deficient in quartz, a mineral that is unduly affected by stress and provides virtually no adsorptive capacity. This then implies that the best plutons would be those of rocks high in feldspar and low in quartz.

Our second alternative is rock salt. Since the salt in Ontario occurs in areas of high population density, and since it is a mineral which may have value, either for itself or as a precursor for other minerals, we think that this is a second choice. But, keeping in mind that the capacity for salt as a disposal medium is under intensive investigation in other countries, we think that the Canadian contribution to the problems of nuclear waste disposal could best be directed towards rock types other than salt.

Our third priority is that of shaly rocks, which are common in Ontario. Little is known about them in the Canadian circumstance and we have some doubts about their acceptability because of their unusual association with rocks that carry substantial amounts of water.

It may be, that as time goes on, the possibilities of deep ocean burial will appear more and more attractive. Such burial will, of course, come under international jurisdiction and for that reason is not now attractive in the Canadian sense. However, the potentialities of ocean burial strike us as having such good possibilities we would urge that the Government of Canada keep a close watch on development in this area, and initiate some research.

On the basis of present technology, international complications, and technical feasibility, we consider that extra-terrestrial disposal, or disposal in Arctic and Antarctic ice sheets should not be considered further.

Chapter 7. PRESENT CANADIAN AND INTERNATIONAL PROGRAMS

Canadian program

The responsibility for developing methods for storage and disposal of radioactive wastes from nuclear power stations rests with AECL. Until recently the development of a safe and economic nuclear power system took virtually all the effort and money available, so that waste management got only enough attention to assure temporary, but safe, waste storage. During the last few years, however, AECL has defined a program on environmental protection and radioactive waste management.

The overall objectives of this program are listed by AECL as:

(a) To develop and demonstrate waste management principles which minimize radiation doses to man and adverse effects on the environment, while placing minimum responsibility on future generations, i.e. safety and responsibility.

(b) To develop methods, models and data for the assessment of radiation doses to man and changes in his environment due to the operation of nuclear power facilities.

(c) To contribute to understanding the effects of ionizing radiation on living matter and to develop instruments and techniques as required for the detection and measurement of radioactivity.

(d) To provide means of meeting AECB and IAEA requirements for instruments and techniques to safeguard CANDU reactors and fuel cycle operations against diversion of fissile materials.

The program is organized under three categories:

(a) Radioactive waste management
  - reactor wastes
  - fuel cycle wastes

(b) Protection of man and the environment
  - environmental research
  - biological research

(c) Safeguard systems.

We reviewed mainly the work on radioactive waste management. AECL have planned and organized the program and have established working relationships with the utilities, other government departments and agencies, universities and industries.

The program on reactor wastes management is aimed at developing and demonstrating methods for their treatment, storage and final disposal. It is well conceived with targets and a schedule.

There are four main aspects to the development program on fuel cycle wastes:

1. The interim storage of irradiated fuel.
2. The decommissioning of nuclear facilities.
3. The transportation of irradiated fuel.
4. The development of a permanent disposal method.

The interim storage of irradiated fuel is being studied in cooperation with Canadian utilities, mainly Ontario Hydro, with the AECL work centred on the development and proof testing of the concrete canister concept. The decommissioning of nuclear facilities is being assessed, but so far only theoretically. Systems for the transportation of irradiated fuel are being evaluated by Ontario Hydro with some AECL participation.

The program to develop a permanent disposal method for fuel cycle wastes has proceeded on the assumption that the irradiated fuel would be processed to recover the plutonium and that the wastes would be those arising from such processing. Little detailed attention has been given to the idea of immobilizing and disposing of the irradiated fuel directly.

AECL and Ontario Hydro concluded that a central site should be developed for the interim storage of irradiated fuel. To avoid moving irradiated fuel more than once, this site should also be suitable for a permanent disposal facility and, in addition, if deemed desirable in the future, for a fuel processing plant. These conclusions formed the basis of a program of site selection, the key element of which was the permanent disposal site. The schedule was determined by Ontario Hydro's requirement for an interim storage facility to be in operation by 1985.

AECL undertook, with the help of EMR and other government departments and agencies, to find, by 1981, a site warranting detailed testing and development. This program has already slipped by two years and 1983 is now the target date. The selection would be limited to igneous rock (plutons) in Ontario.

