LURAGROUP

AN ISSUE PAPER

ON THE MANAGEMENT OF NUCLEAR

FUEL WASTES

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Environmental Management Strategists

"Several technologies in particular appear to pose unprecedented issues to the public, if not to their practitioners. On close scrutiny, however, none appears to involve problems that are truly novel; rather, it is the combination of issues posed and the associated uncertainties that causes them to transcend or confound our current modes of evaluation and social choice".

Kasperson

"It is at this point that many technical and scientific people find themselves becoming increasingly frustrated, as they are barraged by what appears to them as a host of non-scientific objections. Of course, from the layperson's point of view, there is a similar frustration as engineers and technicians stubbornly discuss profound value issues in narrowly technical terms".

Colglazier et al.

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GLOSSARY OF TERMS

The terms and acronyms in this glossary are used frequently in this issue paper.

AECB:	Atomic Energy Control Board.
AECL:	Atomic Energy of Canada Limited.
Actinide:	An element heavier than uranium which is created when a uranium atom absorbs a neutron but does not fission.
Analogue:	Anything similar in character and function to something else.
Backfill:	In a disposal vault, the material used to refill remaining empty spaces after the waste packages and buffer have been emplaced; backfill typically consists of a mixture of clay, sand and perhaps gravel and crushed rock.
Biosphere:	The life zone of the earth, including the land surface, the plants and animals, the regions below the land surface to the limit of biological activity, the lower part of the atmosphere, and surface water bodies and their bottom sediments. It includes the human habitat or environment in the widest sense.
Buffer:	A barrier surrounding the waste containers in a disposal vault, consisting of highly absorbent material intended to retard the movement of water, the rates of container corrosion and fuel dissolution, and radionuclide migration.
CANDU:	CANada Deuterium Uranium. A Canadian designed reactor which currently uses natural uranium fuel.
Disposal:	Emplacement of waste materials in a vault, or at a given location, with no intention of retrieval.
Disposal vault:	Underground chamber for the disposal of nuclear fuel wastes.

Fission:	The splitting of an atomic nucleus into two approximately equal parts with the release of a large amount of energy; may be spontaneous or can be induced by neutrons hitting the nucleus.
Fission product:	A nuclide produced either directly by nuclear fission or by the subsequent radioactive decay of a radionuclide produced by fission.
Fuel bundle:	A grouping of metal tubes containing uranium fuel in the form of pellets.
Fuel recycle wastes:	Wastes resulting from fuel reprocessing.
Geological transport:	The movement of radioactive or other material through the geosphere. The most common mechanism is the movement of material dissolved in groundwater through fractures in the surrounding geology.
Geosphere:	The solid outer portion of the earth's crust.
Half-life, radioactive:	The time in which half of the atoms of a given element decay.
Hydraulic:	Operated by the movement and pressure of liquid.
IAEA:	International Atomic Energy Agency.
Immobilization/packaging:	Treatment of radioactive waste to convert it to a form that reduces the potential for migration or dispersion of radionuclides during storage, transportation and disposal.
Intrusive igneous rock:	Rock formed by the solidification of molten material which has forced itself into an existing rock formation. This rock type is typical in the Canadian Shield.
Model:	In computer science or applied mathematics, an analytical or mathematical representation or quantification of a real system and the ways that phenomena occur within the system.
Modelling:	In computer science, the establishment or application of a model to understand a physical, biological or geological system to which it is analogous in some way.

Nuclear fuel wastes:	Used fuel bundles from a nuclear reactor as well as fuel recycle wastes.
Permeability:	The capacity of a rock, for example, to transmit water or other fluid.
Quality Assurance:	Systematic actions necessary to provide adequate confidence that an item, facility or person will perform satisfactorily in service.
Radiation:	The emission of very fast atomic particles or rays by nuclei. Some elements are naturally radioactive, while others become radioactive after bombardment with neutrons or other particles. The four major forms of radiation are alpha and beta particles, neutrons and gamma rays.
Radionuclide:	A radioactive chemical element.
Recycling:	The re-use of fissionable materials from used fuel bundles in new reactor fuel after it has been recovered by chemical processing.
Simulation:	In general terms, mimicking some aspect or all of the behaviour of one system with a different system.
Storage:	Emplacement of waste materials in a facility with the intent of retrieving it at a later time.
SYVAC:	SYstems Variability Analysis Code. A family of computer programs written by AECL that perform calculations on the long-term performance of disposal systems.
Used fuel bundle:	A fuel bundle that has been removed from a nuclear reactor.

CHAPTER ONE

SETTING THE STAGE

1.0 INTRODUCTION

Of the many technological advancements made during the twentieth century, few have evoked such widespread and intense debate as has the technology associated with nuclear fission and particularly its use for energy. One of the major factors contributing to public concern over nuclear energy is that there is at present no proven method for managing used fuel from nuclear reactors over the long-term. It has been said that making decisions pertaining to the management of these highly radioactive nuclear fuel wastes is one of the greatest challenges facing society today. Clearly, there are no easy answers. There are as many approaches to managing nuclear fuel wastes as there are countries which use nuclear energy. As noted by the World Commission on Environmental Development in 1987:

> "Civil nuclear energy programmes world-wide have already generated many thousands of tons of spent fuel and high-level waste. Many governments have embarked on large-scale programmes to develop ways of isolating these from the biosphere for the many hundreds of thousands of years that they will remain hazardously radioactive.

> But the problem of nuclear waste disposal remains unsolved. Nuclear waste technology has reached an advanced level of sophistication. This technology has not however been fully tested or utilized and problems remain about disposal."

In Canada, as elsewhere in the world, nuclear power plants have created a significant quantity of nuclear fuel wastes. There is, however, no broad consensus in Canada on how these wastes should be managed over the long-term. Under the direction of the government of Canada, Atomic Energy of Canada Limited (AECL), following a decade of research, has proposed a concept which involves disposal of nuclear fuel wastes 400 metres or deeper in the intrusive igneous rock of the Canadian Shield. Because these wastes pose health hazards to man and have the potential of causing damage to the environment for thousands of years, any management technique must be subject to the most rigorous review and full public scrutiny. The disposal concept proposed by AECL is, therefore, to be reviewed under the federal Environmental Assessment and Review Process (EARP).

1.1 BASIC CONCEPTS OF RADIOACTIVITY

One of the most difficult aspects of deciding how to manage nuclear fuel wastes stems from the fact that these wastes are highly radioactive. The radiation released cannot be seen, felt or smelled. However, human, animal or plant cells exposed to radiation can be damaged or killed. Exposure to radiation can cause injury to humans or animals and can result in changes to offsprings, through genetic mutations. It is therefore very important to ensure that nuclear fuel wastes are not allowed to contaminate the environment.

Radioactivity is not a simple phenomenon. It is the property inherent in certain atoms by which the nucleus of an atom spontaneously decays to produce new atomic structures while releasing radiation. Nuclear fuel wastes are made up of a mixture of radioactive elements which decay at different rates. These rates are expressed in terms of a radioactive element's half-life. The half-life is the time in which half of the atoms of a given element

decay. The length of time an element is radioactive depends on how rapidly it decays. Plutonium^{239}, for instance, has a half-life of 24,390 years, which means that it will give off radiation for tens of thousands of years because after almost 25,000 years one half of the atoms will still be emitting radioactivity. Iodine^{131}, on the other hand, has a half-life of eight days, so that after a year or so only a trace of the substance would remain.

1.2 NUCLEAR FUEL WASTES: THE NATURE OF THE PROBLEM

Nuclear fuel wastes consist of the used fuel bundles taken from the reactors or the wastes that would be left over if the used fuel bundles were recycled. The recycling of used fuel bundles would be initiated to extract fissionable material for use again in the reactor fuel. The steps leading to the production of these wastes are as follows.