The environmental and biological research programs are aimed at developing methods, models and data for the assessment of radiation dose to man and changes in his environment, stemming from the operation of nuclear facilities. This work has been underway in AECL for 25 years and is well coordinated with related studies in other institutions such as NRC, DFE and universities. The main work related to waste management is modelling, data storage and environmental pathway analysis.

Waste management is a non-competitive area and international cooperation is extensive. Canadian organizations participate in committees and study groups in IAEA, NEA, IEA and other internationally organized conferences or advisory groups. Cooperation on technical exchange is good with many countries, and particularly close with the USA and Sweden.

International programs

A large number of nations with nuclear power programs are also investigating and evaluating methods of radioactive waste management. Most of this work is aimed at defining conditions for geological storage of wastes from fuel processing. The Belgian program is directed to the study of clay formations that are about 100 metres thick and 180 metres below the ground surface. In France the use of salt beds and crystalline rocks is being examined. In Italy, because of the tectonic instability of the country, studies are being concentrated on salt and clay formations as possible repositories for processing waste. Spain and Switzerland are also surveying possible sites in their countries.

In Sweden the government has requested a detailed study of waste management methods and has suggested that future commitments to nuclear power plants will be contingent upon the outcome of such a study. There, the use of deep crystalline rock, perhaps backfilled with clay, is the reference geological formation for a waste repository.

The UK, because of its continuing program of fuel processing, has accumulated a considerable volume of high-level liquid wastes. There is now underway a very active program to convert these wastes to solids, probably glass, and then to bury them in a deep geological repository yet to be chosen.

Germany is very advanced in the use of salt beds or domes. Reactor wastes have been stored in drums in the Asse mine since 1967. The Netherlands also has a program to evaluate salt formations.

The program in the USA is very large and still growing. Next year their budget will be $90 million for studies in wastes from the civilian program alone. They are investigating a variety of methods for the interim surface storage of LWR fuel, for the treatment of processing wastes and for geological disposal.

Chapter 8. INSTITUTIONAL RESPONSIBILITIES AND THE PUBLIC

At present there is a clear-cut division of responsibility for the management of irradiated fuel and wastes. AECB is responsible for licencing sites at which such management is undertaken. The provincial utilities own the fuel and wastes and actually look after them. AECL has major responsibility for research and development work on management and disposal techniques. It is complicated in some provinces by the existence of review processes for environmental impact, relationship to energy policy and other provincial concerns. We see nothing to criticize in this allocation of responsibility.

There is no provision, however, for the disposal of wastes and irradiated fuel, or for directing how and when this should be done. We are proposing that this be the responsibility of an appropriate federal agency, as part of a national plan. There is also inadequate provision for public consultation and information. Clearly the question arises: How should these new responsibilities be handled?

The future role of the AECB seems clear. It will continue to licence and inspect all nuclear facilities and these must include radioactive waste and fuel storage sites and disposal repositories. Under the new legislation that is pending, we understand that the Board will conduct public hearings on applications for licencing such facilities. This will provide a forum for informed and concerned citizens' groups to comment on the proposed developments before they are licensed. The Board's guidelines will be directed towards the preparation of such applications.

Our views on this matter are as follows:

(i) the responsibility for constructing and managing a disposal site (repository) should rest with an appropriate federal agency;

(ii) provincial utilities should retain ownership of and be responsible for wastes and irradiated fuel until they have been transported to the repository and formally transferred to the federal operator;

(iii) two options exist as to the identity of the federal operator, given that responsibility for research and development on disposal techniques should be assumed by the agency operating the repository:

(a) AECL could assume responsibility (the option we favor). It already has considerable skill in the area and is in close touch with the provincial utilities. It would have to operate, however, under a federal mandate and treat the disposal function as a distinct, high-priority responsibility;

(b) a new agency could be set up with specific responsibility for all aspects of the disposal function. In such a case, the work and facilities of AECL now assigned to waste management studies, would need to become the nucleus of the body's structure.

We have proposed the adoption of a national plan for radioactive waste management to cover these and other functions. Such a plan will need the sanction of the Canadian Government. Before such adoption, it is essential that there be an opportunity for wide public discussion of the plan's provisions. This should involve the wide circulation of drafts of the plan for comment and criticism by members of the public, citizens' groups, and all official agencies concerned with nuclear, health and environmental affairs. It may be desirable to hold formal public hearings, or to organize conferences and seminars on the subject. The plan should be seen to have broad public support before it is put into operation by the government —but the urgency is such that immediate action is required to get this support.

In any case, AECL should actively seek more comment and discussion of their programs than they have in recent years. Their program documents and progress reports on waste management should not only be public documents, but they should be sent to interested groups and individuals in an active search for comments. We also suggest they organize and sponsor at least once a year symposia on the waste management program inviting representatives from utilities, the nuclear industries, universities, citizen groups and interested individuals, as a means for informing the public and also for receiving comments and criticism.

The nuclear industry is not alone in finding the public wary of its plans. All high technology industry faces the same problem. Many people now question the wisdom of highly technical solutions to social needs, even when these are urgent and inescapable. The disposal of nuclear wastes, which Canadian society cannot now avoid, is just such a case. It has become surrounded by myths and suspicions. Only wide public consultation can sweep these away.

Chapter 9. DISCUSSION

It has been widely asserted that no method is available for the safe disposal of nuclear wastes, and that their interim management also presents serious hazards. Our conclusions are more optimistic. We find that interim management techniques are being well developed in Canada and present very little hazard to the public. As regards ultimate disposal, geological repositories offer good prospects for the safe, permanent disposal of either reactor wastes or irradiated fuel. We see no reason why the disposal problem need delay the country's nuclear power program. But there is great urgency in testing these conclusions. Wastes and irradiated fuel are accumulating now. It is imperative that the required research and development programs be started at once—given the long period required to solve the technical problems, and to satisfy the public that the repositories work as expected.

There remain many arguments to which the country must listen attentively, and act accordingly. One of these—and a critical one—is the sheer urgency of this problem, which has been badly underestimated. There has been little internal pressure in the industry to do more than the adequate minimum work on this problem, nor has government applied any. We do not suggest complacency on the part of AECL and the utilities, as they have so far managed all their wastes in a safe manner; little, if any, damage has been done to people or the environment. Where the nuclear industry has gone wrong, however, is in assuming that they would be allowed to accumulate these large amounts of radioactive materials until it was technically and economically convenient for them to take further action, be it processing or disposal. Outside pressures are now demanding that a permanent solution be demonstrated physically as well as analytically. This demand must be answered.

It is argued by some that if the wastes are stored in accessible, leakproof structures on the surface of the earth, it will be possible to correct anything that might go wrong. However, such a method would require vigilance for many centuries, and would be a continuing burden on society. While it is accepted that if something should go wrong with a deep geological disposal site it would indeed be difficult to rectify, nevertheless, if done correctly, such disposals could be ignored or forgotten by future societies.

We have assessed the possibility of designing, building, operating and finally closing a deep disposal facility in a manner such that the chances of significant escape of radioactive nuclides are very low, and are satisfied that this can be done. It will require a sizeable research and development program to study and measure the characteristics of a particular site, especially the effect of ground heating by the wastes, and the possible movement of water through deep rock formations disturbed by the actual construction of the facility. From all our considerations, we now believe deep geological burial is a potentially very safe method of disposal. This accords with recommendations being made in several other countries.

We did not attempt, within so brief a period, to consider the cost benefit ratio likely to apply to such a facility. But costs, though not trivial, are bound to be small by comparison with the value that the public will place on as secure a solution as possible to a hazard so much feared. The public derives great benefit from electric power. It will also derive benefit from a solution to the disposal problem—a benefit that will be bequeathed, moreover, to all ensuing generations. We are sure that all costs necessary to achieve this end will be readily borne.

In any case these costs should be small by comparison with the capital cost of other aspects of the industry. A consultant's report to AECL, to which we had access, estimates that the capital cost of the repository could be as much as $200 million. Operating costs might resemble those of a mine producing 4,000 tonnes per day. This would correspond to about 1 or 2 per cent of the production costs of nuclear power. If Canada does proceed to install 75,000 MWe of nuclear power, this implies an annual operating budget for the repository of $100 million. We present these rough calculations not as accurate predictions but as the basis for our conviction that costs will be trivial by comparison with the benefits. Their smallness reflects the fact that nuclear wastes are not bulky. By comparison with the huge volumes of material handled routinely by the mining industry, their bulk is very small.