Uranium fuel is fabricated from refined uranium dioxide by Canadian manufacturers who press and sinter it into fuel pellets which are sealed inside metal (zirconium alloy) tubes. Many tubes are grouped together to make a fuel bundle and several thousand of these bundles are used as fuel to power a CANDU (CANada Deuterium Uranium) nuclear reactor.

During the operation of the reactor, the nuclei of some of the uranium^{235} atoms contained in the fuel pellets absorb neutrons and split apart (fission), releasing large amounts of energy. This fissioning process produces heat and radiation and releases other neutrons which cause fission in more uranium atoms in a chain reaction. The heat produced by this continuous fission process is used to turn water into steam, which in turn is used to generate electricity.

During its time in the reactor, new radioactive elements called fission products and actinides are created in the fuel bundle. Actinides are elements heavier than uranium which are created when a uranium atom absorbs a neutron but fission does not occur. The most prevalent actinide created is plutonium^{239}, a fissionable element that also produces energy in the reactor and has potential as a future reactor fuel. Fission products, on the other hand, act as a brake on the chain reaction by absorbing neutrons and keeping them from producing fission in uranium atoms. When too many fission products build up in a fuel bundle -- after about a year and a half -- it becomes inefficient. After about 18 months, about 70 percent of the uranium^{235} in the fuel bundle is used up, and the fuel bundle must be replaced with a new one containing a fresh supply of uranium. These used fuel bundles look the same as the unused fuel bundles, but are highly radioactive, give off considerable amounts of heat, and are called "nuclear fuel wastes".

The radioactivity of the used fuel bundle is caused by the remaining uranium^{235} as well as new unstable atoms in the fuel. As these atoms decay the level of radioactivity decreases. Nuclear fuel wastes are 100 times less radioactive after one year and 1000 times less radioactive after ten years. The majority of fission products in the used fuel have short half-lives and will decay to stable forms within 500 years. After that, actinides with much longer half-lives are responsible for most of the remaining radioactivity.

Each decay also releases energy so that the used fuel bundle produces heat -- some 2000 watts the day after it leaves the reactor. This decreases rapidly to about 60 watts (the heat from an ordinary light bulb) after one year.

1.3 MANAGEMENT OF NUCLEAR FUEL WASTES TODAY

Since 1965, Canadian built CANDU reactors have been providing heat through the nuclear fission process in order to generate steam needed to run turbines for producing electricity. For reasons of simplicity, the electricity produced by using nuclear reactors is called nuclear energy. In 1986, nuclear energy provided 15% of Canada's electrical requirements. To date, the resultant nuclear fuel wastes have been placed in storage at the point of generation until a satisfactory solution to their long-term management is developed. Storage can be defined as the "confining of material with the intention of recovering it." By the end of 1987, some 12,400 metric tonnes of nuclear fuel wastes were in storage at

Canadian nuclear power plants. This amount would cover an ice hockey rink to a depth of approximately one metre. By the year 2,000, there will be 42,000 tonnes in storage.

As stated earlier, when removed from the nuclear reactor the used fuel bundles are highly radioactive and cannot be handled directly by human beings. As such, they are removed by remote control from Canadian nuclear power reactors and are stored in deep water-filled pools. Once under water, these fuel bundles are placed in storage baskets within a stacking frame or cage which is designed so that the water can circulate around the used fuel bundles.

Used nuclear fuel emits gamma rays and alpha and beta particles. Since the stored fuel bundles remain intact and isolated from the environment, radioactive materials emitting alpha and beta particles are shielded from man. Penetrating gamma radiation is blocked by about 4 metres of water over the fuel stacks.

After the used fuel bundles have been stored in water for five years, they no longer require as much cooling and can be transferred to dry storage. Thick-walled concrete above-ground storage canisters have been developed for this purpose. The one-metre thick concrete walls provide shielding against penetrating radiation. Whether it be wet -- the main form of storage -- or dry storage, with suitable maintenance used fuel bundles can be stored for very long periods of time -- at least 50 years.

In Canada, the activities relating to nuclear fuel waste management are subject to regulatory control, which is administered by the Atomic Energy Control Board (AECB). The AECB is a federal crown corporation which was created following the adoption of the Atomic Energy Control Act (1946) to control and supervise the development, application and use of nuclear energy. In its regulatory role, the AECB is responsible for setting safety standards, issuing licenses and monitoring nuclear power generating stations and waste management facilities.

electricity generation as a contribution to Canada's future energy, and the increasing public concern regarding the overall safety of nuclear power.

A landmark contribution toward developing such a policy was the establishment in April 1977 by the Department of Energy, Mines and Resources of a study group whose terms of reference 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 prepared by the study group, chaired by F.K. Hare, described the alternative options open to Canada for disposal of nuclear fuel wastes, examined public concerns regarding the management of nuclear fuel wastes, and recommended appropriate research options which Canada should pursue. The study concluded that a national plan for managing and disposing of nuclear fuel wastes was timely, and that such wastes could not be allowed to accumulate indefinitely in storage. Of the various disposal options considered, the study team considered that underground disposal in igneous rock was the most promising research option for Canada, with salt as the second alternative.

In June of 1978, the governments of Canada and Ontario announced a program to determine whether radioactive wastes from nuclear power reactors could be permanently disposed of in a deep underground vault in a stable rock formation. The program was to test whether burial of both used fuel bundles and recycled wastes in a specially constructed facility deep in the intrusive igneous rock of the Canadian Shield could isolate the wastes from the environment until they were harmless. This program was to be undertaken by AECL, the federal crown corporation responsible for developing nuclear technology. At the same time, Ontario Hydro was given the responsibility of researching the best methods for interim storage and transportation of nuclear fuel wastes.

AECL's initial program of geological research was perceived by many members of the public as being a site selection process, rather than a program to evaluate the technology. Many communities in the Canadian Shield portion of Ontario opposed AECL's testing program, fearing that if they participated in the program, they would end up with the nuclear fuel wastes being disposed in their backyard. The subsequent delays in geological research due to public opposition prompted a re-statement of the government's research and development plans for nuclear fuel wastes. This came in August of 1981, when the governments of Canada and Ontario reaffirmed their commitment to a long-term management program for nuclear fuel wastes. The August 1981 announcement stated that no site selection for a permanent disposal facility would be started until the concept of geological disposal had undergone extensive research and a full regulatory and public review, and had been accepted as safe, secure and desirable by both governments.

1.6 THE ENVIRONMENTAL ASSESSMENT AND REVIEW PROCESS

In September of 1988, following ten years of research into the deep geological disposal option, AECL was ready for a public review of the disposal concept. The Minister then responsible for Energy, Mines and Resources, the Honourable Marcel Masse, requested that the Minister of the Environment initiate the federal Environmental Assessment and Review Process (EARP) to review AECL's deep disposal concept. In his request for a review, the Minister wrote:

> "The long-term management of nuclear fuel wastes raises issues of great concern to Canadians, including very basic questions of health and safety. This review will provide an opportunity for full public discussion of these issues. It will be one of the most important environmental assessments ever undertaken in this country and will provide an essential foundation for future decisions on energy policy.
>
> I believe that the review of the safety and environmental impacts of the disposal concept must take place in the context of a broad public review of the issues of public concern and with full awareness of a range of approaches to long-term management of nuclear fuel wastes. These should include the programs of other leading

countries in this field, different geological media, and different plans and schedules for the siting and construction of nuclear waste-management facilities."

A federal Environmental Assessment Panel is to examine the broad range of issues that the disposal concept raises. The Panel will allow for public input and participation in the Review throughout the country and especially in the provinces of Ontario, Quebec and New Brunswick, where nuclear fuel wastes are now being produced and stored. Because the scientific and technical material in this review will be complex, a Scientific Review Group of independent experts will be established by the Panel to undertake an indepth review of AECL's proposed concept and also provide technical advice and input to the Panel if and when required.