It is also often argued that nuclear wastes are uniquely dangerous, and that their exclusion from the biosphere transcends all other considerations. We agree that they are dangerous, and should be so excluded. But dangerous wastes are not unique to the nuclear power industry. The major fuel alternative to uranium—coal—generates and releases large quantities of toxic wastes. The ash from burning coal contains radioactive nuclides, including radium-226, which presents about the same hazard to man as plutonium-239. In addition, the ash contains many other toxic elements. The quantities of these discharged annually from a 1,000 MWe coal-fired plant are surprising, i.e.:

Element	Approx. annual discharge kg/y
Arsenic	90,000
Barium	300,000
Chlorine	20,000
Manganese	70,000
Mercury	20,000
Nickel	70,000
Vanadium	70,000

Depending on the stack filtration system used, anywhere from 1 to 10 per cent of this ash is dispersed with the carbon dioxide, sulphur and nitrogen oxides and other pollutants. Several estimates of the number of premature deaths caused by the entire coal fuel cycle place the number as much higher than that considered as possible for a uranium fuel cycle. We do not suggest that the hazards of producing electricity in coal-burning plants are necessarily unacceptable, but rather that any method of generating electricity presents some potential hazard.

Having opted for continental geological repositories, we have considered the question of hard, igneous rock versus salt formations. The Canadian development program was aimed at hard rock because we have lots of it, and because salt technology would be available from other countries. We could wait until the two technologies are demonstrated and then make a choice, but in practice, unless something very fundamentally wrong is found, the momentum of the Canadian program will lead to the use of hard rock as the host for our nuclear wastes. Salt avoids the problem of the radioactivity getting into the groundwater, but salt is a mined resource, so that future generations could conceivably stumble on our wastes. The latter would be of low activity then, but still hazardous.

As discussed in pages 32 to 35, water is contained in rocks, and does move. The research and development program will have to show, by actual measurement, that this water movement (at the depth of disposal and in the specific area being considered) is in fact as slow as now predicted, and that the rock will have the sorption capacity to slow the movement of the radionuclides well below that of the water. Provided that the rock can do this, taking account of the heating due to the radioactivity, and the disturbances caused by opening the cavity, hard rock should be an acceptable host for the repository, and the best choice for Canada. We should, however, keep fully aware of the salt technology.

There exists today in Canada over 1,500 tonnes of irradiated fuel discharged from power reactors. This fuel is stored in water-filled, double-walled concrete tanks at the power plant sites. As more irradiated fuel is produced, additional storage facilities will be needed. Several interim storage methods have been examined by AECL and Ontario Hydro.

After reviewing these possibilities, we have come to favor the dry concrete canister approach because of its simplicity and the lack of need for constant operating facilities. Moreover, it produces no additional radioactive wastes during the storage period. The ultimate transfer to a geological site or a fuel processing plant may present some problems, as the canisters might have to be opened: but we expect these to be less, overall, than those presented by wet storage in water-filled bays.

If the site of the interim storage facility is to be the same as the geological repository, it is unlikely that Ontario Hydro's need to have central operating fuel storage facilities by 1985 to 1987 can be met. The selection of a site for detailed geological investigation will not be made until at least 1983, and it will take several subsequent years of underground testing to measure the various characteristics before a firm decision on its suitability can be made. It seems to us, then, that the utilities should plan on storing irradiated fuel at the nuclear power plants where it is produced until at least 1990, if not longer, to avoid shipping it more than once.

The time needed to develop a geological repository and that needed to develop a plutonium recycle capability are not very different, about 15 to 25 years. On present estimates of uranium reserves, it will not be economical to start commercial plutonium recycle with either uranium or thorium for at least a similar period. Hence Canada has little choice other than to keep the irradiated fuel in surface storage facilities for many years. The repository should be ready as soon as possible, however, and this means a major increase in the priority, money and manpower assigned to this aspect of the waste management program. The Government of Canada should declare itself committed to such an accelerated program and provide the resources, both political and financial, as needed.

The argument that the irradiated fuel is a potential source of future nuclear energy will be with us for many years. If, however, it is not economical or acceptable to recover and reuse the plutonium in, say, 20 years, consideration should be given to the question: How much longer should the irradiated fuel be held in interim storage? Granted that there is no immediate need to decide, we suggest a time limit should be set for this decision, so that the inventory at the surface will not continue to grow. Thus we believe the technology for the disposal of unprocessed but immobilized irradiated fuel should be developed and operationally available by 1990.

Quite apart from the need to find the right sort of rock, the choice of site will also depend on the answer to several socio-economic questions. Should the repository be near the reactors, to minimize transportation? Should it be remote from centres of population? If so, how remote? Will its existence have a local economic impact, for example on real estate values, or on employment? Clearly these questions, too, should be publicly argued.

Two quite different principles affect choice of site in relation to where people live:

1. If there are risks involved in operating and maintaining the repository, it is equitable that these risks should be borne by the people who benefit most from the power to be generated. This points to a site near the reactors, which are built near the power demand to minimize transmission losses and costs. Taken to its logical conclusion, this might argue for the permanent disposal of wastes and irradiated fuel at the power stations themselves, if that is feasible. To do so would minimize transportation and would disperse the risks to the same degree as those of reactor operation.
2. In rebuttal, however, one can argue that one should minimize risks to human populations in the event of an unforeseen escape of radioactive materials from the repository. In this case, the logical site would be in areas remote from human habitation. If an accidental release occurred, the effects if any would then be borne by the local ecosystems, not by large numbers of human beings.

The latter criterion—remoteness from settlements—will probably be preferred by most members of the Canadian public. Few people want to see the repository close to their own homes. Hence, the inhabitants of densely settled southern Ontario are likely to opt overwhelmingly for disposal in remote, central or northern areas. It happens that the igneous rock bodies preferred as sites in this report are also located in such areas—though they do extend southeastwards through Algonquin Park to the Thousand Islands area of the St. Lawrence Valley, and are present at some depth under southwestern and eastern Ontario.

A decision to locate the repository in central or northern Ontario, however, may be resisted by local populations, environmentalists, conservationists, wildlife specialists and the recreation industry. In some areas it may also be opposed by native people's organizations. "Why should we accept noxious wastes that arise from the demands of city-folk down south?" This familiar cry will be raised wherever in northern areas the repository is finally placed.

But there are extensive areas of crown land that are not peopled at all, except for temporary settlement associated with recreation, mineral or forest development, or communications. In such areas, if suitable rock bodies can be found, the decision to site the repository will impose little real hardship. Some such areas already have extensive mineralization: some of it naturally radioactive. Other areas have mining developments that create radium and actinide-bearing radioactive wastes that already require treatment and disposal. It would make sense to choose a repository site in such an area.

A repository is bound to have an economic impact on the region in which it is located. Here again conflicting forces arise. Fear of the hazard involved, even if groundless, may affect real estate values, especially for those people already holding property in the vicinity. On the other hand, the construction phase will create local jobs and involve substantial expenditures within the region. Long-term operation of the repository might involve several hundred workers and may bring economic gains to the region.

In southern Ontario the construction and operation of the Pickering and Bruce generating stations have had some local effects on amenity and recreation, but surprisingly little impact on property values. They are not perceived as major drawbacks by the large urban populations that they serve. The loss of much of Inverhuron Provincial Park to the exclusion zone of Bruce Nuclear Development was, however, resented. It is to be expected that the same will apply to a repository site: it will be wise to avoid any area now dedicated to public recreational use, and actually used by a lot of people.

Future plans for the transportation of irradiated fuel in the year 2000 anticipate about 2,500 movements per annum by rail, with some local movement by transporter trucks. Though these are well within the capacity of existing rail systems, the choice of a site in a remote central or northern area may call for the upgrading of certain rail lines, with construction of necessary spur access to the site itself. A much larger movement of lower level wastes in immobilized form is also likely. This may involve truck movement as well, which will call for good road access.

We heard arguments that it would be wise to locate the repository outside the Great Lakes basin, which already accommodates a large and growing number of nuclear generating stations. Though leakage is not expected from the repository, the radionuclides that would result from such an unforeseen leak would inevitably move into the Great Lakes in dilute form, unless the repository were outside the basin.

The James Bay drainage basin begins quite close to the north shore of Lake Superior and the North Channel of Lake Huron. The main line of the Canadian National Railways from Sudbury to Sioux Lookout and Minaki is never very far from the divide between James Bay and the Great Lakes. Sites close to that line, or to the north of it, would drain away from the Great Lakes in most places (except where the line descends into the Nipigon basin near Armstrong). It may be, therefore, that a site could be found that would avoid any further possible loading of the Great Lakes—but any escaping materials might then enter James and Hudson's bays.

Arguments of this sort are largely self-defeating. We have said that we expect the repositories to be leak-proof for a very long period. Hence the case for transferring the risk from the Great Lakes basin to that of James Bay is hypothetical: it presupposes an accident that we regard as very unlikely. Moreover, we cannot predict what effects such an accident might have on the Hudson's Bay area, nor do we know what future human populations will be. Conceivably there may be large populations in the north in future centuries. We conclude that selecting a site outside the Great Lakes basin is not an advantage. The paramount consideration must be to pick a site that will not fail.