ISSUES ADDRESSED BY THE REVIEW

It is expected that the federal Environmental Assessment and Review Process will include an examination of such issues as:

* criteria for determining safety and acceptability;
* criteria for managing nuclear wastes, as compared to non-nuclear wastes;
* approaches to the long-term management of nuclear fuel wastes;
* what burden the concept should place on future generations;
* social, economic, environmental implications;
* the experience and approaches of other countries to the problem of nuclear fuel wastes;
* recycling or other processes to reduce the volume of waste;
* recommended process and criteria for siting a long-term nuclear fuel waste disposal facility;
* future steps to be taken with respect to nuclear fuel wastes in Canada; and
* transportation of nuclear fuel wastes.

ISSUES NOT ADDRESSED BY THE REVIEW

Because no site selection will occur until a disposal concept has been accepted, the Panel will not consider specific sites for nuclear fuel wastes disposal facilities. The Panel will also not address the energy policies of Canada and the provinces; the role of nuclear energy within these policies; whether or not fuel reprocessing should be undertaken; and military applications of nuclear technology.

CHAPTER TWO
ISSUES RELATING TO PROCESS

2.0 INTRODUCTION

In countries which use nuclear reactors to generate a portion of their energy supply, the way in which nuclear fuel wastes are managed depends largely on policy decisions made by governments and their agencies as well as a regulatory framework adopted by each country. The process by which decisions concerning nuclear wastes are made is often very complex and varies from country to country. Such processes may differ in terms of: who is involved in the process, who makes decisions, the timing and scope of the process, the degree of information-sharing, and the availability of resources to implement the decisions and other factors. The way in which decisions about nuclear fuel wastes are made in Sweden, for example, is different than in the United States.

Process issues in the debate on the management of nuclear fuel wastes relate to the ways and means by which the international nuclear community reached the conclusion that geological disposal was an appropriate option for long-term management. Included in this search for an appropriate option is the assertion that something must be done other than what is currently being done with nuclear fuel wastes.

In Great Britain, for example, nuclear fuel wastes first became fully established as a policy problem in 1976, when the Royal Commission on Environmental Pollution pronounced that:

> "...there should be no commitment to a large programme of nuclear fission power until it has been demonstrated beyond reasonable doubt that a method exists to ensure the safe containment of long-lived highly radioactive wastes for the indefinite future."

By alluding to the inappropriateness of current practices for the indefinite future, the search for other options was initiated. Geological disposal is the "something other" which has been recommended by the international nuclear community for the management of nuclear fuel wastes for the indefinite future.

Public confidence in and support of the process by which this recommendation for geological disposal was arrived at is crucial for attaining public support for any recommendation to proceed with a project or program.

In Canada, both federal and provincial governments have played lead roles in the management of fuel waste from CANDU reactors since the beginning of the nuclear industry in this country. Prior to 1978, most federal government initiatives relating to nuclear fuel wastes were conceived and implemented by Atomic Energy of Canada Limited, the federal crown corporation in charge of nuclear research and development and/or the Atomic Energy Control Board, the federal nuclear regulatory agency. Provincial initiatives were generally conceived and carried out by the provincial utilities operating nuclear power generating plants in Ontario, Quebec and New Brunswick.

However, in 1978, the governments of Canada and Ontario decided to adopt a co-operative approach in the management of nuclear fuel wastes. At that time, the two governments issued a joint announcement directing AECL to co-ordinate and administer a research and development program on the immobilization and disposal of nuclear fuel wastes. Specifically, AECL was asked to assess whether permanent disposal of the waste in a deep, underground repository in intrusive igneous rock is a safe, secure and desirable method of managing nuclear fuel wastes. This government directive was based on recommendations forwarded by a study group chaired by Dr. Kenneth Hare, as well as results of earlier research by AECL. Since 1978, AECL has been conducting detailed research on the suitability of burying nuclear fuel wastes in vaults deep within the igneous rock formations of the Canadian Shield portion of Canada. An evaluation of this work is an essential component of the review to be conducted under the federal Environment Assessment and Review Process.

With any such review, a wide variety of issues or questions can be expected to arise. The issues or questions generally related to process range from the need and viability of the proposed activity, project or concept to the social setting in which the need was established and viability assessed. The following sections look at some of the major related issues and questions in the context of the management of nuclear fuel wastes. The Canadian experience is used as an example to illustrate the kinds of issues which may arise in the process of managing nuclear fuel wastes.

2.1 ESTABLISHING THE NEED TO DEVELOP A LONG-TERM PROGRAM

Obviously the implementation of any concept for the management and/or disposal of nuclear fuel wastes will have environmental impacts -- both positive and negative. A fundamental question with respect to reviewing any such process is the establishment of need for the undertaking.

* Has the need to initiate the undertaking or course of action been clearly demonstrated?

* Is it necessary to develop an alternative waste management strategy which differs from the current approach of storing nuclear waste at reactor sites?

* On what basis was it decided that Canada should pursue the concept of disposal of nuclear fuel wastes?

2.2 FAIRNESS OF THE PROCESS

The concept of fairness is extremely important in assuring public acceptability of any decision-making process, particularly in a setting where democratic principles are prevalent. In the case of the management of nuclear fuel wastes, it is necessary to consider both current and future interests when considering the question of fairness. This is because nuclear wastes remain extremely radioactive for many years and as a result, decisions made today will have serious implications for future generations.

Fairness to Current Interests

* How will collective consent be obtained on how to manage nuclear fuel wastes? Is this process acceptable to those who must bear the consequences?

* Are the goals and objectives of the process clearly stated and defined?

* Who is involved in the process? Are all interests adequately represented?

* What are the respective roles and responsibilities of government bodies, the nuclear industry, and the public?

* How and when does public consultation occur and how will public input be taken into account?

* Is sufficient funding provided to enable those involved to participate effectively?

Fairness to Future Generations

* What responsibility does the current generation have to future generations in selecting a method for managing nuclear fuel wastes?

* Should an alternative which strives to minimize or eliminate management obligations for future generations -- such as burying waste in a sealed vault -- take precedence over an approach which may require more diligent management on the part of future generations -- such as the current method of storing waste at reactor sites -- but which would allow these generations more flexibility in responding to potential problems?

* Should we commit ourselves now to a permanent management option based on current technology when the possibility exists that a more desirable method of managing nuclear fuel wastes may be developed in the future?

2.3 CAPABILITY/CREDIBILITY/ACCOUNTABILITY OF PARTICIPANTS

The perceived capability, credibility and accountability of participants in the process are equally important variables which may give rise to a number of issues and questions.

* Is the existing social institutional framework for managing nuclear fuel wastes capable of dealing adequately with issues and problems having a time span of several thousand years?

* How important is the idea of agency, organization and individual credibility in the whole area of the management of nuclear fuel wastes? How is this credibility demonstrated?

* What are the relationships between the proponents and the regulatory bodies and how is accountability illustrated?

2.4 OPENNESS OF THE DECISION-MAKING PROCESS

The degree of openness in a decision-making process has a direct bearing on the success of that process.

* Is all pertinent information on the undertaking available to the public?

* To what extent is information shared among the participants in the process?

* Are those involved given adequate opportunity to comment upon the submissions of other participants in the process?

* Is there adequate opportunity for public scrutiny of proposals and decisions arising from the process?

2.5 ALTERNATIVES TO GEOLOGIC DISPOSAL

An examination of the alternatives to the proposed undertaking assists in evaluating the relative strengths and weaknesses of the proposal itself.

* What management and disposal alternatives were considered for nuclear fuel wastes?

* How do other approaches compare to deep geological disposal?

* How were these alternatives evaluated? On what basis were they rejected?

* Is it appropriate to rule out alternative disposal or management options on the basis of current knowledge and technical expertise?

CHAPTER THREE
DISPOSAL TECHNOLOGY ISSUES

3.0 INTRODUCTION

Pursuing the disposal option raises a number of scientific and technological issues. These issues have been raised from both radiological and non-radiological perspectives. In essence, the technology for the disposal of nuclear fuel wastes involves three broad areas of research and development:

1) the design and construction of the transportation cask;
2) the preparation or packaging of the nuclear fuel wastes for disposal; and
3) the design, construction and operation of the disposal vault.

3.1 UNDERSTANDING THE DEBATE

In addition to the very real scientific and technological challenges of a new and untried system, the evidence put forward to address these challenges is interpreted differently based on one's prevailing view of the nature of science.

One view assumes that:

* science is driven mainly by evidence (facts, data) which can clearly be distinguished from theories;
* science produces answers and reduces uncertainties;
* consensus is normal and desirable in science;
* peer review and other self-regulatory mechanisms are adequate for ensuring quality in research; and
* scientific knowledge is established on a relatively short time scale (e.g. fast enough to demonstrate, in time for the disposal facility to open on schedule, "reasonable assurance" that the facility will meet the regulatory criteria).

An alternative view of science maintains that:

* science is primarily driven by theory and assumptions which also affect the selection, nature and interpretation of evidence (facts, data);
* research generates as many questions as answers (so that we should expect significant surprises in research results on geological disposal);
* consensus may be a sign of hasty thinking (and pluralism of theories, research programs and methods is normal and desirable);
* peer review is prone to scientific orthodoxy and political manipulation; and
* science proceeds more slowly than the disposal programs appear to assume.

These contrasting views of science affect one's views pertaining to the real significance of scientific and engineering achievements and the resultant uncertainties as well as the time needed to resolve these uncertainties. Supporting evidence such as theories, experimental and analytical tools, regulations and human factors are therefore discussed and evaluated accordingly. Indeed, the controversies over disposal evidence reveal a great deal of confusion as to the meaning of phrases like "technically credible", "resolve uncertainties", "verify or validate a theory or model", "technically sound", "technically flawed", "reasonable assurance", etc. This confusion appears to add to further disagreement as to the relative

roles of "objective" and "judgmental or evaluational" factors in science.

3.2 TRANSPORTATION CASK ISSUES

Proceeding with the geological disposal option necessitates the transportation of nuclear fuel wastes from the reactors to final disposal site(s). Several issues have been raised relating to transportation cask technology ranging from quality assurances to cask integrity to the design of tests for assessing transportation cask performance.

3.2.1 Quality Assurance

While performance requirements for a transportation cask can be established on the basis of stated needs, the quality of the workmanship that goes into developing the cask can create problems. These problems can result from either human factors or manufacturing process deficiencies.

* Can quality assurance be obtained?

* How can this assurance be obtained?

3.2.2 Cask Integrity

Prior to licensing a transportation cask, a cask must comply with international standards established by the International Atomic Energy Agency (IAEA). The main licence requirement is that the cask be capable of containing the contents after a series of tests designed to simulate severe accident conditions. These include a nine-metre drop onto a hard, unyielding, flat surface; a one-metre drop onto a solid steel spike 15 cm in diameter and 20 cm long; exposure to a temperature of 800 ^{0}C (from a petroleum fire) for at least 30 minutes; and immersion in 15 metres of water for eight hours.

* In view of the issues raised in Section 3.2.3, is there too much reliance on the soundness or integrity of the transportation cask?

3.2.3 Testing Transportation Cask Performance

Concerns have been raised about the representativeness of the transportation cask tests, the way in which the tests are conducted and the appropriateness of scale model tests/computer simulations to real world conditions. Relating to the crush test, for example, especially in train transport, the crush forces can exceed considerably those simulated in a nine-metre vertical drop onto a hard, unyielding, flat surface. Also, while temperatures from a petroleum fire reach 800 ^{0}C, temperatures from the burning of butane, ethene, ethyl acetate, liquid natural gas and propane -- to mention a few -- burn with flame temperatures greater than 1750 ^{0}C.

* Are the standards set by IAEA for cask performance adequate to protect human health and the environment?

The way in which tests are conducted has also raised concerns. For example, in the Sandia Laboratories tests in Arizona, U.S.A, the transportation cask "tie-down" devices rigidly hold the cask to the truck trailer bed so that the latter would absorb a portion of the shock from a crash. (In the Sandia tests the truck hit an immovable wall at 95-130 km per/hr but because of the rigid "tie-down" devices the cask itself hit the wall at about 50 km per/hr.). If, for whatever reasons -- human, equipment malfunction -- the "tie-down" devices were not rigid, these devices could snap, causing the cask to impact at much higher speeds.

* Are the protocols for testing transportation casks stringent enough to protect against human error or equipment malfunction?

* Can scale model tests and computer simulations replace actual tests in providing accurate results?

* Can scale model tests and computer simulations provide an acceptable level of confidence in the projected outcome?

3.3 PACKAGING NUCLEAR FUEL WASTES

Packaging (also referred to as immobilization) of the wastes acts as an initial barrier to the migration of radionuclides into the environment. A number of combined engineered barriers are envisaged as forming the packaging technology:

* a solid, highly insoluble waste form;
* a waste canister constructed of corrosion-resistant materials; and
* an overpack, which can be another canister, or a buffer/backfill material that would ultimately separate the waste in a vault from the geological formation.

The effectiveness of the packaging as a barrier depends on its own physical and chemical properties, on the effects of heat and radiation from the waste, the chemical composition of the waste and on the properties of the geological medium (granite, clay, volcanic tuff, salt, etc.) including flow of groundwater and its chemical composition.

Since the most likely means for radioactive material to reach the surface is for it to be dissolved and carried by groundwater, four broad time-related areas of concern exist:

* the time before the waste is exposed to water;
* the time it takes for waste in various forms to dissolve in water;
* characteristic times for processes that change a waste form, causing, for example, the breaching of a canister or the crumbling of the solid waste form; and

* the effects of failures in quality control.
* What are the guarantees, if any, in these time-related packaging issues?

3.3.1 Insoluble Waste Form

In terms of used fuel bundles, the waste form is a highly insoluble solid encased in a corrosion resistant (zirconium) alloy. To package the liquid radioactive waste arising from recycling, ceramics or glasses are being considered.

The appropriateness of glass for packaging is often supported with reference to either Egyptian glasses produced more than 3,000 years ago (1400 B.C.) and Roman glass produced 2,000 years ago (75 A.D.) which have survived the ravages of time. They have survived despite their creation for decorative rather than for durable purposes.

Today, for example, a variety of nonradioactive glass and glass-ceramic waste-form samples have been prepared by such countries as Canada, U.S.A., Germany, France, Belgium, Japan and Italy. A number of these samples have been emplaced for testing purposes in the Waste Isolation Pilot Project (WIPP), in New Mexico. A similar experiment was initiated in 1957 at Chalk River Nuclear Laboratories in Ontario.

* What are the advantages and disadvantages of materials available for making the nuclear fuel wastes insoluble?

3.3.2 Waste Canister

For packaging nuclear fuel wastes, the favoured idea is to place the material into metal containers (titanium, nickel-based alloys, stainless steel, copper etc.) along with some filling material (concrete, glass beads etc.). The metal selected will be corrosion-resistant. For example, early in the Canadian research program stainless steel was ruled out as a candidate canister material because of the field research discovery that groundwater within the Canadian Shield was highly saline.

* Is there a potential for changes in groundwater chemistry over time which could impair the corrosion resistance of the waste canister?

3.3.3 Buffer/Backfill

A final engineered barrier as part of the packaging technology would be the emplacement of buffer and backfill material in the vault to separate the waste form from the geological formation. Materials such as bentonite or other low-permeability clay-based materials are being considered for this role.

* How important are the emplacement procedures for buffer and backfill material relative to their selection because of low permeability?

3.4 DISPOSAL

The proposed use of a mined geological repository for the disposal of nuclear fuel wastes is based largely on the long-term stability of geological systems. Advocates of the geological disposal option often cite the Oklo phenomenon as an appropriate example. In the Oklo phenomenon, a nuclear "reactor" was created naturally in a rich uranium deposit in West Africa. When the site was discovered in 1972, it was found that the plutonium and most other long-lived radionuclides that were formed had stayed near their point of origin for nearly 2 billion years. In fact, the plutonium had not left the grains of uraninite ore in which it was formed.

3.4.1 Geological Formations

A number of geological formations are being considered for a mined repository for the disposal of nuclear fuel wastes. Intrusive igneous rocks such as granite and basalt are being considered in Sweden and Canada for example, salt formations are under intensive study in West Germany, while clays and/or shales are being considered in countries such as Belgium and Italy. Each country is focusing its financial resources and research efforts on the geological formations most common in their country. Bi-lateral, multi-lateral and international co-operative agreements are used as means of obtaining information on research programs in other geological formations. The properties of each geological formation -- its advantages and disadvantages -- vary. These variations range from permeability to resistance to radiation damage to thermal conductivity properties.

* Is igneous rock appropriate for the geological disposal of nuclear fuel wastes?

* How does igneous rock compare to other geological formations as to its suitability for the disposal of nuclear fuel wastes?

* How was salt ruled out as an option for geological disposal?

3.4.2 Geological Transport

Except for human intrusion, the most likely route for nuclear fuel wastes to reach the surface is via groundwater. Dramatic events such as earthquakes, volcanoes, meteorites and glaciations are also considerations relating to geologic transport, but these are events much more likely to change the hydrogeologic characterisation of a site than to directly bring radioactive material to the surface.

The conditions that determine the time it takes groundwater to transport material from the repository to the surface are very complicated. Variables that affect groundwater transport to the surface relate to the hydraulic conductivity of the host geological formations, the chemical and thermal properties of the rock and groundwater, the depth and lateral extent of groundwater basin, and the existence of pathways (faults) that provide potential outlets to the surface.

Because of this complexity, exact estimates of transport time have to be site specific.

Alternatively, research could define the desirable characteristics of a site that would guide the selection of a repository. Such a definition will help determine a typical favourable estimate of transport time.

* Having done this, one then can ask what is the effect of having one unfavourable characteristic, such as a nearly vertical fault?

The existence of unfavourable characteristics is not the only factor that contributes to the reduction of the time it would take to transport radioactive material to the surface. A variety of geological phenomena can change most of the variables within the times for which the nuclear fuel wastes are a hazard. Seismic or volcanic activity can produce faults, for example, and erosion can change the geometry and hydraulic potential of the groundwater basin.

* How confident can we be that unplanned geologic activity will not alter transport times in a geological nuclear waste disposal site?

The level of knowledge about groundwater movements in general varies depending upon the geological formation being considered. In some geological formations, water movements are well established. For example, the very existence of a salt bed indicates that large flows of water through the salt has not occurred or the salt would have been dissolved. In others, such as granite, very little was known in the earlier stages of the research programs, hence the need for extensive field research and regional groundwater flow studies.

* How much confidence do we have in the prediction of groundwater movement in granitic rock?

The possible introduction of radionuclides into the groundwater raises further questions relating to transport times from a vault. Questions such as these, and others, are largely the reasons behind the construction and/or development of large underground research laboratories. Examples of international facilities are at Stripa, Sweden; Canada's

Underground Research Laboratory in Manitoba and the Grimsel Rock Laboratory, Switzerland.

* Are we confident in the results of the tests being conducted in these underground research laboratories?

Unwitting human intrusion into a sealed waste repository is to be guarded against by locating repositories in areas with no valuable resources and locating then at substantial depths.

* Should these sites be marked for identification purposes, and if so, how?

3.4.3 <u>The Biosphere</u>

How any dissolved radioactive material reaching the surface would be diluted by surface water and how much would be taken up and retained by plants and animals is also the subject of disposal research programs. Answers to these questions are then used to calculate how much of the radioactive waste might reach man through the air he breathes, food chains and water.

Issues arising from this biosphere component of the research can be divided in two broad categories. First, man is considered to be the ultimate receptor of any radioactive releases from the disposal vault.

* Should man be considered the most important recipient of any radionuclide releases?

* Should other living organisms in the environment be considered solely as buffers for man or should they be considered entities unto themselves that can be affected by radioactive releases?

Secondly, there are the issues relating to human health and resistance to levels of radiation. The existence of natural background radiation -- radiation from the sun, naturally occurring radioactive elements in the earth, etc. -- and its variations in intensity from place to place have raised issues related to human health. Additions to natural background radiation -- from X-ray machines and radioactive materials used in medicine and industry, the emissions from nuclear power plants, etc. -- further complicate issues relating to effects on man.

Generally, the controversy stems from estimates of the number of health effects induced by added increments of radiation exposure. The argument usually centres about "the linear hypothesis" -- the hypothesis that the number of radiation-induced health effects is proportional to the dose of radiation and that there is no threshold dose below which effects are not found. Agreement or disagreement with "the linear hypothesis" and thresholds are at the root of issues relating to the health effects induced by additional increments in radiation exposure from a disposal vault.

* How much confidence is there that a threshold level for radiation effects exists?

* Given the scientific debate with regard to the existence of a threshold or not for radiation effects, which model should we choose?

3.5 PREDICTING PERFORMANCE BEHAVIOUR

According to a recent publication of the Swedish Consultation Committee for Nuclear Waste Management:

> "... in order to minimize as much as possible the risk of long-term negative effects on the environment, we must seek to create systems that are closely allied to Nature itself."

Two of the underlying assumptions in the geological disposal concept are that nature (geosphere/biosphere) can provide barriers to the movement of radionuclides and that man can complement nature with the provision of engineered barriers. Accompanying this combination of natural and engineered barriers are a number of uncertainties. Because of the impossibility of demonstrating performance behaviour due to the long period of time for which the facility must function properly, there is the necessity to achieve levels of scientific confidence in the technology through other means. In order for a nuclear fuel wastes disposal program to be implemented, it will be necessary to obtain public understanding and confidence in the technology, as well.

Achieving this level of confidence requires overcoming certain hurdles:

1) the identification of all factors which could affect the overall performance of the disposal facility covering a period of at least 10,000 years (in order to satisfy regulatory criteria);

2) the identification of the many complex, time-related interactions within and between natural and man-made components of the disposal technology;

3) the measurement of both uncertainty and variability arising from inaccurate measurements or incomplete data; and

4) the development of a flexible and versatile assessment approach since the focus of the environmental review is a concept of disposal -- rather than a specific site and design.

A number of tools are being utilized throughout the international community to overcome these hurdles and achieve the aforementioned levels of confidence. Unlike the techniques mentioned earlier -- field research, laboratory research and underground research laboratories, etc. -- these tools are designed to "pull-together" information and predict performance behaviour of a conceptual disposal facility.

* How confident can we be in our predictions when there are so many hurdles?

3.5.1 <u>Models</u>

Modelling of disposal facility components -- packaging, vault, geosphere and biosphere -- is one of the initial steps in characterizing performance behaviour. Models are developed when full knowledge about a component is unavailable. Models, then, are an effort to represent reality using assumptions based on theoretical, laboratory and field test data. A model of the geosphere, for example, has been produced based on experiments with rock samples, deep-hole drilling and the excavation and operation of an underground laboratory. This model, like the others, contains mathematical descriptions of processes which could affect the performance of the disposal facility.

* Can mathematical descriptions of unknowns be used to make long-term predictions of various phenomena and resultant impacts such as groundwater movement?

3.5.2 <u>Computer Simulations</u>

The interactions between the various components of the disposal facility -- the vault, the geosphere and the biosphere -- pose a separate challenge. Computer simulations are used here to predict performance when more that one model is involved. AECL, for example, has developed SYVAC (the acronym for <u>SY</u>stems <u>V</u>ariability <u>A</u>nalysis <u>C</u>ode) a computer program for use in assessing the concept of disposal. SYVAC is designed to consider the uncertainty and variability inherent in the models being assessed and predict over a period of time the performance of the disposal system. Typically such computer simulations provide results in terms of consequences versus the frequency of their occurrence.

* In addition to a number of other possible shortcomings, how does one protect against human error in conducting computer simulations?

3.5.3 Natural Analogues

An analogue is defined as the comparing of something point by point with something similar. Natural analogues are often used to provide validation support for certain aspects of the models and data and for the overall results of the assessment of disposal. The Oklo natural analogue mentioned earlier in this chapter is a case in point, and is often referred to by proponents of geological disposal.

The Cigar Lake uranium deposit located in northern Saskatchewan is said to have features that are analogous to features of concepts being developed internationally for disposal in igneous rock formations. It is argued that an understanding of this and other natural analogues can provide useful insight into the long-term behaviour of disposal facilities.

* Are there instances where natural analogues have been used to predict behaviour of a technology, and where that technology, once applied, verified the natural analogue?

CHAPTER FOUR
IMPACTS AND IMPLEMENTATION ISSUES

4.0 INTRODUCTION

The implementation and operation of any project raises concerns about impacts. The thirty or so years of operating experience with nuclear power plants has resulted in significant amounts of nuclear fuel wastes, and subsequent concerns about the economic, social and environmental impacts of existing and potential management approaches. With any waste management approach, both positive and negative impacts must be considered. In addition, because of the radioactive character of nuclear fuel wastes, both radiological and non-radiological impacts must be addressed. Of course, when contemplating future options for managing nuclear fuel wastes, siting issues also come into play. Approaches to siting as well as identifying, assessing, and mitigating anticipated impacts are therefore very important issues which need to be addressed during any review process.

This chapter looks at impacts and issues arising from the storage, disposal, packaging/immobilization and transportation of nuclear fuel wastes. Following this, brief discussions on impact measurement, impact mitigation, and siting are presented.

4.1 STORAGE

Storage of nuclear fuel wastes refers to a management technique which involves accumulating wastes in wet or dry facilities with the intention of recovering them. This approach is used in all countries which have nuclear power programs.

4.1.1 Current Practice

In Canada, used nuclear fuel is currently stored in water-filled pools at reactor sites. After several years, some of the used fuel is transferred to above-ground dry storage facilities. With suitable maintenance, used fuel bundles can be stored in either wet or dry storage for very long periods of time.

As the amount of used nuclear fuel requiring storage increases over time, two main storage options are available:

* the on-site facilities at nuclear reactors can be expanded; or
* the used nuclear fuel can be transported from a number of reactor sites to a centralized storage facility.

The latter approach is being used in Sweden and being considered in the United States.

4.1.2 Economic Issues

When looking at the economic implications of managing nuclear fuel wastes by storing them at a reactor site or centralized facility, a number of issues become apparent.

* Is it more economical to expand existing storage facilities or to develop a centralized storage facility?

* Should used nuclear fuel be treated as a unique waste separate from all other wastes at a reactor site?

For example, a resource economics study conducted at Cornell University in the United States of America suggests that in economic terms, keeping used fuel bundles on site over the lifetime of a nuclear reactor and then eventually "entombing" the entire site (including the reactor and used fuel storage facilities) could be cost effective in that costs of transporting the wastes to a centralized storage (or disposal) facility will not be incurred.

4.1.3 Social Issues

With any project or practice, important social issues may arise depending on the distribution of benefits and risks. The current management approach of storing nuclear fuel wastes at reactor sites carries with it certain benefits and risks. For example, residents of Pickering, Ontario enjoy economic and other benefits from hosting a nuclear power plant yet it can be argued that these same residents are at a higher level of risk in the event of an accident or other occurrence. The underlying principle here is that the beneficiaries of an activity (nuclear power generation) should bear a proportionate risk of that activity (the storage of nuclear fuel wastes). If a centralized storage facility is established, the distribution of risks and benefits would change, with the transport of the nuclear fuel wastes becoming a factor in the apportioning of benefits and risks.

Other social issues relating to storage revolve around health and safety.

* Is the storage of nuclear fuel wastes an appropriate method of management from a health and safety perspective?

* What are the implications for the general public and workers at the storage site(s)?

* What are the comparative health and safety implications of the storage of nuclear fuel wastes at reactor sites and at a centralized facility?

* Should there be different health and safety standards for members of the general public and nuclear industry workers? For example, the exposure limits for radiation for nuclear industry workers are 10 times higher than those for members of the general public in Canada.

* How should the health effects of storing nuclear fuel wastes be measured? Is it sufficient to monitor reactor and storage sites for routine or accidental emissions of radiation or should health studies be conducted on industry workers and residents in the vicinity of the sites?

4.1.4 Environmental Issues

The environmental impacts of storage of nuclear fuel wastes, whether at reactor sites or at a centralized facility must be considered along with economic and social impacts.

* How are environmental impacts measured? What factors should be considered in assessing environmental impacts?

* What are the environmental impacts associated with on-site storage and storage at a centralized facility?

* Should baseline or preliminary studies be conducted to assess environmental impacts prior to building a storage facility?

4.2 DISPOSAL

Disposal of nuclear fuel wastes refers to a form of management which involves isolating these wastes from the environment with no intention of recovering them. Many disposal methods have been given serious consideration by one or more of the countries which have nuclear power programs. Disposal techniques studied include: launching wastes into space; burying wastes in polar icecaps; burying wastes under the ocean floor; and placing wastes in vaults in deep geological formations. One underlying objective of the search for an appropriate disposal method is to relieve future generations of all or most management responsibilities by developing a permanent approach for managing nuclear fuel wastes.

4.2.1 Current Practice

No commercial disposal facility for used nuclear fuel wastes exists in the world today. Current consensus within the international nuclear community is that deep geological disposal in several different types of geological formations (such as granite, basalt, volcanic tuff, shale, and clay) may be an appropriate long-term method for managing nuclear fuel wastes. Many countries, including Canada, are involved in detailed research programs to assess the appropriateness of geological disposal while several nations (such as the United States) are in the early stages of actually constructing a disposal facility.

4.2.2 Economic Issues

Because an objective of disposal is to relieve future generations of management responsibilities, another dimension is added to the cost of managing nuclear fuel wastes. That is, today's beneficiaries of nuclear power will bear virtually all costs of the long-term management of nuclear fuel wastes if disposal is deemed to be the most appropriate way of dealing with these wastes. These costs are above and beyond those presently incurred with storage.

* Should the current beneficiaries of an activity be responsible for all costs (including many future costs) associated with that activity?

* Given that the additional costs of disposal are acceptable, who should pay these costs (the general public, users, etc.) and what should be the method of payment (utility bills, disposal fund, etc.)?

* Could part of the cost of disposal be covered by recycling used fuel bundles to extract the energy potential before the wastes are prepared for disposal?

* Should funds be set aside now by today's beneficiaries of nuclear power in order to rectify or mitigate the consequences of an accident or problem at a disposal facility in the future?

4.2.3 Social Issues

An underlying premise of disposal is that future generations should not be burdened by an activity for which they receive few or no benefits. As such, the decision to proceed with the disposal option has social ramifications for both the current generation charged with the responsibility for designing, constructing and operating the disposal facility and future generations who are to be relieved of management obligations.

The Current Generation

* Is the disposal of nuclear fuel wastes an appropriate way of managing the material from a health and safety perspective? What are the implications for the general public and workers at the disposal site?

* Do regions, provinces, states and countries which host nuclear power plants have an obligation to dispose of their own nuclear fuel wastes? Should one region, province, state or country accept another's nuclear fuel wastes for disposal in its facility?

* Should employment or any other factors override considerations of public health and safety in locating disposal facilities?

Future Generations

* Should a disposal concept selected by the current generation remove all management obligations from future generations or should provision be made in the design of the concept for monitoring and accessibility capabilities to allow subsequent generations to identify and respond to potential problems?

4.2.4 Environmental Issues

The actual and potential environmental impacts of any disposal concept are of considerable importance in assessing the desirability of that concept.

* What environmental impacts will result from the construction and operation of the disposal facility? How will local water supplies, biota, etc. be affected?

* Can we design and engineer barriers (eg. vaults) which will prevent the release of radioactive materials to the environment and remain effective over the long period of time which the wastes will remain hazardous to human beings and the environment?

* With geological disposal, can we predict and prepare for the possibility of the disruption of geological formations due to earthquakes or other causes which may affect the integrity of the disposal facility?

4.3 PACKAGING OF NUCLEAR FUEL WASTES

It is not necessary to package (or immobilize) used fuel bundles for storage either at reactor sites or at a centralized storage facility. This is because the used fuel bundles are already a solid, highly insoluble waste form.

In preparation for disposal, though, nuclear fuel wastes require additional packaging. Recycled wastes need to be transformed into a highly insoluble solid waste form using glasses and ceramics. As discussed in Chapter 3 both used fuel bundles and recycled wastes have two more packaging stages in preparation for disposal:

* a waste canister constructed of corrosion-resistant materials; and

* an overpack, which can be another canister, or a buffer/backfill material that would ultimately separate the waste in a vault from the geological formation.

4.3.1 Current Practice

Packaging of nuclear fuel wastes destined for eventual geological disposal is still in the research and development stage. Scientists in Canada and other countries are currently conducting studies to determine the most effective methods for ensuring that nuclear fuel wastes do not dissolve readily in groundwater.

In their June 1978 joint announcement, the governments of Canada and Ontario directed AECL to conduct immobilization research on both used fuel bundles and recycled wastes. Despite this direction, there was no suggestion made that Canada should proceed with the fuel recycling option. Other countries such as France, the United States and Switzerland have well advanced fuel recycling programs.

4.3.2 Economic Issues

One of the major issues relating to the economics of immobilization is whether or not used fuel bundles should be packaged directly for disposal or recycled first then packaged..

* Should used fuel bundles be immobilized when economic benefits may be realized by utilizing the energy remaining in used fuel bundles and recycling?

* Are the economic costs of constructing and operating recycling facilities justified by the energy saved as a result of reprocessing?

* What are the differences in costs/risks and benefits between recycling solid wastes (garbage) and nuclear fuel wastes?

Other economic concerns relate to how and where immobilization occurs.

* In economic terms, should the container metal selected depend on its availability, either geographically or cost-wise, or should the safest metal be selected regardless of its availability or cost?

* Would immobilization be more cost effective when undertaken at reactor sites, a centralized storage facility or at the ultimate disposal site(s)?

4.3.3 Social Issues

Building and operating an immobilization facility would result in social impacts.

* What are the health and safety implications of immobilization facilities for members of the general public and industry workers?

* What impacts would an immobilization facility have on day-to-day life in the host community?

* If recycling occurs before immobilization, what effects will this have on employment in the uranium mining sector which has traditionally supplied the raw materials for use in nuclear fuel bundles?

* What are the comparative health effects of immobilizing used fuel bundles and recycle wastes?

4.3.4 Environmental Issues

The nature and extent of environmental impacts resulting from packaging activities would likely vary depending on whether the operation involves used fuel bundles or the gaseous, solid and liquid wastes which are created during recycling.

* What are the environmental impacts associated with immobilizing used fuel wastes?

* What are the environmental impacts of recycling used fuel bundles and then immobilizing the wastes resulting from these procedures? For example, negative environmental impacts (such as leakage of radioactive materials into water supplies) have been experienced at immobilization facilities in the United States (West Valley, New York) and Great Britain (Sellafield), raising questions about the ability to manage the recycling wastes.

4.4 TRANSPORTATION

The transport of nuclear fuel wastes would be necessary when:

* storage is at a centralized facility;
* immobilization is at a site other than the reactor site; or when
* a disposal site(s) has been selected and developed.

In order to transport the nuclear fuel wastes, they would have to be removed from their current storage location, prepared and loaded on some sort of vehicle, shipped to a specific destination, and unloaded upon arrival at that destination.

4.4.1 Current Practice

Although not in large volumes, nuclear fuel wastes are currently being transported by various means in countries which have nuclear power programs. In Canada, for example, there have been more than 500 shipments of used fuel bundles during the past 25 years, mostly to and from research facilities. Both casks that carry two used fuel bundles and larger containers that hold about 25 bundles have been used. More recently, the Atomic Energy Control Board has licensed a prototype transportation cask which can carry 196 used fuel bundles, although its use has not gone beyond the testing stage.

* How does this prototype transportation cask compare to what is being considered in other countries?

In most countries, nuclear fuel wastes are transported by truck and this is the case in Canada. Sweden has developed a transport cask for use on trucks but currently moves its nuclear fuel wastes to a central storage facility by ship. Researchers in the United States are presently developing designs for casks which could be transported by rail or barge.

4.4.2 Economic Issues

In Canada, transportation costs relating to used nuclear fuel wastes are relatively low as the wastes are currently stored at reactor sites. Any movement away from this practice will result in a substantial increase in the transportation cost component of managing nuclear fuel wastes.

* Are the additional costs of transporting nuclear fuel wastes to a centralized storage or disposal facility justified when compared with the economic benefits of constructing and operating such a facility? For example, procuring a fleet of transport carriers, obtaining service contracts for training, security inspection and maintenance, and establishing emergency response capabilities would all involve substantial costs.

* In economic terms, which mode of transport -- road, rail, water -- would be the most cost effective means of transporting wastes?

4.4.3 Social Issues

The movement of nuclear fuel wastes implies impacts on the population at large as well as on individuals and businesses along the transportation corridors.

* What are the health and safety implications for the general public and industry workers of transporting nuclear fuel wastes?

* How will transportation routes be selected? For example, routing transportation corridors through populated versus relatively unpopulated areas raises numerous social issues in relation to the individual, family/household, community and region. These social issues include concerns about health and safety, risk of accidents, potential for property devaluation, adequacy of emergency response, and liability.

* How will shipments occur? Scheduling of shipments and whether or not convoys are utilized for these shipments have important implications for people in the areas through which nuclear fuel wastes will be transported.

4.4.4 Environmental Issues

Protecting the environment during transportation involves minimizing the number of times the nuclear fuel wastes are handled and finding the most environmentally-sound type of transport system.

* What are the actual and potential environmental impacts of transporting nuclear fuel wastes? Has provision been made for the potential occurrence of accidents with very severe consequences (i.e. planning for the "worst case scenario")?

* Would a water-based or land-based transport system pose less risk to the environment?

* In order to minimize the potential for the release of radioactive materials to the environment, should the transportation cask or container and the immobilization canister be one and the same?

4.5 IMPACT MEASUREMENT

The above discussion illustrates the economic, social and environmental impacts and many related issues associated with managing nuclear fuel wastes. The identification and categorization of these impacts and issues are difficult tasks given the complex interrelationships between the different types of impacts. Even more difficult is attempting to measure the economic, social and environmental impacts relating to the management of nuclear fuel wastes.

Various techniques and methods have been developed to measure and assess economic, social and environmental impacts. For measuring economic impacts, formal approaches such as risk-cost-benefit analysis have been widely used. Social impact assessment and environmental impact assessment methodologies have been employed to gauge social and environmental impacts. However, there is no clear consensus among the practitioners of these techniques as to what type of impacts should be assessed and how these impacts should be measured.

* What are the similarities and differences in international approaches to risk-cost-benefit analysis, social impact assessment and environmental impact assessment?

* Do the radiological implications of nuclear fuel wastes complicate the measurement and assessment of economic, social and environmental impacts?

With respect to managing nuclear fuel wastes, the measurement of economic, social and environmental impacts is further complicated by the many different viewpoints which exist in society about the relative benefits and risks associated with nuclear energy in general and with certain methods (including storage and disposal) of managing nuclear fuel wastes in particular. Much has been written about these different views of benefits and risks, with the phenomenon of risk perception receiving considerable attention. Risk perception refers to the intuitive evaluation and interpretation of risks. The way in which risks are perceived generally depends on one's past experiences and outlook on life, among other things. Different people and groups of people perceive different risks in many different ways. The perception of risk, therefore is often a personal and/or social judgement. Another complicating factor is the complex and highly specialized nature of nuclear technology and the difficulty for the general public to understand and comprehend it. As a result, assessing and measuring the anticipated impacts of a major undertaking, such as a facility for managing nuclear wastes, is for the most part a very challenging endeavour.

* What means are available for taking the perception of risk into consideration when attempting to measure impacts?

* Who should be responsible for identifying and measuring risk?

4.6 IMPACT MITIGATION

Efforts to mitigate, or lessen, the anticipated impacts of a facility for the management of nuclear fuel wastes involve equally complex issues. These are complicated by the potential length of time over which mitigation measures might be appropriate and the fact that the potential recipients of such mitigation might include several generations of residents.

In general, mitigation measures are beneficial to developers, local communities, and to society at large to the extent that they result in the more efficient, equitable, and expeditious construction of essential projects. Mitigation usually involves measures to minimize demands on local systems, to enhance the capacity of local systems, to compensate communities/individuals or to provide incentives to local interests.

A complex range of alternatives has been used to mitigate the impacts of other large-scale projects (e.g., property value protection, notification, preferential hiring, nuisance effect measures, local control of monitoring facilities), but which mitigation alternatives may be most appropriate for the selected management approach to nuclear fuel wastes is open to debate. Even more difficult is the question of who should be compensated. Although some interests should clearly be compensated (e.g., landowners, local government), other parties such as residents some distance from routes or facilities or future generations of local residents raise more perplexing questions.

* Given that there are/will be impacts in the management of nuclear fuel wastes and mitigation measures are desirable, should monitoring be part of the management approach?

* If so, what should be monitored and for what periods of time (in order to measure the effectiveness of mitigation measures including technical components of the system)?

4.7 SITING PROCESS

Many of the issues related to siting have been touched on in earlier parts of this paper. However, given the perplexing nature of facility siting including technical requirements; economic, social and environmental impacts; individual perceptions of impacts; and the various mitigation opportunities available, the process by which sites for facilities are selected becomes an issue in itself.

Assuming that a siting agency has to be established (its make-up, whether private or public, international or national, are issues in themselves), a range of three alternative siting processes exist. The issues inherent in each alternative cited here are complex and interrelated.

4.7.1 Siting Agency Initiative

Here the siting agency makes the decision on the location of facilities (e.g., storage, transport routes, disposal facility) using a combination of scientific/technical, geological, economic, social, and environmental information about the site(s), route(s) and the potential impacts of the activity upon the community.

* Is a siting process initiated from the top down the most appropriate strategy?

4.7.2 Siting by Mediation

The siting agency makes the decision as in 4.7.1 but provides the community with an intervenor or advocate to argue the community's case within the agency's decision-making framework. Presumably, the community would argue against selection, or the intervenor might be assigned specifically to argue the case for special segments within the community, such as the elderly.

4.7.3 Community-Based Siting

The siting agency invites communities to engage in an auctioning process, with mitigation or compensation being the price paid by the siting agency to obtain acceptance. In this case, all potential communities would be informed that they were eligible and they would be advised of the forms of compensation packages available. The communities would be required to present bids consisting of compensation packages that would make the facility acceptable to them. The siting agency would then select the site.

* Is a siting process initiated from the bottom up, as in the case with Canada's Siting Process Task Force on Low Level Radioactive Waste Disposal, the most appropriate strategy?

Of course, the siting process ultimately employed may involve elements from each of the alternatives outlined above.

SUGGESTED FURTHER READING

This section provides a list of additional suggested readings on issues related to the management of nuclear fuel wastes. The readings cited are generally intended for public consumption. The reading materials are accompanied by a brief summary of their content.

Acres International Limited. A Review of Various Approaches Being Undertaken by Industrialized Nations for the Management and Disposal of High-Level Nuclear Waste. Niagara Falls: A Report Prepared for the Federal Environmental Assessment Review Office, 1989.

A comprehensive report on major international research and development programs for the management and disposal of nuclear fuel wastes. Also covers international agreements for cooperation in research and development activities.

Armour, Audrey. Socially Responsive Impact Management: A Discussion Paper. Ottawa: Report to the Siting Process Task Force on Low-Level Radioactive Waste Disposal, 1987.

This discussion paper reviews a number of impact management approaches that have been and could be implemented. These measures are related to the whole issue of public resistance to the siting of unwanted facilities.

Atomic Energy Control Board. Regulatory Policy Statement. Deep Geological Disposal of Nuclear Fuel Waste: Background Information and Regulatory Requirements Regarding the Concept Assessment Phase. Ottawa: Regulatory Document R-71. January 29, 1985.

A representative regulatory document from the AECB designed to guide AECL in the assessment of the geological disposal concept for nuclear fuel wastes. While outlining the regulatory process, it highlights some of the technical and impact issues that must be addressed by a proponent.

Brisco, Bob et al. High-Level Radioactive Waste in Canada: The Eleventh Hour. Ottawa: Report of the Standing Committee on Environment and Forestry on the Storage and Disposal of High-Level Radioactive Waste, 1988.

One of several reports over the last decade or so addressing the subject matter of nuclear fuel wastes from the point of view of the process by which decisions are and should be made. The report contains several recommendations related to this process.

Brundtland, Gro Harlem et al. Our Common Future. Oxford: Oxford University Press, Report of the World Commission on Environment and Development, 1987.

A United Nations project, the report overviews a number of environmental problems including waste management in an international context. It makes recommendations to ensure that human progress will be sustained through development without bankrupting the resources of future generations.

Cobb, Charles E. Jr. "Living with Radiation". National Geographic (April 1989): 403-437.

A good general overview of the nature of radiation, history of its use and international experiences in the beneficial and hazardous applications of radiation.

Hare, F. K. et al. The Management of Canada's Nuclear Wastes. Ottawa: Report of a Study Prepared Under Contract for the Minister of Energy, Mines and Resources, 1977.

This report was commissioned to make a number of recommendations to the government on the management and disposal of nuclear fuel wastes. Many of its recommendations form the basis of AECL's research activities regarding nuclear fuel wastes.

Johnson, Harry and Marvis Tutiah. Radiation is Part of Your Life. Atomic Energy of Canada Limited: Whiteshell Nuclear Research Establishment. Pinawa, Manitoba, 1985.

A layman's guide to the different kinds of radiation, its measurement and associated risks. Brief discussion of international standards for human exposure to radiation.

Kasperson, Roger E., ed. Equity Issues in Radioactive Waste Management. Cambridge, Massachusetts: Oelgeschlager, Gunn & Hain, Publishers, Inc., 1983.

Equity relates to the concept of fairness. This collection of articles looks at equity issues from three perspectives: geographical, intergenerational and the general public versus nuclear industry employees.

Murdock, S. H. et al. Nuclear Waste: Socioeconomic Dimensions of Long-Term Storage. Boulder, Colorado: Westview Press, 1983.

This book examines the socioeconomic implications of the management of nuclear fuel wastes and the siting of a disposal facility. While several of the issues addressed in this book are nuclear-related, many are applicable to other types of large, long-term management programs and problems.