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No attempt has been made to compile a bibliography of published material related to the management of irradiated fuel, processed fuel and reactor wastes for such a compilation would be longer than our report. We include here documents that we consider to be especially pertinent to our study or which will be of interest to readers who wish more detail. We have drawn directly on the work described in several of these documents.

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GLOSSARY

*Actinides:*Elements following actinium in the periodic table. They include uranium and plutonium.

Activation product: Material made radioactive by neutron absorption, changing a stable nuclide into an unstable one.

Breed: To form fissile nuclides, usually as a result of neutron capture, possibly followed by radioactive decay.

Cladding: Material used to cover nuclear fuel in order to protect it and to contain the fission products formed during irradiation. Zirconium alloy is used as the cladding material in CANDU reactors.

Decay: Disintegration of a nucleus through the emission of radiation.

Enrichment: The process of increasing the concentration of the uranium-235 isotope in uranium beyond 0.72 per cent in order to make fuel made from it more reactive.

Environmental pathway: The route by which a radionuclide in the environment is transferred to man, e.g. by biological concentration in foodstuffs.

Fertile: Of a nuclide, that it can become fissile by capture of one or more neutrons, possibly followed by radioactive decay; thorium-232 and uranium-238 are the main examples.

Fissile: Of a nuclide, that it will undergo fission if it is struck by and captures a neutron.

Fission: The splitting of a heavy nucleus into two (or more) parts, accompanied by a release of energy.

Fission product: A nuclide of intermediate size formed from fission of a heavy nuclide such as uranium. Such a nuclide may be radioactive.

Genetic effects: Mutations produced on genes by radiation that may result in changes to the species.

Half-life: The time in which the number of atoms of a radioactive nuclide is reduced by radioactive decay to one-half.

Heavy water: Water in which the hydrogen atoms all consist of deuterium, the stable isotope of hydrogen of mass 2, which is present to the extent of 150 parts per million in ordinary hydrogen.

Isotopes: Nuclides of the same chemical element that differ only in mass.

Light water: Ordinary water, used as moderator and coolant in some reactors called "LWR's".

Nuclear fuel cycle: The sequence of operations in which uranium is mined, refined, fabricated into fuel, irradiated in a reactor and, in the case of some systems, but not CANDU's, reprocessed to yield uranium and plutonium for re-use as fuel.

Nuclides: All isotopes of all elements, i.e. all atoms.

Radioisotope/Radionuclide: A nuclide that is radioactive.

Processing (often referred to as reprocessing): The chemical separation of irradiated nuclear fuel into uranium, plutonium, thorium, if present, and radioactive waste (mainly fission products).

Shielding: Material placed around source of radioactivity to reduce the radiation field.

Alpha particle: A heavy, positively-charged particle; the nucleus of a helium-4 atom containing two protons and two neutrons.

Beta particle: An electron; a light, negatively-charged particle.

Gamma ray: Electro-magnetic radiation of very short wavelength.

Units

Curie (Ci): A unit of radioactivity equal to 3.7 x 10^{10} disintegrations per second.

Rad (Radiation Absorbed Dose): The unit of absorbed radiation, corresponding to 0.01 joules of energy per kg of material.

Rem (Roentgen equivalent man): A unit of measure for the dose of ionizing radiation that gives the same biological effect as one rad of 250 kvp X-rays; it is the product of the dose in rads and a quality factor that depends on the nature of the radiation. Alpha particles and neutrons have factors of 10, whereas beta particles and gamma radiation are weighted as 1. Hence 1 rad of gamma radiation = 1 rem; but 1 rad of alpha particles = 10 rem.

Man-rem/MW(e)y: A unit used on page 26 to describe the exposure of 1 person to 1 rem of radiation per megawatt of electric power generated for 1 year.

ACRONYMS

AECB: Atomic Energy Control Board

AECL: Atomic Energy of Canada Limited

CRNL: Chalk River Nuclear Laboratories

DFE: Department of Fisheries and the Environment

DRB: Defence Research Board

EMR: Department of Energy, Mines and Resources

ERDA: Energy Research and Development Administration (USA)

IAEA: International Atomic Energy Agency

IEA: International Energy Agency

NEA: Nuclear Energy Agency

NRC: National Research Council of Canada

OECD: Organization for Economic Cooperation and Development

WNRE: Whiteshell Nuclear Research Establishment

UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation.