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NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

Assessing the Options

**FUTURE MANAGEMENT
OF USED NUCLEAR
FUEL IN CANADA**



NWMO Assessment Team Report

June 2004

Assessing the Options



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OF USED NUCLEAR
FUEL IN CANADA**

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Assessing the Options

FUTURE MANAGEMENT OF USED NUCLEAR FUEL IN CANADA

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Executive Summary

The Assessment Team was asked by NWMO to evaluate a set of approaches for the management of used nuclear fuel in Canada. In particular, the Team was required (1) to develop a rigorous methodology by which such an evaluation could be carried out, and (2) to perform a preliminary assessment using such a methodology on a number of specific options for managing nuclear fuel waste.

A “management approach” includes both a technical method as well as a larger management system which supports and sustains that method. Three methods have been specified for assessment in the applicable federal legislation: reactor-site extended storage, a centralized storage facility, and a deep geological repository. The assessment methodology developed here was, therefore, applied to these three methods, although the Team also took into consideration the relevance of some other proposed options to its assigned task.

The initial chapters of the Team’s report set the stage for its assessment. First, there is a recognition that any management approach for used nuclear fuel will be embedded in a larger “systemic” context, composed of the many and diverse elements within the prevailing and dynamic social, economic, and political conditions in Canada. Second, the Team took into consideration the large body of relevant technical information and experience that has been accumulated by Canada and many other countries around the world, all of which are wrestling with similar issues. Third, the Team acknowledged that certain overriding considerations were applicable to its work – for example, the existing frameworks of international law as well as the strong regulatory framework for the oversight of radioactive substances that has been developed in Canada over many years.

An assessment methodology was chosen that was capable of handling the special challenges inherent in managing used nuclear fuel: in particular, the high degree of inherent complexity in this problem; the extremely long time horizon, as well as the special types of health and environmental risks which must be taken into account; and public controversy and the inevitable uncertainties which attend any proposed solution. The many attributes of the problem itself led to the selection of a methodology known as multi-attribute utility analysis.

Using this methodology, the Team identified a set of important objectives that, in its view, an adequate management approach would be required to meet, namely: fairness; public health and safety; worker health and safety; community well-being; security; environmental integrity; economic viability; and adaptability. The selection of these objectives was, in the Team's opinion, consistent with the major requirements identified in the prior process of public consultations conducted by NWMO and summarized in the "ten questions" in the report, *Asking the Right Questions?* The Team recognized that it is unlikely that all values which Canadians consider important can be reflected in their entirety in a single set of objectives. Nor can all values be satisfied equally by a single technical method or management approach; as a result, a balancing is required involving trade-offs.

The Team then systematically assessed three management approaches against these objectives, assigning scores and weights to the expected performance of each approach against each of the eight objectives considered individually. In other words, every member of the Team was asked to estimate the degree to which each of the three approaches was likely to achieve each of the eight objectives, and then the individual responses were "rolled up" into an overall score. The resulting performance value scores are given in the report both as a range, reflecting differences in judgment among the Team members, and as an average score.

The average scores, which reflect the judgments made by the Team, indicate that the repository option is expected to perform better than either at-reactor-site or centralized storage on nearly every objective. Considering the *ranges* of the scores, rather than the average score, there is a certain degree of overlap in the results which reflects the inherent uncertainty of future possibilities. The Team encourages each reader to examine closely the detailed explanation of the results provided in its report and to reflect on the implications of the assessment framework and its results.

In view of the extended time horizon for this management challenge, the Team was aware that its judgments might be conditioned by the differing expectations about what the long-term future holds. Therefore it undertook a further analysis involving the use of a number of scenarios about the future. Under "optimistic" scenarios about the future, the differences in scoring among the three options are reduced, whereas under all "pessimistic" scenarios, the repository option consistently scores significantly better than the other two.

In summary, as a result of these deliberations:

- 1. Three management options for used nuclear fuel were assessed – extended at-reactor-site storage, centralized storage, and deep geological repository.**
- 2. All three options were assessed against eight objectives: fairness, public health and safety, worker health and safety, community well-being, security, environmental integrity, economic viability, and adaptability.**
- 3. The assessment found that each of the options has specific, and quite different, strengths and weaknesses, which are summarized in the final chapter of the report.**

- 4. The assessment also found that the deep geological repository option is expected to perform significantly better, when evaluated against the eight objectives, than the other two options, especially in the light of the long term during which any management option must perform well.**
- 5. The assessment also found that the centralized storage option was expected to perform better than the option of extended at-reactor-site storage.**
- 6. Since the process of implementation necessarily will stretch out over an extended period of time, at least many decades, it is both desirable and advantageous to consider the development of any selected approach in a staged, flexible manner. This will provide an opportunity for new learning and new experience to be brought to bear on the difficult issue of choosing an approach to the management of used nuclear fuel that will enjoy a high degree of public acceptability.**

The process by which a management approach is implemented, and the institutions and systems which are put in place, will be important determinants of the overall effectiveness of the approach and the extent to which it is and continues to be responsive to societal needs and concerns. Whatever technical method is ultimately selected for implementation, the implementation process must invite and achieve the involvement of citizens at key decision points throughout the process. It must also involve the identification and configuration of institutions and systems, likely at multiple levels of government and administration. The assessment suggests it will be necessary to ensure there is a clear and transparent path for decision making and a mechanism in place to provide assurance that commitments made will in fact be met.

Introduction

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- 1.1 Background
- 1.2 Assessing Management Approaches
- 1.3 Mandate of the Assessment Team
- 1.4 Applying a Systems Perspective and Building on Canadian Values
- 1.5 Fundamental Assumptions
- 1.6 Steps in the Assessment Process
- 1.7 Report Structure

1.1 Background

The management of used nuclear fuel in Canada has some distinctive features and challenges. Although policies for production and supply of energy, including nuclear energy generation, are the responsibility of provincial governments, the federal government has legislated responsibility for matters having to do with radioactive materials.¹ Since 1974, under this responsibility, the government has commissioned studies and issued guidelines, regulations and policies regarding nuclear power generation.

In 1984, a concept for the management of all used nuclear fuel in Canada was developed by Atomic Energy of Canada Limited (AECL) at the request of the federal and Ontario governments. This concept was subjected to a ten-year public Environmental Assessment and Review process which, in 1998, culminated in a report² known as the “Seaborn Report” after its chairman, Blair Seaborn. Among the key conclusions of the report were the following:

- “From a technical perspective, safety of the AECL concept has been on balance adequately demonstrated for a conceptual stage of development. But from a social perspective, it has not.”
- “As it stands, the AECL concept for deep geological disposal has not been demonstrated to have broad public support. The concept in its current form does not have the required level of acceptability to be adopted as Canada’s approach for managing nuclear fuel wastes.”

¹ Government of Canada, Ottawa: *Atomic Energy Control Act, 1946. Nuclear Safety and Control Act, 1997. Nuclear Energy Act, 2000.*

² Federal Environmental Assessment and Review Office, 1998. Report of the Nuclear Fuel Waste Management and Disposal Concept Environmental Assessment Panel. Ottawa.

The federal government response to the report of the Panel³ articulates a policy framework for management of radioactive waste and provided direction for federal nuclear fuel waste management policy, leading to the implementation of the *Nuclear Fuel Waste Act (NFWA)* in 2002, which put into law the requirement that the companies which produce used nuclear fuel must:

- Establish a waste management organization (nuclear waste management agency) as a separate legal entity to provide recommendations to the Government of Canada on the long-term management of used nuclear fuel.
- Establish segregated funds to finance the long-term management of used fuel.

The *Nuclear Fuel Waste Act* was enacted in November 2002 and simultaneously, the Nuclear Waste Management Organization (NWMO) was created by the joint waste producers, Ontario Power Generation, Hydro Quebec, New Brunswick Power Corporation, and Atomic Energy of Canada Ltd.⁴ The Act requires NWMO to first study the issue and provide a recommendation by November 15, 2005 to the Minister of Natural Resources Canada on a preferred management approach for Canada to adopt. The NWMO must include in its study, at a minimum, three technical methods: deep geological disposal in the Canadian Shield; storage at nuclear reactor sites; and, centralized storage, either above or below ground. Once a course of action has been decided by the federal government, NWMO will become the implementing agency.

The Nuclear Waste Management Organization (NWMO) has taken as its mission to develop collaboratively with Canadians a management approach for the long-term care of Canada's nuclear fuel that is socially acceptable, technically sound, environmentally responsible and economically feasible. In short, NWMO is seeking a management approach that safeguards people and respects the environment, now and in the future.

1.2 Assessing Management Approaches

Consistent with the Act, and building upon discussions with Canadians, NWMO interprets the concept of a management approach to consist of both a technical method and a management system.⁵ The technical method involves a technology type for example continued on-site storage or deep geological disposal, along with its detailed design. The management system includes the institutions, governance, financial arrangements, and managerial and legal frameworks designed to support the technical method through the various phases of its operating life. NWMO will weave together all of these elements in a comprehensive implementation strategy.⁶

From the beginning of its existence, NWMO has sought broad input from Canadians on the issue before it. Insight from this effort through the first year was synthesized in NWMO's first of three anticipated Discussion Documents, *Asking the Right Questions? The Future Management of Canada's Used Nuclear Fuel*. *Asking the Right Questions?* identifies ten questions that provide an initial understanding

³ Natural Resources Canada, 1998. Government of Canada Response to Recommendations of the Nuclear Fuel Waste Management and Disposal Concept Environmental Assessment Panel. Ottawa: Natural Resources Canada.

⁴ Nuclear Waste Management Organization, June 2004. "Vision, Mission and Values." <www.nwmo.ca>

⁵ NWMO, 2003. *Asking the Right Questions? The Future Management of Canada's Used Nuclear Fuel*. Available online at <http://www.nwmo.ca>. Page 20.

⁶ A preliminary implementation strategy will be released for public review in early 2005 with the full NWMO Draft Final Report.

of Canadians' concerns and priorities. In turn, these concerns and priorities have served to guide the current step in NWMO's task – the process of undertaking a comparative assessment of the alternative approaches for managing used nuclear fuel over the long term. This assessment will provide the foundation to NWMO's second discussion document, *Understanding the Choices*.

To assist NWMO in this task, a nine-person Assessment Team (Appendix 1) was convened in order to evaluate the methods mandated by the *Nuclear Fuel Waste Act*, including development and application of an appropriate assessment methodology. The valuable lessons that NWMO has been learning from its on-going engagement activities and other efforts have informed the work of the Assessment Team. This report describes the work and conclusions of the Assessment Team.

1.3 Mandate of the Assessment Team

The Assessment Team was charged with several tasks, including:

- Describing the alternative approaches for the management of Canada's used nuclear fuel.
- Developing a set of objectives for the assessment reflecting the concerns and values of Canadians.
- Developing and applying a rigorous methodology for comparing the alternative approaches for the management of Canada's used nuclear fuel.

The charge did not include the development of an ultimate recommendation, nor did it require that the economic regions figure into this part of the assessment. Rather, an emphasis was put on generating material that would contribute to the on-going dialogue with Canadians as NWMO continues its process of developing the draft recommendation that will be released to the public in early 2005.

The full Terms of Reference for the Assessment Team is found in Appendix 2.

1.4 Applying a Systems Perspective and Building on Canadian Values

From the outset, the Assessment Team took a broad view of the question of assessing options for managing used nuclear fuel, emphasizing the complex interactions of the many variables which make up the issue as a whole. In its conceptual orientation, therefore, the Team adopted an approach consistent with the Seaborn Panel's recognition of the fact that a focus on technical methods alone is not sufficient for an effective resolution of this public policy question. In accepting this fundamental premise, the Team has put a great emphasis on incorporating the social and ethical considerations which have emerged as important to Canadians.

The ten key questions in NWMO's first major discussion document, *Asking the Right Questions*, which touch upon the ethical, social, environmental, technical and economic aspects of nuclear fuel waste management, provided an important foundation for the analysis. The subsequent *Citizens' Dialogue on Canadian Values* and the NWMO's *Roundtable on Ethics* have served to enrich and re-enforce this starting point, as have other components of the NWMO engagement program and the various commissioned studies and background papers.

1.5 Fundamental Assumptions

In addition to the emphasis on social and ethical considerations as major building blocks of the evaluation, the Assessment Team accepted three fundamental assumptions as key elements underlying its work:

- Used nuclear fuel now exists and is being appropriately managed on-site at nuclear facilities; however, this is an interim solution, and an appropriate approach for the long-term management of the used fuel is needed.
- For the purpose of this assessment, the volume of used nuclear fuel which needs to be managed was assumed to be limited to the projected inventory from the existing fleet of reactors.
- A superior management approach would be one that is robust for a long period of time.

1.6 Steps in the Assessment Process

The Assessment Team's work included the following steps:

- Reviewing the complex context to developing a management approach.
- Describing the key attributes of the options under consideration.
- Articulating the objectives against which these would be assessed.
- Developing an assessment methodology to determine the degree to which an option meets the objectives.
- Applying the methodology and highlighting results.
- Providing a discussion of insight gained during the assessment process.

1.7 Report Structure

These steps are mirrored in the structure of this report and define its key chapters. Thus, following this first, introductory chapter:

Chapter 2 reviews key factors affecting the effective implementation of a management approach to used nuclear fuel, provides an overall “systems” view of the issues involved, and highlights their implications.

Chapter 3 provides a description of the three options for managing used nuclear fuel required by the Act and outlines key assumptions regarding their technical characteristics, timelines and requirements for implementation.

Chapter 4 provides a description of the assessment methodology selected for assessing the mandated management options.

Chapter 5 describes the objectives and their related criteria derived from NWMO’s ten key questions and reshaped for the needs of the assessment methodology.

Chapter 6 describes in detail the assessment process and highlights its results.

Chapter 7 synthesizes the Assessment Team’s thinking regarding the results of its work and includes consideration of a staged, comprehensive approach.

The Assessment Team hopes that this report provides insight and helps build further understanding as Canada moves forward in its efforts to make a decision regarding the long-term management of used nuclear fuel.

The Systemic Context to the Issue of Managing Used Nuclear Fuel

2

CONTENTS

- 2.1 Managing Used Nuclear Fuel:
Challenges to Public Policy
- 2.2 Understanding the Context:
A General Systems View
- 2.3 Towards a Comprehensive Approach

2.1 Managing Used Nuclear Fuel: Challenges to Public Policy

Management of used nuclear fuel represents an important public policy issue with which all countries producing energy from nuclear sources have been struggling. As a public policy issue, it is particularly complex. It involves scientific issues unfamiliar to many members of the public. It involves a complex technology, a significant financial commitment, and a multiplicity of environmental, political, social, ethical, and security considerations, not always easy to debate and resolve. Ultimately, it involves qualitative questions about society and the well-being of current and future generations, as well as of other forms of life – all questions that are deeply rooted in societal values.

A number of unique aspects characterize the management of used nuclear fuel. These aspects pose difficult challenges to all those concerned with planning, decision-making and implementation. They include complexity, long time-horizon, special hazards, negative public image, controversy, and the fact that there is no previous experience with a number of implementation questions. Briefly, each can be described as follows:

- **Complexity:** Issues concerning the management of used nuclear fuel are embedded in a complex context which could best be characterized as a dynamic system comprising multiple variables and many interactions, with underlying conditions which change over time (governments change, new technologies emerge, public perceptions evolve, economic conditions fluctuate). Not all the components of the overall system are completely understood nor can they be completely controlled over time. A political complexity also results from the fact that under the Canadian constitution, energy policies (and thus the activities that produce used nuclear fuel) and land management are responsibilities of provincial governments, while management of radioactive materials is a responsibility of the federal government.

- **Long Time-Horizon:** Some of the issues involved are characterized by an unusually long time-horizon. Solutions must take into account current needs but at the same time be sensitive to future generations. Because of the long-lasting effects of the substances involved, management approaches must contemplate a perspective stretching for thousands of years.
- **Risk and Heightened Public Image:** The materials which must be managed are toxic and highly radioactive, requiring active, effective management for a long period of time. Views about the risks, combined with the association of nuclear technology with weapons and war, tend to heighten public concern.
- **Controversy:** Many aspects of managing used nuclear fuel are controversial. Strongly differing opinions are held on most aspects of the issue, ranging from broad societal objectives to program goals, implementation strategies, institutional arrangements, values and ethical considerations.
- **Lack of Precedence:** While many aspects of handling used nuclear fuel are well-understood, there are important areas where knowledge is lacking. For example, the long-term performance of natural and engineered barriers has not yet been demonstrated.
- **Uncertainty:** The divergent nature of issues, the different domains of the factors involved (some technical, others ethical), inherent complexity, and the other factors cited above, mean that decisions about the management of nuclear fuel must be made in the face of inherent uncertainty.

The factors identified above suggest a need for humility in approaching issues of public policy of this kind. They also suggest taking a comprehensive approach both to the study of all the essential dimensions of the problem and to the design of an acceptable approach. Finally, they suggest the need for a well-managed, dialectic process in which solutions emerge as a result of a broad, respectful and fair dialogue among all those involved.

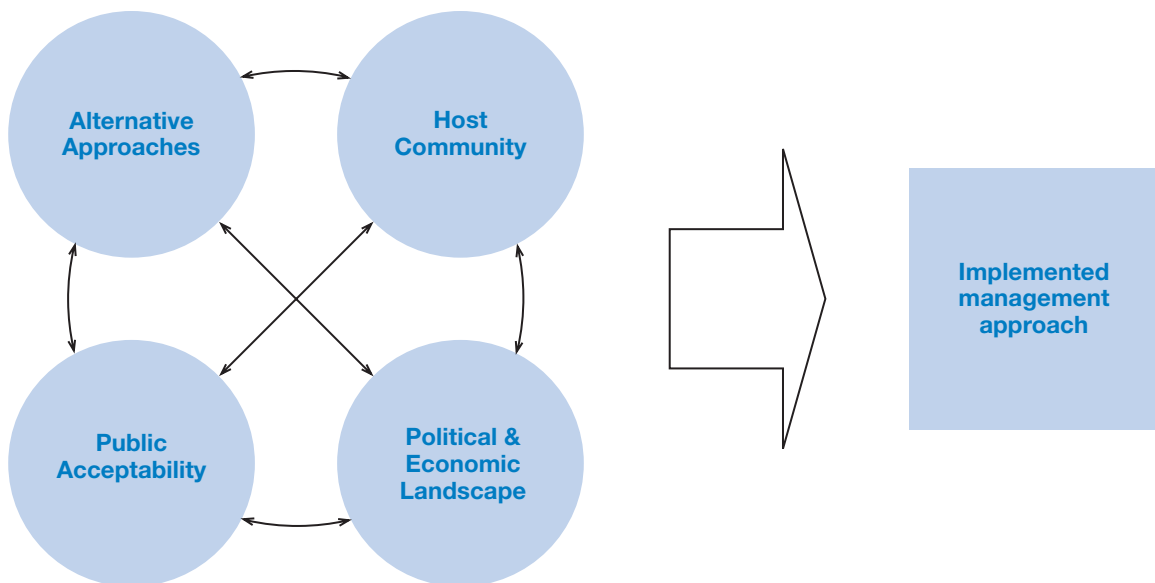
2.2 Understanding the Context: A General Systems View

The question of managing used nuclear fuel cannot be reduced to technical issues alone. This was recognized and clearly expressed by the Seaborn Report when it stated that an ethical and social framework is also required. In order to ensure a comprehensive approach touching upon all the key factors which would influence the development and effective implementation of a management approach, an overall “system” view is offered in this chapter as a conceptual starting point. The emphasis is on identifying the key factors which must be taken into account and understanding the manner in which they interact.

Emphasizing a need for taking a systems view has some particular connotations. Three fundamental characteristics are implied: multiple variables; complex interactions; and non-linear behaviours – behaviours that are often counter-intuitive. In fact, some of the unique factors alluded to earlier, specifically complexity, controversy and uncertainty, stem directly from the systemic characteristics of the issue.

In order to assist the construction of such a whole-system overview, it is useful to organize the many variables involved into logically consistent, interacting clusters which influence one another and together affect the implementation of a desired management approach. Four such major clusters are suggested in Figure 2-1. They include the cluster incorporating factors related to the possible management solutions themselves, along with their specific features and key characteristics; the cluster which includes the various factors that affect public acceptability; the cluster which includes the various factors making up the political and economic landscape; and the cluster containing factors which pertains to issues related specifically to host communities.

Figure 2-1 Four Main Clusters of Factors



The system diagram which follows in Figure 2-2 resolves these four clusters into their essential components. It illustrates graphically the underlying key factors and major causal relationships which would influence the implementation of a particular management approach to used nuclear fuel. As a visual map, it is intended to assist those concerned with evaluation, decision-making and implementation in understanding the general characteristics of this particular public policy issue. It offers a framework designed to assist the public, as well as policy-makers, navigate a difficult terrain by conceptualizing the whole as well as identifying the critical parts.

In order to facilitate review of this framework, each of its four principal clusters is described individually below. The arrows in the diagram represent causal connections.

Alternative Approaches

The alternative approaches represent the different options available to Canada to manage its used nuclear fuel. Each solution, defined as a “management approach”, includes both a technical method and a management system. The technical method involves a technology type, whether continued on-site storage or deep geological emplacement of the used nuclear fuel, for example, and its detailed design. The management system includes the institutions, governance, financial arrangements,

and managerial and legal frameworks designed to support the technical method through the various phases of its operating life. Together, the characteristics of a technical method and the management system, with the associated construction, transportation of the used nuclear fuel, and operation of a particular site, affect the level of safety for humans and ecosystems from adverse effects of the used nuclear fuel and also determine the cost of the management approach as a whole. The systems map illustrates the main features of the management solution that the public and policy-makers need to evaluate. These include:

- Safety to humans and ecosystems from adverse effects due to exposure to toxic and radioactive releases during construction, transportation, operation, and in the case of a repository, after closure
- Security of the used nuclear fuel waste from human intrusion and deliberate misuse
- The overall costs of the system and how those costs are distributed through the population and across the generations, over the timeframe in which the used nuclear fuel will have to be managed.

As mentioned above, each of the arrows in the diagram represents a causal connection. For example, the technical method choice, along with the management system and the total amount of used nuclear fuel to be managed, will determine the estimated safety to humans and ecosystems while also driving the ultimate cost of a given approach.

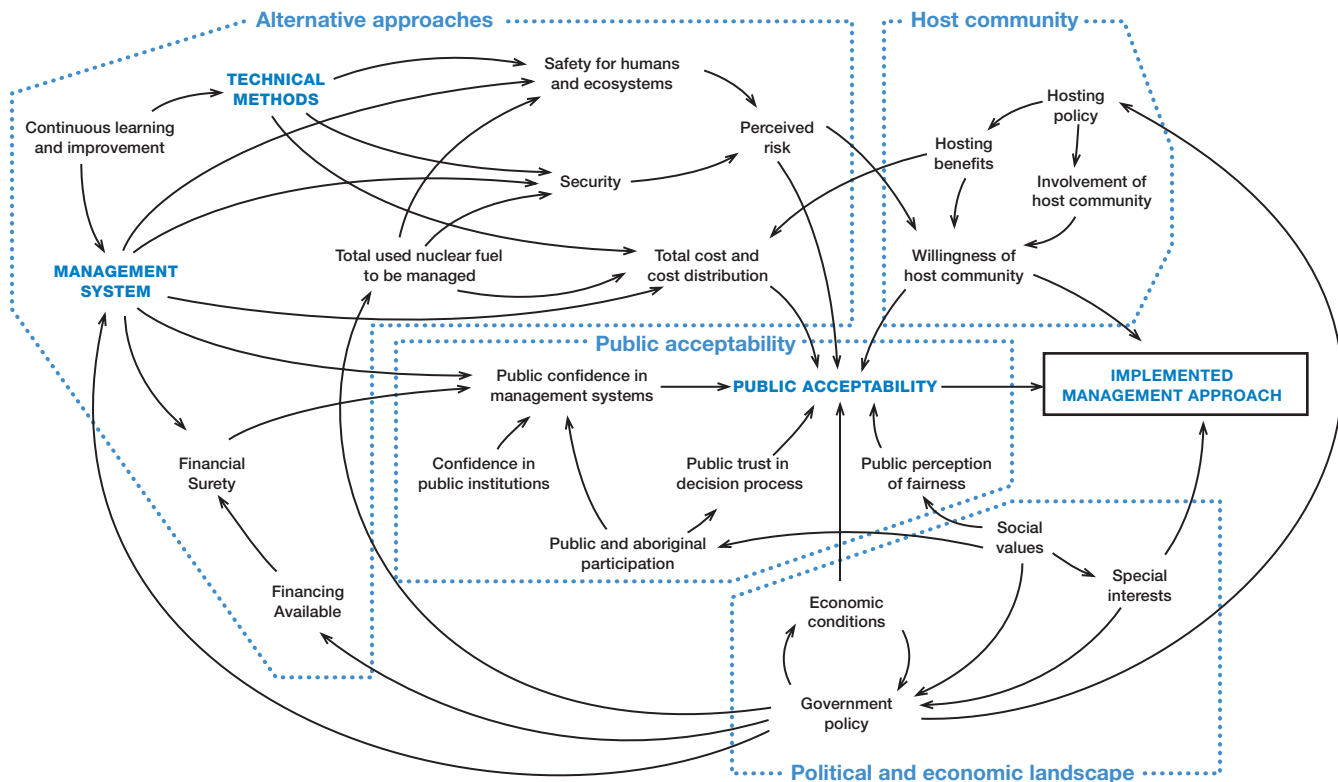
Some of the questions in assessing the safety of a solution include:

- Robustness in the face of uncertainty – will the management facility be robust through time to changes in both the environment and social structures?
- Capacity to withstand extreme events – can the facility withstand extreme natural or human-driven events?
- Flexibility and adaptability – as more is learned through research and development, the experiences of other nations, and the monitoring of sites, will the management approach be flexible enough to incorporate improvements? Is the used nuclear fuel retrievable should a critical need arise or a superior management approach be developed in future?
- Management system integrity – are the institutional, financial, legal and managerial structures expected to be adequate for managing the system over time, given future uncertainties?

Public Acceptability

The decision about a used nuclear fuel management approach ultimately needs to be supported by Canadians, particularly by those communities who will bear the risks and costs. Acceptability of a management approach by the public and Aboriginal peoples will be influenced by both the particular characteristics of a given approach, the extent to which these particular characteristics are responsive to the concerns and values of Canadians, and the process by which decisions are made. In fact, all factors in the diagram resolve to or will have an influence on public acceptability.

Figure 2-2 A Systems Perspective of Factors Leading to Implementation of a Management Approach



Acceptance of and confidence by the public in a management approach would depend upon adequate public participation in addressing key questions such as:

- Safety and security risks
- Total cost of the system, economically, environmentally, and socially
- Distribution of risks, benefits and costs
- Distribution of cost and risk across generations
- The balance between proceeding with known technology now and waiting for potentially new and better technologies to emerge.

In addition to being driven by public perceptions of fairness and the ethical dimensions of a given approach, public acceptance will require genuine opportunities for public and Aboriginal peoples' input to the decision-making process, as well as their involvement in the implementation and operation of a given solution, recognizing the diversity and dynamic nature of different views. It will also require both trust in the decision-making process itself and confidence in the management systems required for implementation of the approach. Trust in the decision-making process may be increased through the extent and quality of direct participation in the decision-making process.

Confidence in the management system will reflect the public's confidence in government and industry in general. It can be increased through effective public participation, transparency in the decision-making process and the level of stability and robustness designed into the structure of the management system and the surety of its related financing scheme.

Political and Economic Landscape

The shape of the management solution and its implementation will be also influenced by the political and economic landscape. Central to the selection and implementation of a used nuclear fuel management approach is Canada's provincial and national policy. Legislation and regulation will shape the management system and influence how the management system performs over time. Policy will dictate the form of the financing, the necessary legal framework and the mechanisms for financial management. Energy policy will influence the future of nuclear power production in Canada, which will drive the total amount of used nuclear fuel that will ultimately need to be managed over time. Policy must ensure that necessary funds and enduring financing mechanisms are in place independently of a particular nuclear future.

National and Provincial policy, in turn, is shaped by broad social values and by pressures exerted by special interests reflecting, again, particular sets of social values across the range of attitudes towards nuclear energy. It is also driven by economic conditions and calculations, which influence both the policy itself and the public's sense of the affordability of alternative solutions. While the costs and implications of a used nuclear fuel management solution will last for generations, it is important to recognize that the economic pressures at the time of decision-making will influence both the sense of urgency and affordability of a proposed solution.

Also in the general landscape of issues that will influence the choice of a used nuclear fuel management solution are included the many aspects of social values, perceptions of fairness, cross-generational concerns and others which will guide both the choices regarding general public and aboriginal participation in the process, and how the different risks, costs, and cost distribution are weighed.

Host Community

Ultimately, a solution for used nuclear fuel management requires a geographically-specific site. Options which have been mandated for evaluation include continued storage on existing nuclear plant sites; a centralized long-term storage facility; and a deep geological repository in a stable rock formation which can be found through much of Canada. Any possibility will ultimately require a focus on a specific site and will impact certain communities. The welfare of those communities is therefore integral to successful implementation.

It is vital to consider what would lead a community to agree to having a used nuclear fuel facility within its boundaries. Primary is a relationship that builds confidence over time, ensuring that the community has a meaningful role in the conduct of the program, and that those implementing and regulating the approach have the community's best interest as a fundamental consideration. The siting policy may also include benefits to a host community to compensate that community for taking on the burden associated with used nuclear fuel while a much wider population shares the benefits. The willingness of communities to host a facility will likely be influenced by the community's weighing of the perceived risks associated with such a facility to human health, the environment, and the future well-being of its members, relative to potential economic gains that might flow from jobs and investments directly

related to constructing and operating a site, and from any benefits provided in return for accepting the used nuclear fuel. Each community will weigh these trade-offs according to its particular needs, perceptions and values.

For Canada to achieve public acceptance of a used nuclear fuel management solution and implement an effective management approach, the risks and costs involved must meet the public's perception of fairness, safety, affordability and inclusion; the public must have trust in the decision-making process and in the institutions responsible for implementation and long-term management; there must be a willing community or communities to host the facility; and, all stakeholders and special interests vital to implementation must be part of the process.

2.3 Towards a Comprehensive Approach

For Canada to effectively implement a used nuclear fuel management solution it must develop a solution that is: technically sound, feasible, safe, and secure; acceptable to Canadians; compatible with the political and economic landscape; and acceptable to a host community associated with a specific site. Site-specific considerations are of paramount importance, since lack of support by a particular affected community or communities that might be called upon to host a site can derail the results of an abstract study of options.

Some of the unique challenges and implications of the systemic characteristics of managing used nuclear fuel as an issue of public policy were briefly alluded to earlier in this chapter. One important idea emerges, even from a cursory review of the general landscape involved, with its myriad ethical, social, economic, financial, legal, environmental, and technological factors and considerations. It suggests the wisdom of contemplating a comprehensive, multi-faceted plan for implementing a management approach.

The time dependence of activities associated with implementation of different approaches is such that some elements of distinct options may co-exist for some time. This in itself suggests that rather than focusing on one specific technical solution to the exclusion of all others, it might be prudent to proceed with a flexible approach, taking a sequence of actions, so that in the long run, an acceptable, sensible solution is ensured. Such an approach could involve distinct actions over time, some of which could be reversed, accelerated, slowed or discarded as necessary, ensuring public safety but keeping options open until they are ready for closure.

Given the various factors to be taken into account, the unusually long time-horizon, and the many uncertainties involved, such a comprehensive strategy would seem to offer a sensible way to proceed.

Options and Assumptions

3

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- 3.1 Introduction
- 3.2 Initial Screening of Options
- 3.3 Current Used Nuclear Fuel Management Operations in Canada
- 3.4 Basic Assumptions in the Conceptual Designs
- 3.5 Description of the Methods
- 3.6 Other Parameters Considered in the Assessment

3.1 Introduction

The *Nuclear Fuel Waste Act (NFWA)* requires that the NWMO study include an assessment of three specific technical methods:

- Deep geological disposal in the Canadian Shield, based on the concept described by AECL in the Environmental Impact Statement on the Concept for Disposal of Canada's Nuclear Fuel Waste and taking into account the views of the environmental assessment panel set out in the Report of the Nuclear Fuel Waste Management and Disposal Concept Environmental Assessment Panel dated February, 1998
- Storage at nuclear sites
- Centralized storage, either above or below ground.

Anticipating their responsibilities under the Act and prior to the establishment of NWMO, in 2001 the Joint Waste Owners (Ontario Power Generation, Hydro-Québec, New Brunswick Power and AECL) commissioned a team of consultants to develop conceptual designs and engineering cost estimates for the alternatives. These conceptual designs were provided to the NWMO in December 2003. The principal sources of information in developing the conceptual designs were:

- The Joint Waste Owners – descriptions of current operations
- CTECH (a joint venture of CANATOM and AEA Technologies) – descriptions of siting considerations, construction, operation, monitoring, closure and decommissioning
- Cogema Logistics – descriptions of retrieval from storage and transportation of used nuclear fuel.

The overall engineering assumptions and cost estimation process used in developing the conceptual designs have been reviewed and validated by an independent firm.

This Chapter presents the three options that formed the basis of the assessment. It also provides a general perspective on the timelines, institutional requirements and key characteristics sufficient for comparative assessment purposes. In addition to the conceptual design information, Assessment Team members have drawn on the Background Papers prepared for NWMO, the global literature on used nuclear fuel management, and their own experience and expertise in used nuclear fuel management and related fields such as environmental assessment, economics, radiological safety and risk management. The Assessment Team has also been informed by the numerous inputs and submissions provided to NWMO through its engagement activities.

The Chapter is organized as follows:

- Section 3.2 identifies the methods that the Assessment Team did not assess, and provides the Team's reasons for not assessing them.
- Section 3.3 summarizes current used nuclear fuel management operations in Canada.
- Section 3.4 summarizes the conceptual design process and the key assumptions applicable to all of the assessed methods.
- Section 3.5 describes the three assessed technical methods – reactor-site extended storage, centralized extended storage and the deep geological repository. Section 3.5 also includes information on timelines and the institutional requirements.
- Section 3.6 provides background on key characteristics of the assessed methods, such as environmental impacts, security aspects and costs.

3.2 Initial Screening of Options

Options for the long-term management of used nuclear fuel and other long-lived highly active radioactive wastes have been under investigation in various countries over the last forty years. Numerous methods have been suggested and recent published assessments of these options suggest that they can be prioritized for future consideration.⁷ Accordingly, in its first discussion document, *Asking the Right Questions*, NWMO described possible used nuclear fuel management options in the following way:

- Methods requiring review as specified by legislation.
- Methods receiving international attention.
- Methods of limited interest.

⁷ NWMO Background Paper 6-5. Range of Potential Management Systems for Used Nuclear Fuel. Phil Richardson & Marion Hill, Enviros Consulting Ltd.

3.2.1 METHODS REQUIRING REVIEW

While it is not intended to dismiss future options and possibilities, it is clear that the three long-term management methods specified in the NFWA (i.e., storage at nuclear sites; centralized storage, and the deep geological repository concept) are of immediate interest to Canada. These three methods form the basis of the Assessment Team's comparative assessment and each is described in the Canadian context later in this chapter. It is worth noting that these three methods are also being assessed in detail and in some cases being implemented in other national programs around the world.

3.2.2 METHODS RECEIVING INTERNATIONAL ATTENTION

In addition to the primary three methods outlined in the NFWA, the Assessment Team examined the possible implications of options currently receiving international attention. These include:

- Reprocessing, partitioning and transmutation.
- Emplacement in deep boreholes.
- The international used nuclear fuel repository concept.

These options were screened out of the comparative assessment for the reasons outlined below. The Assessment Team noted, however, that Canada may wish to maintain some interest in each of these options by undertaking research and/or tracking related international developments.

Reprocessing, Partitioning and Transmutation

Reprocessing is the application of chemical and physical processes to used nuclear fuel for the purpose of recovery and recycling of fissionable isotopes. Reprocessing technology was first developed to extract weapons-grade plutonium-239 for the nuclear weapons programs of the United States, the United Kingdom and Russia, and later in the military programs of France, China and India. This initial military-related interest has significantly influenced the choice of fuel cycle-related infrastructure in these and other countries which have subsequently established civilian nuclear power programs.

Reprocessing can take place after the used nuclear fuel is removed from the reactor. The fuel is moved in large lead and steel casks to a reprocessing facility. There, it is dissolved in nitric acid while the volatile radioactive gases are contained. Several separation and segregation processes are then used to isolate the different streams of products including uranium, plutonium, highly radioactive liquid waste; and less radioactive solids, liquids, and gases. Reprocessing rearranges and recycles components of the used nuclear fuel, but does not reduce the quantity or toxicity.

At present, Canadian reactors use a once-through fuel cycle and thus far there has been no need for Canada to reprocess used nuclear fuel. Nevertheless, it is recognized that other fuel cycles aimed at the optimum use of uranium and/or plutonium could at some point be implemented in Canada and that some of these fuel cycles could involve reprocessing. While there is no purely technical obstacle to reprocessing, the economic costs suggest that it is unlikely Canada will implement reprocessing in the near future. The Assessment Team noted that both the cost of building the necessary industrial capacity to undertake reprocessing and the need to commit to an expanded and multi-generational nuclear fuel cycle are significant limitations in the Canadian context. It was also noted that with this

technology, there would still be wastes to manage and that reprocessing would increase the types of wastes and the risks of spreading technology which could be used for production of nuclear weapons material.

Eventually it may be possible to further process and actually transform some of the radioactive components into non-radioactive elements or elements with shorter half-lives using nuclear reactions initiated by neutrons, protons, or even photons from lasers. This process, called partitioning and transmutation, essentially changes one element to another. The partitioning step involves a series of physical and chemical separation processes similar to reprocessing. The transmutation step involves the conversion of one element into another by means of particle bombardment. Partitioning and transmutation is at an early stage of development. Its scientific and technical foundation is not yet sufficiently advanced for implementation and long-term management of the residual materials would still be required.⁸

If in the future there is a decision to further process CANDU fuel for the purpose of reducing the volume and toxicity of the fuel, there would need to be significant advances in the area of partitioning and transmutation. This would require an additional process step at the back-end of the nuclear fuel cycle and a commitment to the continued use of nuclear energy by current and future generations. Exposure risk would increase appreciably due to the complexity of the fuel cycle and the multiple processing steps involved in partitioning and transmutation. As is the case for reprocessing, there would be further risk of spreading technology which could be used for production of nuclear weapons material. Costs are very difficult to determine with any certainty and the timeframe for investments would span many decades, imposing financial limitations with uncertain outcomes. While partitioning and transmutation might reduce the volume and the toxicity of the used nuclear fuel to be managed, it would not avoid the requirement for long-term management of the residual wastes that would be produced.

Emplacement in Deep Boreholes

Deep borehole emplacement of radioactive waste has been examined in a number of countries, including Sweden, Finland and Russia. The application of this concept as a used nuclear fuel management option would involve placing used fuel packages in deep boreholes drilled from the surface to depths of several kilometers, with diameters of typically less than one meter. The packages would be stacked on top of one another in each borehole, separated by layers of bentonite or cement. Boreholes could be drilled in many types of rock; however, retrieval of the used nuclear fuel packages would be extremely difficult. Furthermore, a number of significant technical questions remain regarding the mechanical integrity of the used fuel packages under high stress and temperature conditions both during and after emplacement, thus necessitating significant further research and development. Deep borehole emplacement is currently viewed as a possible method for the disposal of small quantities of radioactive waste but would be difficult to implement as a management option for large quantities of used nuclear fuel.

International Repository Concept

The Assessment Team also discussed the concept of an international repository, both where the repository would be located in another country and where Canada would be the host. It was noted that the assessment of an international repository option would have to include all the attendant costs,

⁸ U.K. House of Lords Select Committee, 1999.

benefits, and risks of the particular site and related infrastructure (including transportation) linked to all of the implicated societies and cultures. It was also noted that while the trans-boundary movement of used fuel would not be against any international treaty, in some cases it might contravene the self-sufficiency principle which guides the radioactive waste management activities of most countries with substantial nuclear programs. It was acknowledged that the international repository option may become more attractive for some countries over the next few years, but it is not a decision that would be made solely by Canada. Canada could maintain some currency in this area by coordinating with other countries and international agencies that are following this option.

3.2.3 METHODS OF LIMITED INTEREST

The NWMO discussion document, *Asking the Right Questions*, describes eight used nuclear fuel methods to be of limited interest. As shown in the Table below, these eight methods were screened out of the assessment based on the following criteria:

- Contravention of international treaties (e.g., the Convention on the prevention of marine pollution by dumping of wastes and other matter)
- Insufficient proof-of-concept to undertake an adequate assessment at the conceptual design level.

It was noted that this judgement is consistent with assessments undertaken in other countries. Furthermore, both before and after its assessment of the three methods specified in the NFWA, the Assessment Team was of the opinion that each of the eight methods of limited interest would score poorly in a comparative assessment and hence further consideration of them as part of this assessment process could not be justified. It was recognized however, that Canada may wish to maintain interest in some of these methods by undertaking research and/or tracking related international developments. Further rationale for screening these methods out of the assessment is provided in Appendix 3.

Table 3-1 Screening Rationale – “Methods of Limited Interest”

METHOD	CONTRARY TO INTERNATIONAL CONVENTIONS	INSUFFICIENT PROOF-OF-CONCEPT
Dilution & Dispersion	X	X
Disposal at Sea	X	X
Disposal in Ice Sheets	X	X
Disposal in Space		X
Rock Melting		X
Disposal in Subduction Zones		X
Direct Injection		X
Sub-Seabed Disposal		X

3.3 Current Used Nuclear Fuel Management Operations in Canada

Most of the used nuclear fuel in Canada is managed by OPG at three locations in Ontario: Pickering (site of the Pickering A and B reactors), Clarington (site of the Darlington reactors), and Kincardine (site of the Bruce A and B reactors). NB Power manages used nuclear fuel at Point Lepreau (site of the Point Lepreau reactor). Hydro-Québec manages used nuclear fuel at Bécancour (site of the Gentilly-2 reactor). AECL also manages used nuclear fuel at the Bécancour Gentilly site (from the decommissioned Gentilly-1 reactor), at the Kincardine Bruce site (from the decommissioned Douglas Point reactor), at Chalk River (from the decommissioned Nuclear Power Demonstration reactor), and at Pinawa (a small amount from the decommissioned Douglas Point reactor).

Current practice in Canada is to allow used nuclear fuel to cool in water-filled pools (“wet storage”) for a minimum cooling period of seven years (ten years for OPG fuel), and then to transfer the fuel to above-ground dry storage. Wet storage provides a safe medium for both thermal cooling and radiation decay during the initial, hottest stage. The scope of the assessment only covers management of the fuel after this transfer, since wet storage is necessary in all cases.

3.3.1

ONTARIO

OPG currently operates dry storage facilities on the Pickering and Bruce sites and plans to construct a third dry storage facility on the Darlington site. All OPG dry storage facility designs are based on the storage of casks or dry storage containers (DSCs) within storage buildings. Dry storage containers are loaded with four used fuel storage modules, each with a capacity to store 96 fuel bundles. These modules are loaded into a dry storage container at the Station Irradiated Fuel Bays. Loaded with 384 fuel bundles, the container is then drained, vacuum-dried and transferred to the DSC Processing Building. In the DSC Processing Building, the container is seal-welded, vacuum-dried, backfilled with helium, leak tested, provided with the appropriate safeguard seals, and transferred to a DSC Storage Building using a dedicated cask transporter.

OPG has developed plans for the management of used fuel on the assumption that all reactors would operate for 40 years, resulting in a total of 3.3 million used fuel bundles. At the end of the nuclear generation program, it is estimated that there would be 2.3 million bundles in dry storage and about 1 million bundles in wet storage.⁹ The current and/or planned used fuel dry storage facilities on the three reactor sites in Ontario are summarized below.

Pickering Site

The Pickering reactor site is located on the north shore of Lake Ontario, 32 km east of Toronto. The entire 240-ha site is fenced and access is restricted and controlled by OPG. The Pickering Waste Management Facility is located at the southeast corner of the Pickering site, and comprises the Used Fuel Dry Storage Facility and the Retube Components Storage Facility. At the end of the committed nuclear program, it is expected that about 930,000 fuel bundles would be in storage on the Pickering site.

⁹ As of December 2002 there were 1.4 million bundles in wet and dry storage.

Bruce Site

The Bruce Nuclear Power Development site is located within the administrative boundaries of the Municipality of Kincardine.. The majority of the site was leased to Bruce Power in May 2001. Some parts of the site, including the Western Waste Management Facility, were retained by OPG. The 932-hectare site is fenced and access is restricted and controlled by Bruce Power. Also located on the Bruce site are the Bruce A and Bruce B Nuclear Generating Stations, the Bruce Heavy Water Plant (now being dismantled) and AECL's Douglas Point Nuclear Generating Station. At the end of the committed nuclear program, about 1.5 million fuel bundles would be in storage on the Bruce site. AECL also operates a silo dry storage facility at the Bruce site which holds approximately 22,000 used fuel bundles from the decommissioned Douglas Point Nuclear Generating Station.

Darlington Site

The Darlington site is located about 70 km east of Toronto on the north shore of Lake Ontario, in the Municipality of Clarington, Regional Municipality of Durham. The 485-Ha site is fenced and access is restricted and controlled by OPG. The Darlington Nuclear Generating Station is located on the site and all used fuel produced by the station is now being stored in the station wet bays. At the end of the committed nuclear program, about 880,000 fuel bundles would be in storage on the Darlington site.

3.3.2

NEW BRUNSWICK

The Point Lepreau Generating Station (PLGS) is owned and operated by New Brunswick Power. The station is located on the Bay of Fundy, approximately 40 km west of Saint John and 45 km from the border between Maine and New Brunswick. Point Lepreau is on a headland, characterized by undulating and rocky terrain.

After used fuel is discharged from the reactor, it is initially held within the Irradiated Fuel Bay (IFB) for at least seven years. After cooling in the Irradiated Fuel Bay, the used fuel is loaded into baskets while submerged. Each basket holds 60 fuel bundles. The loaded basket is raised into a shielded workstation where the basket and fuel are dried by heated air. The cover is then seal-welded to the basket base using automated welding equipment. The dried and sealed basket is then ready for loading into the shielded flask, which in turn is loaded onto a transporter for the transfer to the concrete silo storage area. The PLGS silos are designed to accommodate nine baskets each.

The fuel inventory for the projected life of the PLGS is 119,500 used fuel bundles. This figure is based upon an assumption that the final reactor shutdown would take place in March 2008. New Brunswick Power (NBP) is currently seeking approval to extend the operating life of the station and has developed plans for the interim management of all of the used fuel scheduled to arise on the Point Lepreau site.

As of March 2001, approximately 46,440 fuel bundles had been transferred to the dry storage silos. At the end of 2001, 140 silos had been constructed.¹⁰ The silos are passively cooled and constructed in the open on reinforced concrete foundations on top of bedrock, above the water table.

¹⁰ This information is taken from CTECH, CANATOM NPN Inc. and RWE NUKEM Ltd. 2003. Conceptual Designs for Reactor-Site Extended Storage Facility Alternatives for Used Nuclear Fuel: Alternatives for New Brunswick Power's Point Lepreau Reactor Site – Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro-Québec and Atomic Energy of Canada Limited. Report v1105/MD18084/REP/13.

3.3.3 QUÉBEC

The Gentilly site is situated on the banks of the Saint Lawrence River, 15 km from the City of Trois-Rivières. The site is owned and operated by Hydro Québec. The site houses two reactors, Gentilly-1, owned by AECL, which is awaiting decommissioning, and Hydro-Québec's Gentilly-2, which is operational.

Gentilly-1

The Gentilly-1 reactor has been de-fuelled and is no longer operational. There are currently 3,213 used fuel bundles held in dry storage on the Hydro-Québec Gentilly-1 site. This used fuel is held within 85 baskets, stored within an array of concrete canisters (silos) inside a redundant turbine building. There are 38 fuel bundles in each Gentilly-1 fuel basket. The baskets are stacked nine-high within the concrete canisters. A total of eleven canisters have been constructed to house the Gentilly-1 used fuel. This used fuel is owned by AECL and is monitored and controlled within a compound for which AECL retains responsibility. The AECL "compound" is within the general Hydro-Québec Gentilly site. It is assumed that the Gentilly-1 fuel would remain on this site and would be integrated into the reactor site extended storage alternative if it were to be selected for implementation at the Gentilly site.

Gentilly-2

The fuel inventory for the current projected life of the Gentilly-2 reactor is 132,838 used fuel bundles. The reactor is scheduled to be shut down in October 2013. The transfer from wet to dry storage is similar to that at Point Lepreau. The dried and sealed basket is loaded into a shielded flask, which in turn is loaded onto a transporter for transfer to the concrete vault storage area. Each vault is designed to hold 200 baskets, stored ten baskets per vault liner in 20 liners. Currently five basket concrete vaults have been constructed which house the fuel currently available for dry storage. The concrete vaults are constructed in the open and are passively cooled. The projected used fuel inventory at Gentilly -2 combined with the Gentilly-1 would require a total of 12 vaults.

3.3.4 AECL

Chalk River Laboratories

Chalk River Laboratories (CRL) is a nuclear research establishment with a number of test reactors, fuel inspection and other facilities. The site is approximately 37 square kilometres and is a two-hour drive northwest of Ottawa. Following the termination of operations at the Nuclear Power Demonstration (NPD) reactor at Rolphton, Ontario, the reactor was de-fuelled and the used fuel shipped to Chalk River for storage in its spent fuel bays. Previous shipments of NPD spent fuel had also been stored at Chalk River. This fuel was later sealed into baskets and placed into storage silos.

The Chalk River dry storage area comprises a base slab with 14 concrete silos. Only 11 of the concrete silos are used for fuel storage, the 12th is available as a spare. The remaining two silos house calcined waste. The silos were built in 1988 to house fuel from the Rolphton NPD research reactor. They were based on the prototype canisters at Whiteshell Laboratory, which were developed in the 1960/70s. It is possible that additional silos may be built to accommodate future fuel waste generated either during reactor operations or decommissioning activities.

Whiteshell Laboratories

The Whiteshell Laboratories (WL) facility is situated in Manitoba. In 1974, Whiteshell started a program to demonstrate the viability of above ground dry storage of spent fuel. Two differently-shaped and instrumented concrete canisters, with electrical heaters to simulate decay heat production, were built to verify design. Some fuel with a cooling time as short as six months was handled and stored safely.

The Whiteshell dry storage area comprises a concrete base slab and 16 open and passively-cooled storage silos. Used fuel from the Douglas Point (DP) Reactor was transferred to the Whiteshell Laboratories (WL) for post-irradiation examination. A total of 360 used fuel bundles from the Douglas Point reactor are currently held at Whiteshell, contained in nine fuel baskets and stored within a concrete silo. The balance of the Douglas Point reactor fuel is stored at the Bruce site.

3.4 Basic Assumptions in the Conceptual Designs

The conceptual designs and cost estimates for the three long-term management methods specified in the NFWA (i.e., storage at nuclear sites; centralized storage, and the deep geological repository concept) are based on proven technologies and on both Canadian and international experience. The principal design emphasis is on fuel receipt and placement of fuel packages into the used fuel management facilities. Consideration is also given to the operations phase, including performance monitoring. For the reactor-site extended storage and centralized extended storage methods, the design approach also outlines requirements for facility refurbishment, repackaging and reconstruction activities that are expected to take place at regular intervals.

3.4.1 USED-FUEL QUANTITIES AND EMPLACEMENT RATE ASSUMPTIONS

The total fuel inventory is assumed to be approximately 3.6 million fuel bundles, as outlined in Table 3-2. For centralized extended storage or a deep geological repository, this would be accumulated at the facility over a period of 30 years. For the centralized extended storage option, for example, the peak receipt would be approximately 120,000 fuel bundles per year.

3.4.2 USED-FUEL CHARACTERISTICS

The reference fuel bundle developed for the Bruce Nuclear Generating Station is representative of typical CANDU fuel. It was used for the thermal analyses and the calculation of radionuclide inventories in the development of the conceptual designs. This fuel bundle consists of 37 fuel elements and is approximately 495 mm long and 102 mm in overall diameter. Its total mass is 23.7 kg and it contains 19.25 kg of elemental uranium (kgU) when initially loaded into the reactor. It was assumed the fuel would have the following characteristics:

- Burn-up: 220 MWh/kgU
- Bundle power: 455 kW/bundle
- Cooling period: 30 years.

These are conservative values for used fuel from OPG reactors which represent approximately 90 percent of the total Canadian used fuel inventory. A higher fuel burn-up rate of 280 MWh/kgU was assumed for radiation shielding calculations. Approximately 90 to 95 percent of used fuel bundles would have a burn-up rate less than this value. Fuel bundles for other CANDU nuclear generating stations would be similar in composition and geometry to the reference fuel and would be amenable to the same packaging and emplacement methods.

Table 3-2 Estimated Future Used Nuclear Fuel Inventory

RESPONSIBLE ORGANIZATION	FACILITIES WHERE USED NUCLEAR FUEL BUNDLES ARE LOCATED	NUMBER OF USED NUCLEAR FUEL BUNDLES AS OF 31 DECEMBER 2002	ESTIMATED FUTURE USED NUCLEAR FUEL BUNDLES
OPG	Bruce A	354,567	3,300,000 ¹¹
	Bruce B	381,198	
	Pickering	529,552	
	Darlington	236,892	
AECL	Chalk River Laboratories	4,853	4,853 ¹²
	Douglas Point	22,256	22,256 ¹³
	Whiteshell Laboratories	360	360 ¹⁴
	Gentilly 1	3,213	3,213 ¹⁵
Hydro-Quebec	Gentilly 2	89,741	133,000 ¹⁶
NB Power	Point Lepreau	97,962	111,480 ¹⁷
Estimated Total		1,720,594	3,575,162

Source: NWMO Discussion Document, *Asking the Right Questions?*

3.4.3

FUEL HANDLING

The design of used fuel handling systems and surface facilities considers that the fuel might be received at a used nuclear fuel management facility in packages of different types, originating from different organizations. For the purposes of the conceptual designs, it was assumed that fuel transferred from existing sites would arrive in road-weight transportation casks. Used fuel from Ontario reactors would be shipped in an Irradiated Fuel Transportation Cask (IFTC). Fuel stored in baskets (AECL, Hydro-Québec and New Brunswick Power) would be transported in a cask designed to accommodate three baskets.

All of the conceptual designs incorporate safe fuel handling methods, and where fuel bundle transfers are affected, employ shielded cells to minimize radioactive dose and maintain appropriate contamination control. Consideration was also given to the safe handling of fuel containers during transfer and placement in the storage facilities.

¹¹ OPG, 2002. Revised Plan and Cost Estimates for Management of Used Fuel. Report W-CORR-00531-0052., submitted to the CNSC. This report provides OPG's predicted total inventory of 3.3 million bundles assuming all of the reactors operate for 40 years.

¹² This is a research facility that no longer produces used CANDU fuel

¹³ These are decommissioned facilities that no longer produce used CANDU fuel

¹⁴ These are decommissioned facilities that no longer produce used CANDU fuel

¹⁵ These are decommissioned facilities that no longer produce used CANDU fuel

¹⁶ Hydro-Quebec, 2001. Preliminary Decommissioning Plan for G-2 Nuclear Generating Station – Attachment to Document H08-1374-003., submitted to the CNSC. This document refers to an estimate of 133,000 bundles to be produced by 2013. The assumed Gentilly-2 station design life is 30 years. No decision has been taken yet regarding the refurbishment of Gentilly-2. If the refurbishment is approved, the operation of Gentilly-2 would be extended and the estimated bundles will be revised accordingly.

¹⁷ Attachment 1 of August 2003 letter from NB Power submitted to the CNSC. The attachment to this letter refers to an irradiated fuel inventory of approximately 111,480 bundles at the end of NB Power's current Power Reactor Operating Licence (March 31, 2006). If the operation of Point Lepreau is extended beyond March 2006, the estimated bundles will be revised accordingly.

3.4.4 TRANSPORTATION SYSTEM DESIGN

If continued storage at the current sites is chosen, then no transportation system would be required. For a centralized extended storage facility or deep geological repository, a used-fuel transportation system (UFTS) would be required to move approximately 3.6 million bundles from their current storage facilities.

The UFTS would need to be ready by approximately 2023 for a centralized extended storage facility or 2035 for a deep geological repository, consistent with the earliest potential in-service dates for emplacement of the used nuclear fuel. For the purposes of describing the conceptual designs and estimating costs, an underlying assumption for both of these options is that the facility would be located somewhere in Ontario.

Three alternative transportation systems were considered in the development of the conceptual designs – all road, mostly rail and mostly water. These systems would incorporate an existing cask, OPG's Dry Storage Container Transportation Package (DSCTP), and a new cask, based on OPG's existing IFTC, the Irradiated Fuel Transportation Cask for Baskets or Modules (IFTC/BM). There is substantial international experience in the transport of used nuclear fuel casks and the Canadian system would be designed to meet IAEA standards for packaging and operations.

3.4.5 MONITORING

It was assumed that all used nuclear fuel management facilities would be regularly monitored to ensure they remain suitable for housing used nuclear fuel. A program of preventive maintenance and repair would also be in effect.

In the reactor-site extended storage and centralized extended storage options, the storage buildings and structures would need to be regularly monitored, including checking walls, roofs and concrete floors for signs of deterioration. Internal and external drainage systems would have to be checked to ensure that pumps are in good condition and that trenches and collection sumps are free of sediments. Ground water would also have to be monitored.

For the deep geological repository option, it was assumed that regular monitoring of operating facilities would continue at least until the final decommissioning of the repository.

3.4.6 FACILITY REFURBISHMENT

For the reactor-site extended storage and centralized extended storage options, it is assumed that the storage structures would ultimately deteriorate, due to normal wear and tear, and weathering processes, and would need to be replaced or refurbished. The steps necessary to perform a building refurbishment cycle would be:

- Construction of a new storage facility.
- Provision of appropriate fuel package handling equipment.
- Establishment of a fuel transfer route.
- Transfer of fuel packages from the old storage facility.
- Refurbishment or demolition of the empty old storage facility.

3.4.7 USED FUEL REPACKAGING

For the reactor-site extended storage and centralized extended storage options, the used fuel bundles would be periodically removed from their existing casks and transferred to new ones. This transfer would take place within a shielded facility housed within a larger building. The shielded facility would permit opening of seal-welded casks and the withdrawal of the fuel bundles contained within. The fuel bundles would be inserted into new casks that would be seal-welded.

3.4.8 RADIATION PROTECTION

Used nuclear fuel is radioactive and hazardous if released during handling or storage. Radiological protection technologies and operational procedures using multiple barriers are needed to minimize exposure.¹⁸ CNSC Radiation Protection Regulations specify that the maximum occupational whole-body dose equivalent to a radiation worker shall not exceed 20 mSv/year, or 1 mSv/year to a member of the public. To account for the possibilities of process upset and accident conditions during non-routine operations (i.e., major maintenance, upgrades, and decommissioning), the radiation protection systems incorporated into the conceptual design for the deep geological repository are based on not exceeding a routine dose of 2 mSv/year to an individual worker during normal operations. This limit corresponds to an individual worker being exposed to an average dose rate of 1 µSv/hour for 2000 hours (i.e., nominally a one-year period, based on 50 weeks at 40 hours per week). The radiation protection systems for the reactor-site extended storage and centralized extended storage options are based on the criteria applicable to current used nuclear fuel handling facilities.

3.5 Description of the Methods

As noted previously, the three long-term used nuclear fuel management methods specified in the NFWA (i.e., storage at nuclear sites; centralized storage, and the deep geological repository concept) form the basis of the Assessment Team's comparative assessment. Each of these methods is described in this section. A general perspective on the timelines, institutional requirements and key characteristics sufficient for comparative assessment purposes is also provided.

3.5.1 DESCRIPTION OF REACTOR-SITE EXTENDED STORAGE (RES)^{19 20 21 22}

As noted previously, used nuclear fuel is currently stored at seven sites in Canada, in both wet and dry storage facilities. Atomic Energy of Canada Limited (AECL) and Ontario Power Generation (OPG) began to investigate various options for dry storage in the 1970s. AECL has more than 25 years of experience with dry storage systems. Recent licensing of used nuclear fuel dry storage facilities at various reactor sites in Canada indicate general regulatory acceptance for the increasing use of dry storage at reactor sites as an interim method for managing used nuclear fuel.²³

¹⁸ Candesco Research Corporation 3.1

¹⁹ CTECH, CANATOM NPN Inc. and RWE NUKEM Ltd., 2003. Conceptual Designs for Reactor-Site Extended Storage Facility Alternatives for Used Nuclear Fuel: Alternatives for the Pickering, Bruce and Darlington – Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro-Québec and Atomic Energy of Canada Limited. Report v1105/MD18084/REP/12.

²⁰ CTECH, CANATOM NPN Inc. and RWE NUKEM Ltd., 2003. Conceptual Designs for Reactor-Site Extended Storage Facility Alternatives for Used Nuclear Fuel: Alternatives for New Brunswick Power's Point Lepreau Reactor Site – Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro-Québec and Atomic Energy of Canada Limited. Report v1105/MD18084/REP/13.

²¹ CTECH, CANATOM NPN Inc. and RWE NUKEM Ltd., 2003. Conceptual Designs for Reactor-Site Extended Storage Facility Alternatives for Used Nuclear Fuel: Alternatives for Hydro-Quebec's Gentilly Reactor Site – Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro-Québec and Atomic Energy of Canada Limited. Report v1105/MD18084/REP/14.

²² CTECH, CANATOM NPN Inc. and RWE NUKEM Ltd., 2003. Conceptual Designs for Reactor-Site Extended Storage Facility Alternatives for Used Nuclear Fuel: Alternatives for Atomic Energy of Canada's Limited's Chalk River and Whiteshell Laboratories – Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro-Québec and Atomic Energy of Canada Limited. Report v1105/MD18084/REP/15.

²³ NWMO Background Paper 6-1. Status of Reactor Site Storage Systems for Used Nuclear Fuel. SENES Consultants Ltd.

Extended storage can be defined as permanent or indefinite storage with the necessary on-going maintenance and facility refurbishment. The current design life of dry storage containers is 50 years; however, the expected life of dry storage containers is thought to be 100 years or more. In the event that centralized facilities for the management of used fuel are not available on a timely basis, extended storage could be used indefinitely, with periodic facility refurbishment and fuel repackaging.

Implementation of a reactor-site extended storage (RES) alternative would involve the construction of an extended dry storage facility at each reactor site. There are both surface and below-surface designs involving the use of casks, vaults and silos. As shown in the Table below, various concept alternatives have been considered for existing reactor sites based on current experience.

Table 3-3 Concept Alternatives Considered for Existing Reactor Sites

ONTARIO Pickering, Darlington and Bruce	<ul style="list-style-type: none"> • Casks in Storage Buildings (CSB) • Surface Modular Vault (SMV) • Casks in Shallow Trenches (CST)
NEW BRUNSWICK Point Lepreau	<ul style="list-style-type: none"> • Surface Modular Vault (SMV) • Vaults in Shallow Trenches (VST)
QUEBEC Gentilly	<ul style="list-style-type: none"> • Surface Modular Vault (SMV) • Vaults in Shallow Trenches (VST)
AECL Chalk River and Whiteshell Sites	<ul style="list-style-type: none"> • Silos in a Storage Building (SSB) • Silos in a Shallow Trench (SST)

Reactor-site extended storage facilities would be designed to allow safe retrieval of used nuclear fuel from the storage complex at any point during the service life of the facility. After fuel receipt, all subsequent fuel movements would be under cover, minimizing effects of adverse weather and maximizing fuel container life. For all reactor site options, additional capacity would be provided by the construction of storage facilities on a rolling program (i.e., an on-going, cyclical program of regular replacement and refurbishment activities).

Storage in Casks

A cask is a mobile, durable container for enclosing and handling nuclear fuel waste for storage or transport. The cask wall shields radiation and heat is transferred by conduction through the wall. In the context of reactor site extended storage, a cask is equivalent to the dry storage container (DSC) used by OPG. Concept alternatives include storage of these casks in buildings or in shallow trenches.

Storage in Vaults

The vault concept would involve the storage of fuel baskets confined in concrete vaults. The vaults would be constructed on a concrete foundation slab. Fuel baskets would be transferred to the storage facility in a basket transfer flask. The basket transfer flask would deliver the basket to the dedicated vault on a powered transporter. Additional capacity would be provided by the construction of storage vaults on a rolling program. Cooling and ventilation to regulate the basket temperature inside the vault would be achieved by natural ventilation.

Storage in Silos

The storage of used nuclear fuel inside sealed steel baskets, with the baskets housed within a concrete silo (canister) is a dry fuel storage system used in Canada and other countries for used fuel dry storage. The silos are situated outdoors and are passively cooled. The concrete silos are a cylindrical reinforced concrete shell with an internal liner of epoxy-coated carbon steel. The liner has an internal diameter of 84.5 cm. The external diameter of the silo is 2.59 m and the height is 6.2 m. A shield plug is inserted into the silo liner after completion of the loading operations (nine baskets).

Table 3-4 and 3-5 provide a general perspective of the project timeline and some of the institutional aspects that would need to be considered in the implementation of a management approach involving reactor-site extended storage.

Table 3-4 Summary of RES Project Timeline

Project Phase	Duration, Years									
	10	20	30	40	50	100	200	300	400	
Siting & Approvals	■									
Design & Construction		■								
Initial Fuel Receipts		■	■	■	■					
Extended Monitoring					■	■	■	■	■	■
Building Refurbishment & Repackaging							■	■	■	■

Note: (1) Extended monitoring and building refurbishment/ repackaging activities continue in perpetuity, based on a 300-year cycle.

(2) Schedule based on implementing a surface modular vault (SMV) at the Pickering site.

(3) Schedules for other RES alternatives at various sites will vary, depending on the type of storage concept and the quantity of fuel being stored.

3.5.2

DESCRIPTION OF CENTRALIZED EXTENDED STORAGE (CES)²⁴

The centralized extended storage concept builds from experience with centralized storage systems already in place in a number of countries. Producers of used fuel may build such facilities to provide effective management when they have many reactors producing used fuel. These can be developed within a regional or a national context by the implementing organizations responsible for the management of used fuel.

Centralized storage systems were initially developed as interim storage for periods of up to 50 years. These systems are operational in twelve countries and used over a wide range of circumstances from providing common temporary storage for used fuel from a few reactors, to providing a fully centralized management system for used fuel at the national level. With increasing used fuel inventories, some countries are viewing centralized extended storage as a longer-term management alternative which could encompass time periods of 50 to 300 years. As a result, more research and development is being undertaken on the durability of used fuel storage structures and the effectiveness of designs to ensure containment of radioactivity over extended timeframes.²⁵

²⁴ CTECH, CANATOM NPN Inc. and RWE NUKEM Ltd., 2003. Conceptual Designs for Four Centralized Extended Storage Facility Alternatives for Used Nuclear Fuel – Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro-Québec and Atomic Energy of Canada Limited. Report v1105MD18084/REP/08.

²⁵ NWMO Background Paper 6-1. Status of Reactor Site Storage Systems for Used Nuclear Fuel. SENES Consultants Ltd.

Table 3-5 Timeline and Institutional Considerations for RES

2005 – 2050		
<ul style="list-style-type: none"> The power plants are in operation. Used nuclear fuel goes to wet storage and is transferred to on-site short-term dry storage after 7-10 years. Construction begins of facilities designed for long-term storage. Once the on-site long-term storage is constructed, used nuclear fuel from the wet bays is transferred to the new facility; used nuclear fuel already in dry storage is transferred to the new facility at the end of the life of the interim storage facility. Once the short-term facilities are emptied, they are decommissioned. A monitoring program for workers, safeguards and the environment is developed and maintained. 		
ADMINISTRATIVE ASPECTS	FINANCIAL ASPECTS	REGULATORY ASPECTS
<p>The power plant operator is responsible for the maintenance of wet storage and for the transfer to short-term dry storage containers on-site.</p> <p>A technical design is selected based on current technology or another method (at least two other technical designs have been identified for each site where used nuclear fuel is currently stored).</p> <p>Responsibilities for the used nuclear fuel in both the short-term and the long-term dry storage facilities are clearly defined.</p> <p>Responsibilities for safeguards are defined.</p>	<p>Funds are in place to establish a competent organization and its activities for the long-term management of the used nuclear fuel.</p> <p>Funds are in place for R&D, design, licensing, construction, and operation of the long-term storage facilities, including buildings and containers.</p> <p>Funds are in place for the on-going maintenance of the short-term facilities.</p> <p>Activities funded by the segregated used nuclear fuel management funds are clearly defined. A mechanism is in place to ensure that funds are available in perpetuity for on-going facility maintenance and replacement (e.g., amounts from endowments, operations or other sources), recognizing that the size of fund could limit future decommissioning options).</p>	<p>The institutions providing the required surety (financial, human resources) meet CNSC approval.</p> <p>All storage operations and activities (wet/dry/construction/ decommissioning) meet regulatory (CNSC) approval.</p> <p>New facilities and decommissioning of current ones meet CEA (EA) requirements.</p> <p>Capacity is in place to regulate more than one technical design for long-term management of used nuclear fuel depending on what is selected for the various sites.</p>
~2050 AND UP TO THE NEXT COUPLE OF HUNDRED YEARS		
<ul style="list-style-type: none"> It is assumed that the last fuel bundles will have been moved from wet to dry storage. Based on current projected reactor life, there will be no more wet storage and no nuclear power production at the sites. The last of the fuel in short-term storage will be transferred to long-term storage in this phase. The storage containers will be at their design lifetime (50-100 years) at different schedules and there will be a need for refurbishment and replacement. New facilities/ buildings/ infrastructure will be built, maintained or replaced as required. A monitoring program for environment and workers will be maintained. Efforts will continue to ensure the long-term integrity and safety of the facilities. 		
ADMINISTRATIVE ASPECTS	FINANCIAL ASPECTS	REGULATORY ASPECTS
<p>Organization in place for the long-term management of used nuclear fuel.</p> <p>Organization is competent to maintain the current facility and to address upcoming technologies and possibilities for improvements.</p> <p>Reviews of extended dry-storage technical methods are undertaken and decisions are made to maintain as is or improve.</p>	<p>Funds are in place to cover the routine maintenance costs of facilities plus the costs of refurbishing or changing oldest storage containers which will have reached their design lifetime (50–100 yrs).</p> <p>Funds are in place for security and environmental monitoring at each site.</p> <p>The funding mechanisms previously established in Phase I either continue or are changed as per societal/ governmental/legal conditions at the time.</p>	<p>On-going processes and any facilities not yet decommissioned meet regulatory approvals.</p> <p>New processes and facilities meet regulatory approvals, including licensing and EA requirements.</p> <p>The roles of the organizations responsible for providing the required surety (financial, human resources, technical competence) are clearly defined and meet CNSC approval.</p> <p>All storage operations and activities (wet/dry/construction/ decommissioning) meet regulatory (CNSC) approval.</p>
BEYOND NEXT COUPLE OF HUNDRED YEARS AND ON-GOING		
<ul style="list-style-type: none"> The decision to maintain on-site storage (and the technical option selected) will be reviewed. A monitoring program for environment and workers be maintained. Efforts will continue to ensure the long-term integrity and safety of the facilities. On-going maintenance plus storage-container overhaul or replacement will be required each 50-100 years for each container. 		
ADMINISTRATIVE ASPECTS	FINANCIAL ASPECTS	REGULATORY ASPECTS
<p>A responsible organization is in place to maintain the facilities, address regulatory issues and assess the utilization of new technologies with the possibility for improvement.</p>	<p>Funds are in place for on-going facility maintenance, refurbishment, or replacement.</p> <p>Funds are in place for security and environmental monitoring at each site.</p> <p>The funding mechanisms previously established either continue or are changed as per societal/governmental/legal conditions.</p>	<p>Same regulatory needs as in the previous timeframe.</p>

As previously noted, following its removal from the nuclear reactor, used nuclear fuel is highly radioactive and is stored for about a decade in water pool storage facilities at the reactors. Following this period, it is easier to handle and transport the used fuel and store it away from the reactor sites. This could be done either in wet storage (i.e., in water-filled pools) or in dry storage facilities. The latter have advantages including modularity and less on-going maintenance. Although several centralized water pools have been built, dry storage seems to be the preferred option. The concept that has been developed and that has been considered in this assessment includes variations of dry storage, both above- and below-ground.

Technologies for centralized dry storage of used fuel include metal casks, concrete casks, silos and vaults. Four alternatives for the Centralized Extended Storage Facility (CES) concept were selected by the Joint Waste Owners as representative of a range of possible centralized extended storage designs. The selected alternatives are:

- Casks and Vaults in Storage Buildings (CVSB)
- Surface Modular Vault (SMV)
- Casks and Vaults in Shallow Trenches (CVST)
- Casks in Rock Caverns (CRC).

Site conditions are not considered to be a major constraint in the implementation of these alternatives. Of the alternatives considered, two are surface facilities, in which fuel is stored in a series of storage buildings built above-grade. The remaining two alternatives are below-ground facilities, one near-surface and mounded over and one at about 50m below ground-surface in bedrock. The near-surface alternative, the Casks and Vaults in Shallow Trenches (CVST) are designed to be passively ventilated, with the deeper alternative, Casks in Rock Caverns (CRC), ventilated using a forced system. Three of the alternatives (CVSB, CVST, CRC) are designed to minimize repackaging of fuel upon receipt at the CES facility, which would allow higher fuel throughput and minimize cost. A summary of the principal engineering features for the four CES alternatives is provided in Table 3-6.

Centralized storage could be built at nuclear plant sites or at a fully independent site. For the purposes of the assessment, it is assumed that the CES facility would be located on a greenfield site. The CES facility would not rely on the services or provisions to other nuclear facilities, and would be considered as a stand-alone facility. It is assumed the facility would be constructed in the province of Ontario at a location with low earthquake risk and that the site would be relatively flat, be free-draining, have stable soil structures and competent rock structures.

Irrespective of the alternative under consideration, a CES facility would include a Processing Building and a Storage Complex. Each of the CES alternatives would provide sufficient storage for the full fuel bundle inventory. Therefore, each site layout would need to provide sufficient space to allow for the construction of used fuel storage and repackaging facilities. For all of the alternatives, additional capacity would be provided by the construction of storage facilities on a rolling program.

Table 3-7 and Table 3-8 provide a general perspective of the project timeline and some of the institutional aspects that would need to be considered in the implementation of a management approach involving centralized extended storage.

Table 3-6 Summary of the Principal Engineered Features for CES Alternatives

STORAGE CONCEPT	ENGINEERED FEATURE					
	Primary containment barrier	Secondary containment barrier	Isolation	Intrusion barrier	Shielding	Cooling
Casks and Vaults in Storage Buildings (CVSB)	Module storage cask	None	Storage cask body	Storage building	Storage cask body	Ventilation louvers in storage building
	Fuel basket	Vaults housing fuel baskets	Vault structure	As above	Vault structure	Ventilation ducts in basket vaults and louvers in building
Surface Modular Vault (SMV)	Module canister	Storage tubes in SMV array	SMV walls and charge floor	SMV walls and upper building structure	SMV walls, charge face & shield plugs	Ducted airflow across storage vault tube array
	Fuel basket	As above	As above	As above	As above	As above
Casks and Vaults in Shallow Trenches (CVST)	Module storage cask	None	Storage cask body	Shallow trench structure and earthen overburden	Storage cask body	Ventilation ducts from surface to underground storage chamber complex
	Fuel basket	Vaults housing fuel baskets	Vault structure	As above	Vault structure	Ventilation ducts in basket vaults and from surface to underground storage chamber complex
Casks in Rock Caverns (CRC)	Module storage cask	None	Storage cask body	Cavern/tunnel complex	Storage cask body	Ventilation ducts complete with surface mounted extract fans, from the underground storage complex to the surface
	Fuel basket	Basket cask body	As above	As above	As above	As above

Table 3-7 Summary of CES Project Timeline

Project Phase	Duration, Years									
	10	20	30	40	50	100	200	300	400	
Siting & Approvals	█									
Design & Construction		█								
Initial Fuel Receipts			█	█	█					
Extended Monitoring						█	█	█	█	█
Building Refurbishment & Repackaging							█	█	█	

Note: (1) Extended monitoring and building refurbishment/ repackaging activities continue in perpetuity, based on a 300-year cycle.

Table 3-8 Timeline and Institutional Considerations for CES

2005 – 2050		
<ul style="list-style-type: none"> Power plants are in operation. Used nuclear fuel goes to wet storage and is transferred to on-site short-term dry storage after 7-10 years. Activities in this timeframe include selecting a CES site, further R&D, selecting a technical design, training, construction, commissioning, O&M, as well as the development and production of transport containers and the transportation of used nuclear fuel. Construction begins. Once the centralized storage is complete, used nuclear fuel is transported from the short-term reactor-site storage to the new facility. When the short-term facilities at the existing sites are emptied, they are decommissioned and returned to other uses. Monitoring of the environment begins prior to the construction of the new facility and continues throughout its life. Workers are monitored during transportation and at all locations where used nuclear fuel is handled. 		
ADMINISTRATIVE ASPECTS	FINANCIAL ASPECTS	REGULATORY ASPECTS
<p>The power plant operator is responsible for the maintenance of wet storage and for the transfer to short-term dry storage containers on site.</p> <p>Responsibilities for the used nuclear fuel in both the short-term and the long-term dry storage facilities are clearly defined.</p> <p>Organizational roles and responsibilities for long-term centralized storage and related transportation are clearly defined.</p> <p>A technical design for centralized storage is selected based on current technology or another method.</p> <p>Responsibilities for safeguards are defined.</p>	<p>Funds are in place to establish a competent organization and its activities for the long-term management of the used nuclear fuel.</p> <p>Funds are in place for R&D, design, licensing, construction, and operation of the long-term storage and transportation facilities, including buildings and containers.</p> <p>Funds are in place for the on-going maintenance of the short-term facilities.</p> <p>Activities funded by the segregated used nuclear fuel management funds are clearly defined. A mechanism is in place to ensure that funds are available in perpetuity for on-going facility maintenance and replacement (e.g., amounts from endowments, operations or other sources), recognizing that the size of the fund could limit future disposal and decommissioning options.</p>	<p>The institutions providing the required surety (financial, human resources) meet CNSC approval.</p> <p>All storage and transportation operations (wet/dry storage, construction, transportation, decommissioning) meet regulatory (CNSC) approval.</p> <p>New facilities and decommissioning of current ones meet CEAA (EA) requirements.</p> <p>Capacity is in place to regulate a centralized facility and the associated transportation infrastructure for long-term management of used nuclear fuel.</p>
~2050 AND UP TO THE NEXT COUPLE OF HUNDRED YEARS		
<ul style="list-style-type: none"> The last bundles will be moved from wet storage to on-site short-term dry storage. Based on current projected reactor life there will be no more wet storage and no nuclear power production at the sites. Transportation of used nuclear fuel will continue until the centralized storage facility is completed and the last fuel bundle is received. The storage containers will reach their design lifetime (50-100 years) at different schedules and need refurbishment or replacement. On-going maintenance or replacement of facilities/ buildings/ infrastructure will be undertaken as required. Facilities, workers and environment will continue to be monitored. Security will be maintained. Efforts will continue to ensure the long-term integrity and safety of the facilities and to either maintain or improve the dry storage technical method. 		
ADMINISTRATIVE ASPECTS	FINANCIAL ASPECTS	REGULATORY ASPECTS
<p>Organization(s) are in place for maintaining on-site facilities (while the centralized facility is being completed) and for the subsequent decommissioning of the on-site facilities.</p> <p>Organization(s) are competent to maintain the current facility and to address upcoming technologies and possibilities for improvements.</p> <p>Reviews of extended dry storage technical methods are undertaken and decisions are made to maintain as is or improve.</p> <p>Responsibilities for safeguards are maintained.</p>	<p>Funds are in place to complete construction of the new facility and for transportation of used nuclear fuel from reactor sites.</p> <p>Funds are in place for on-going O&M, including monitoring and security.</p> <p>Routine maintenance costs begin, including costs for refurbishing or changing storage containers which have reached their 50-100 year lifetime.</p> <p>Funds are in place for the decommissioning of the on-site locations.</p> <p>The funding mechanisms previously established in Phase I either continue or are changed as per societal/governmental/legal conditions at the time.</p>	<p>On-going processes and facilities, including facilities not yet decommissioned, meet regulatory approvals.</p> <p>New processes and facilities meet regulatory approvals, including licensing and EA requirements.</p> <p>The roles of the organizations responsible for providing the required surety (financial, human resources, technical competence) are clearly defined and meet CNSC approval.</p> <p>All storage and transportation operations (wet/dry storage, construction, transportation, decommissioning) meet regulatory (CNSC) approval.</p>
BEYOND NEXT COUPLE OF HUNDRED YEARS AND ON-GOING		
<ul style="list-style-type: none"> O&M will continue with monitoring programs for environment and workers, security at the facility, and on-going maintenance of facilities/buildings plus storage container overhaul or replacement each 50-100 years for each container. Efforts will continue to ensure the long-term integrity and safety of the facilities, and to permit review of the technical option selected and its future implications. 		
ADMINISTRATIVE ASPECTS	FINANCIAL ASPECTS	REGULATORY ASPECTS
<p>A responsible organization is in place to maintain the facilities, address regulatory issues and assess the utilization of new technologies with the possibility for improvement.</p>	<p>Funds are in place for on-going facility maintenance, refurbishment, or replacement.</p> <p>Funds are in place for security and environmental monitoring at each site.</p> <p>The funding mechanisms previously established either continue or are changed as per societal/governmental/legal conditions at the time.</p>	<p>Same regulatory needs as in the previous timeframe.</p>

3.5 3 DESCRIPTION OF THE DEEP GEOLOGICAL REPOSITORY (DGR) CONCEPT²⁶

A deep geological repository is an engineered facility located within a naturally-occurring geological formation. A deep geologic repository for used CANDU fuel was developed by Atomic Energy of Canada Limited (AECL) during the period 1978-1996, under the Canadian Nuclear Fuel Waste Management Program. The results of that review are documented in the final report of the Environmental Assessment Panel, published in March of 1998. The Panel report summarized the concept review and recommended changes to address comments from a broad range of stakeholders, including the public.

Since 1996, Ontario Hydro, and subsequently OPG and the other members of the Joint Waste Owners, have continued the development of the original AECL repository concept. Using the design parameters and specifications established through this work, together with information from existing repository design experience in Canada and internationally, a preliminary DGR design was produced to meet the following goals:

- Receive used nuclear fuel shipped from interim storage and/or from extended storage facilities
- Encapsulate the used nuclear fuel in long-lived used fuel containers (UFCS) and place them in the DGR
- Retrieve the used fuel containers from the repository during the pre-closure phase if required.

The modified DGR concept developed by C-Tech on behalf of the Joint Waste Owners is a further development of the in-room emplacement configuration. The design involves the encapsulation of the used nuclear fuel in copper/steel double-shell containers with a capacity of 324 bundles, and emplacement of these containers inside emplacement rooms, in a horizontal position. The containers would be arranged in two rows parallel to the longitudinal axis of the emplacement rooms and would be surrounded and supported by an assembly of pre-compacted blocks of buffer and dense backfill material. A system of monitoring the performance of the engineered barriers during the pre-closure phase would also be incorporated.

It is assumed that the repository would be located in the Canadian Shield at a depth of 1000 meters. In developing the concept, different excavation techniques (including the drill and blast method and the use of tunnel boring machines) were assessed based on cost, design flexibility, proven capability and the effect on long-term performance with respect to blast damage.

The repository would be self-contained, except for the supply of materials, used fuel containers and their components. The facility design is based on the receipt, packaging and placement of CANDU used-fuel bundles at a rate of 120,000 per annum. The design assumes that these used-fuel bundles

²⁶ CTECH, CANATOM NPN Inc. and RWE NUKEM Ltd., 2002. Conceptual Designs for A Deep Geologic Repository for Used Nuclear Fuel – Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro-Québec and Atomic Energy of Canada Limited. Report v1106MD18084/REP/01.

have been discharged from reactors and stored for 30 years prior to receipt at the DGR facility.

The major differences between the AECL design concept for in-floor container emplacement and the modified DGR conceptual design are listed below:

- Now 3.6M fuel bundles vs AECL's 10.1M bundles
- Reference fuel age changed from 10 to 30 years
- Change in container design:
 - titanium to copper outer shell
 - glass beads to steel inner vessel
 - 72 bundle to 324 bundle
- In-room emplacement option engineered and costed
- Extended monitoring period prior to closure

Overall, the conceptual design developed by C-Tech on behalf of the Joint Waste Owners provides sufficient detail to confirm the engineering feasibility of a DGR and to allow the preparation of a conceptual cost estimate for its implementation, including its siting, construction, operation, decommissioning, closure and post-closure management. The concept is sufficiently well-developed to be considered in this assessment.

The Tables which follow provide a general perspective of the timeline and some of the institutional aspects that would need to be considered in the implementation of a management approach involving a deep geological repository. Until the repository is operational, interim measures would be needed to effectively manage the used nuclear fuel and to ensure safety and security.

Table 3-9 Summary of DGR Concept Project Timeline

Project Stage	Duration, Years														
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Siting	█	█													
Design			█	█											
Construction			█												
Operation				█	█	█	█								
Extended Monitoring							█	█	█	█	█	█	█		
Decommissioning and Closure													█	█	█

Table 3-10 Timeline and Institutional Considerations for DGR

2005 – 2050		
<ul style="list-style-type: none"> Power plants are in operation. Used nuclear fuel goes to wet storage and is transferred to on-site short-term dry storage after 7-10 years. Activities in this timeframe include selecting a site, further R&D, selecting a technical design, training, construction, commissioning, and O&M, as well as the development and production of transport containers, and possibly the transportation of used nuclear fuel. Repository construction begins. Emplacement of the used nuclear fuel begins only after completion. Once the short-term facilities at the existing sites are emptied, they are decommissioned and returned to other uses. Monitoring of the environment begins prior to the transfer of used nuclear fuel to the repository and continues throughout its emplacement. Workers are monitored during transportation and at all locations where used nuclear fuel is handled. 		
ADMINISTRATIVE ASPECTS	FINANCIAL ASPECTS	REGULATORY ASPECTS
<p>The power plant operator is responsible for the maintenance of wet storage and for the transfer to short-term dry storage containers on-site.</p> <p>Responsibilities for the used nuclear fuel in both the short-term and the long-term dry storage facilities are clearly defined.</p> <p>Organizational roles and responsibilities for the geological repository and related transportation are clearly defined.</p> <p>A technical design for the geological repository is selected.</p> <p>Responsibilities for safeguards are defined.</p>	<p>Funds are in place to establish a competent organization and its activities for the long-term management of the used nuclear fuel.</p> <p>Funds are in place for R&D, design, licensing, construction, and operation of the geological repository and transportation facilities, including buildings and containers.</p> <p>Funds are in place for the on-going maintenance of the short-term facilities.</p> <p>Activities funded by the segregated used nuclear fuel management funds are clearly defined. A mechanism is in place to ensure that funds are available in perpetuity for on-going facility maintenance and replacement (e.g., amounts from endowments, operations or other sources), recognizing that the size of the fund could be limiting.</p>	<p>The institutions providing the required surety (financial, human resources) meet CNSC approval.</p> <p>All storage and transportation operations (wet/dry storage, construction, transportation, decommissioning) meet regulatory (CNSC) approval.</p> <p>New facilities and decommissioning of current ones meet CEEA (EA) requirements.</p> <p>Capacity in place to regulate a geological repository and associated transportation infrastructure for long-term management of used nuclear fuel.</p>
~2050 AND UP TO THE NEXT COUPLE OF HUNDRED YEARS		
<ul style="list-style-type: none"> The last fuel bundles will be moved from the wet storage. Based on current projected reactor life, there will be no more wet-storage and no nuclear power production at the sites. Once the short-term facilities at the sites are emptied, they will be decommissioned (and eventually returned to other uses). Repository facility construction will be completed. Transportation will be at its maximum in this phase and the repository site will receive the last of the used nuclear fuel from the reactor sites. Prior to final emplacement of all used nuclear fuel, the storage containers at the interim dry storage facility will reach their design lifetime (50-100 years) at different schedules and there may be a need for refurbishment of each as this point is reached if emplacement takes too long. On-going O&M of associated facilities, transportation, interim storage, etc. will continue as used nuclear fuel is emplaced in the repository. Related activities will include security and monitoring of workers, facilities and environment. On-going R&D will continue on the selected method, lessons from other countries, and the results of monitoring in order to maximize knowledge for the long-term integrity and safety of the facilities, improve on choices where appropriate and possible, and determine options for repository decommissioning (closure). 		
ADMINISTRATIVE ASPECTS	FINANCIAL ASPECTS	REGULATORY ASPECTS
<p>Organization(s) are in place for maintaining on-site facilities (while the geological repository is being completed) and for the subsequent decommissioning of the on-site facilities.</p> <p>Organization(s) are competent to maintain the current facility and to address upcoming technologies and possibilities for improvements.</p> <p>Responsibilities for safeguards are maintained.</p>	<p>Funds are in place to complete construction of the new facility and for transportation of used nuclear fuel from reactor sites.</p> <p>Funds are in place for on-going O&M, including monitoring and security.</p> <p>Funds are in place for the decommissioning of the on-site locations.</p> <p>The funding mechanisms previously established in Phase I either continue or are changed as per societal/governmental/legal conditions at the time.</p>	<p>On-going processes and facilities, including facilities not yet decommissioned, meet regulatory approvals.</p> <p>New processes and facilities meet regulatory approvals, including licensing and EA requirements.</p> <p>The roles of the organizations responsible for providing the required surety (financial, human resources, technical competence) are clearly defined and meet CNSC approval.</p> <p>All storage and transportation operations (wet/dry storage, construction, transportation, decommissioning) meet regulatory (CNSC) approval. This would include used fuel emplacement in the repository and its possible decommissioning (closure).</p>
BEYOND NEXT COUPLE OF HUNDRED YEARS AND ON-GOING		
<ul style="list-style-type: none"> Environmental monitoring may be required for a few centuries to establish and test the performance of the system against design specifications. If the decision has not been made earlier, the permanent closure of the repository will be addressed. 		
ADMINISTRATIVE ASPECTS	FINANCIAL ASPECTS	REGULATORY ASPECTS
<p>A small organization may be required to undertake monitoring and reporting, and possibly to address security/safeguards requirements.</p>	<p>Limited funds may be required for on-going environmental monitoring and reporting, as well as security.</p>	<p>Oversight on the status of environmental conditions may be desirable.</p>

3.6 Other Parameters Considered in the Assessment

3.6.1 VOLUME OF USED NUCLEAR FUEL

A number of variables, including the potential for additional nuclear power generation, will determine the actual volume of used nuclear fuel which will need to be managed in Canada. As noted earlier in this chapter, this assessment makes specific assumptions about future nuclear plant operating rates and shutdown dates of the existing fleet of nuclear reactors in Canada. It is important, however, to recognize the possible variability of future used nuclear fuel volumes and characteristics and hence the need to include a “volume safety margin” in design plans and cost estimates. Flexibility and scalability therefore remain important considerations in the development of implementation plans for used nuclear fuel management.

3.6.2 OTHER FUEL CYCLES²⁷

Nuclear fuel can be enriched, or processed, to increase the concentration of Uranium 235 prior to initial insertion into a reactor. Used nuclear fuel can also be reprocessed after removal from the reactor, to extend the supply of nuclear fuels. The fuel for the present generation of Canadian CANDU heavy-water reactors is natural uranium and Canada does not currently reprocess nuclear fuel. This contrasts with many other countries which use enriched uranium in the more common light-water reactors. Some of these countries reprocess used nuclear fuel. In addition, other fuel cycles are being developed, such as the AECL Advanced CANDU Reactor (ACR), either to decrease the capital costs of building reactors, or to permit the use of other fuels in response to declining uranium resources. These advanced fuel cycles may require either enrichment or reprocessing which would result in used fuel with different characteristics than the current Canadian used fuel inventory. This in turn would affect the quantity and type of waste that must be considered in the design of storage or repository facilities.

3.6.3 TIMEFRAME

The implementation timeline for a waste management method is an important design and cost factor. For example, AECL environmental impact studies produced in the early 1990s envisaged a timeline in the order of 90 years for the complete implementation of a deep geological disposal approach, culminating in the final decommissioning and closure of the disposal site.²⁸ By contrast, an alternative, staged approach might either keep the used nuclear fuel accessible in storage before the used fuel is emplaced in a repository, or delay decommissioning and closure of the repository to allow for retrieval in the meantime. While staged or stepwise approaches may offer certain advantages in terms of flexible decision-making, it is important to take into account the different project cost profiles and financial implications that are likely to result.

3.6.4 ACCESSIBILITY

There continues to be an active debate on the issue of future accessibility of used nuclear fuel. Arguments have been made supporting the recovery of valuable constituents (including fissile materials) after a long period of cooling has made the used fuel more amenable to handling and treatment. Further reasons advanced for maintaining accessibility focus on the potential for new technologies which might allow for further productive use of the used nuclear fuel or a way of eliminating its toxicity. By contrast, others argue that used nuclear fuel has few benefits and should be managed to minimize

²⁷ NWMO Background Paper 6-4. Status of Spent Fuel Reprocessing, Partitioning and Transmutation. David Jackson, David Jackson and Associates.

²⁸ Simmons, G.R., and P. Baumgartner, 1994. The Disposal of Canada's Nuclear Fuel Waste: Engineering for a Disposal Facility. AECL Report.

the burden on future generations. The repository option was originally developed in order to remove radioactive wastes from ecosystems and the human environment for the very long times needed to allow for the natural decay of radioactivity.

The perspective in support of accessibility emerged in the 1980s, initiated largely by discussions in Sweden (KASAM 1988) suggesting that society's responsibility to future generations is to give them the widest possible choice of options and therefore accessibility is a positive design feature. Accessibility has also been rationalized based on scepticism that high safety standards can be applied over the very long timescales for used nuclear fuel management. A defined period during which the wastes in their final configuration can be observed, monitored and if necessary retrieved is, in fact, a regulatory requirement of some national programs (e.g., U.S. requirements for an initial 50-year retrieval period). In all cases, there is a trade-off between building-in inviolable physical barriers versus not precluding access for potentially positive uses, which affects both the design and operation of a used nuclear fuel management facility, as well as the institutional and monitoring programs throughout its lifetime.

3.6.5 SECURITY

Used nuclear fuel is highly radioactive and contains fissile materials (uranium and plutonium) which can be used for deliberate acts of malice. The IAEA has identified several categories of risk, including: theft or diversion of nuclear material; an attack or sabotage causing an uncontrolled release of radioactivity at the fuel storage site; diversion of nuclear material for use in a nuclear bomb; and creation of a "dirty bomb" or crude radiological dispersal device. While this last category is perhaps of greatest concern, used nuclear fuel is not as attractive for use in a dirty bomb as other common radioactive sources, including those used in radiotherapy and in research programs. Any attempt at theft or sabotage of used nuclear fuel would require considerable specialized resources, including technically knowledgeable personnel. Furthermore, the self-protecting nature of the highly radioactive fuel, at least over the first 300 years, and the design of the dry storage containers both provide significant security protection.

The CNSC has security requirements that are reflected in the Nuclear Security Regulations and in licence conditions. With the assistance of CSIS, the RCMP, local police and licensees, the CNSC establishes the threat, assesses vulnerabilities and determines vital areas. Facility operators establish specific security programs based on the elements of deterrence, detection, assessment, delay and response. Used nuclear fuel will be subject to security requirements for decades, regardless of the management approach adopted. Even though there has not yet been a credible threat to used nuclear fuel in Canada, the threat environment is dynamic and it is not unreasonable to expect that the threat may change over time, necessitating changes to security requirements.²⁹

3.6.6 TRANSPORTATION OF USED NUCLEAR FUEL

Shipments of radioactive materials, including used nuclear fuel, account for a small proportion of the total amount of hazardous materials shipped every day around the world. Used nuclear fuel is transported internationally by road, rail and sea in large ("Type B") casks. Many shipments involve more than one of these modes.

²⁹ NWMO Background Paper 3-3. Status of Canadian and International Efforts to Reduce the Security Risk of Used Nuclear Fuel. SAIC.

Type B casks are typically cylinders weighing from 25 to 100 tonnes, made from forged steel with walls several inches thick. The largest casks typically carry around five tonnes of used fuel. Shock absorbers are placed on either end of the casks during transport to limit the impact forces in the event of an accident. Type B casks transported within IAEA member countries, including Canada, must comply with IAEA requirements. IAEA requirements involve successive tests of the cask's ability to withstand impact, fire and immersion (i.e., a nine-meter drop onto an unyielding surface at a low temperature; a drop from one meter onto a steel spike; an all-engulfing fire at a minimum temperature of 800°C for 30 minutes; and immersion in 200 meters of water for eight hours). Analyses by designers have shown that Type B casks can withstand immersion under several thousands of meters of water. There have been thousands of spent fuel shipments over four decades and there has never been an accident that has involved the release of radioactive materials from a Type B cask.³⁰

Studies conducted to evaluate the level of risk associated with transportation of used nuclear fuel have consistently shown that the levels of risk are very low whether used nuclear fuel is transported on land or water. These studies have examined a range of accident scenarios, including analyses of what would have happened if used nuclear fuel had been transported during some of the most severe hazardous material accidents. Nevertheless, there continues to be significant public concern regarding the transportation of radioactive materials which could affect the planning and implementation of any used fuel management option.

3.6.7 HUMAN HEALTH ASPECTS³¹

Everyone in society is unavoidably exposed to radiation from many sources at an annual chronic dose of about three millisieverts, almost all of which comes from naturally occurring or medical sources. As long as good practices are maintained, the likelihood of radioactivity dispersing as a result of handling or storage of used nuclear fuel is well below this level. Thus, the greatest concern to health and safety occurs if facilities degrade or good practice is compromised. Under these circumstances, the possibility of contamination entering the biosphere through breach of containment is increased.

In spite of the good record of safety during the transportation of radioactive materials, the possibility of conventional road accidents is considered to be an increased safety risk for the used-fuel management options that require transportation. Heavy construction or mining would be required in the near term for both the centralized storage and repository options, leading to the increased possibility of accidents. It is also important to recognize that health impacts increase with the size of population potentially exposed and that a facility initially located in a rural area, with new roads and infrastructure, may attract a larger community which, over time, would grow into an urban setting. It is therefore important to consider the health and safety factors associated with urban settings and not just rural communities.³²

3.6.8 ENVIRONMENTAL CONSIDERATIONS

The biosphere is anywhere organisms live and therefore it is a potential receptor of contamination or other impacts from a used nuclear fuel management facility. Effects in the biosphere on humans and other biota are the "critical" performance criteria for any option that may be implemented. While the specific elements of the biosphere at risk at a particular location are a function of the site-selection process, it is recognized that, in addition to potential radiological impacts, the development of any

³⁰ NWMO Background Paper 6-8. Review of the Fundamental Issues and Key considerations related to the Transportation of Spent Nuclear Fuel. Gavin J. Carter, Butterfield Carter and Associates, LLC

³¹ NWMO Background Paper 3-2. Human Health Aspects of High-level Radioactive Waste. John Sutherland, Edutech Enterprises.

³² NWMO Background Paper 4-1. Status of Biosphere Research related to High-level Radioactive Waste Management (HLRWM). ECOMatters. Page 25.

facility and associated infrastructure will have direct impacts on environmental elements that may be disturbed. This includes impacts arising from possible developments on undisturbed lands, as well as impacts related to transportation infrastructure.

The ability to determine risks to the environment is compromised by the extremely long timeframes under consideration. These risks include, for example, the ability of facilities to withstand unanticipated conditions, including extreme climatic change. Furthermore, our understanding of the glaciation-deglaciation cycles that have occurred for the last 900,000 years suggests that it is virtually certain that large areas in Canada will be covered by ice for a significant interval within the next 100,000 years. The impact of the thickness of the ice is an important factor that must be considered in a safety assessment.

The concepts developed for each of the options considered in this assessment have been subjected to environmental risk studies. The science of release, dispersion, transport and uptake of radioactive and chemical contaminants in soil, water and air is well advanced³³ and, under normal operations for anticipated conditions, all of the options pose low risks to the environment. For storage facilities there is very low risk of contamination as long as maintenance programs are maintained and effective monitoring and surveillance are implemented. For below-ground repositories, risk relates both to the robustness of the engineered barriers and to the effectiveness of the geological barrier. With little possibility for maintenance in the longer term, and virtually none after closure, the risk of uncertainty of performance increases with time.³⁴

For the repository option, the geosphere plays a key role in isolating the facility from the biosphere.³⁵ The expectation is that if the engineered barriers surrounding the used nuclear fuel are breached, the slow rate of the groundwater flow combined with geochemical immobilization and retardation processes will help to ensure that radionuclides continue to be confined. Thus, an attribute of the geosphere for a deep repository system is that groundwater flow at repository depths be either stagnant or sluggish. The fracture, hydraulic, thermal, mechanical and hydro-geochemical properties of crystalline rock have been extensively studied at the Underground Research Laboratory (URL) at the Whiteshell Research Area (WRA) in Manitoba. The data indicates that below 500 meters, groundwater is very saline, reducing, and old, and hence, can be considered as essentially stagnant over the period of concern for a repository facility (1,000,000 years). The plutonic rock of the Canadian Shield has this attribute, as do bedded salts and shales. It should also be noted that, since the late 1970s, several reports and papers have concluded that there are potentially suitable sites in Canada for a used nuclear fuel repository in geologic media other than the crystalline rock of the Canadian Shield.³⁶

3.6.9

FINANCIAL ISSUES

Management of used nuclear fuel requires careful consideration of costs and financing. Governments will have to create a financial framework because the extreme timeframes involved exceed the time horizons for private investments and because there is no commercial demand that would generate revenue from used nuclear fuel management. The financial framework will need to include the establishment of funding mechanisms covering the full costs of a recommended method. The least expensive method is not necessarily the wisest choice if it does not meet other public policy objectives and cannot be successfully sited.³⁷

³³ NWMO Background Paper 4-1. Status of Biosphere Research related to High-level Radioactive Waste Management (HLRWM). ECOMatters. Page 13.

³⁴ NWMO Background Paper 4-1. Status of Biosphere Research related to High-level Radioactive Waste Management (HLRWM). ECOMatters. Page 26.

³⁵ NWMO Background Paper 4-2. Characterizing the Geosphere in High-Level Radioactive Waste Management. Jonathan Sykes, University of Waterloo.

³⁶ Letter to E. Dowdeswell, NWMO from F. King, OPG, 27 April, 2004.

³⁷ NWMO Background Paper 5-4. Economic and Financial Aspects of the Long-Term Management of High-Level Nuclear Waste: Issues and Approaches. Charles River Associates Canada Limited.

The Assessment Team did not analyze potential financing mechanisms. It was assumed that each of the assessed methods could be financed to completion, although the assessment methodology includes consideration of risk related to financing as well as the overall economic impact of completed facilities.

The choice of discount rate used to calculate present values of future cost streams is an important factor in the estimation of costs and in the determination of the size of an initial fund to cover those costs.³⁸ The lower the assumed discount rate, the more conservative the fund (i.e., the larger the size of the initial fund). The “current value” method represents the conservative limit, corresponding to a discount rate of zero.³⁹

The discount rate assumptions used by various countries in their financing schemes are typically conservative, in the two to four percent range (net of inflation).⁴⁰ For example, the discount rate used in Japan is two percent and is based on the average interest rate of ten-year government bonds over the most recent five-year period, adjusted for inflation.⁴¹ In Sweden, an average real rate of return of four percent is assumed until 2020 and 2.5 percent thereafter.⁴² Some countries have considered separate discount rates for the cost and revenue streams (from contributions by waste producers into the fund), where the discount rate applied to the revenue stream would be higher, reflecting additional risk of payment default by waste producers and other uncertainties such as environmental regulation.⁴³ The cost analysis provided by the Joint Waste Owners assumes a 3.25 percent discount rate, net of inflation.

An independent consultant reviewed all of the documentation which served as the basis for the Joint Waste Owners’ cost estimates for the conceptual designs.⁴⁴ It was concluded that the estimates were prepared with an appropriate methodology and that they are suitable for the review of options and directional decision-making. It was also concluded that the basic engineering assumptions were well developed for all of the alternatives. Standard industry guidelines were used to estimate contingencies, taking into account availability of information, availability and accuracy of quantities, level of engineering and percentage of labour content. The costs estimated by the Joint Waste Owners, including any transportation costs, are as follows:

Table 3-11 Estimate Summary Total Undiscounted Costs (Billion) –

Undiscounted value (2002\$)

METHOD	ESTIMATE
Reactor Site Storage*	\$17.6 – 25.7B
Centralized Storage*	\$15.7 – 20.0B
Deep Geologic Repository	\$16.2B

*Note: The Reactor Site Storage and Centralized Storage options only include costs up to 300 years.

Table 3-12 Estimate Summary Total Present Value Costs (Billion) –

Present value at 3.25% real discount rate (2004\$)

METHOD	ESTIMATE
Reactor Site Storage	\$2.3 – 4.4B
Centralized Storage	\$3.1 – 3.8B
Deep Geologic Repository	\$6.2B

Reference: Joint Waste Owners’ Conceptual Design Work Related to Nuclear Fuel Waste Act; Presentation, Jan. 21, 2004.

³⁸ NWMO Background Paper 5-4. Economic and Financial Aspects of the Long-Term Management of High-Level Nuclear Waste: Issues and Approaches. Charles River Associates Canada Limited.

³⁹ Present value versus current value costing approaches are discussed in NWMO Background Paper 5-4, Economic and Financial Aspects of the Long-Term Management of High-Level Nuclear Waste: Issues and Approaches. Charles River Associates Canada Limited.

⁴⁰ NWMO Background Paper 5-4. Economic and Financial Aspects of the Long-Term Management of High-Level Nuclear Waste: Issues and Approaches. Charles River Associates Canada Limited.

⁴¹ From NWMO Background Paper 5-4. Economic and Financial Aspects of the Long-Term Management of High-Level Nuclear Waste: Issues and Approaches. Charles River Associates Canada Limited.

⁴² From NWMO Background Paper 5-4. Economic and Financial Aspects of the Long-Term Management of High-Level Nuclear Waste: Issues and Approaches. Charles River Associates Canada Limited.

⁴³ This example is based on the experience of Nirex in the U.K.. Based on EC, p. 60.

⁴⁴ ADH/CRA review of JWO Cost Estimates

A deep geological repository is a very large capital project with an unprecedented long construction timeframe and extensive feasibility work. While all of the technology is available commercially, there has been little construction experience globally for such facilities and the parameters of any specific site are necessarily unknown until a site has been selected for analysis. There is substantial financial risk due to potential political delays or for engineering reasons related to site characteristics. The numerous estimates of future costs that have been made by different national programs vary widely.⁴⁵ Estimates based only on conceptual designs may be proven inaccurate once a program for waste management is underway.

On-site and central storage will require periodic investments for thousands of years. While the cost of on-going reactor site storage is relatively more certain than for central storage or a geological repository, the cost estimates provided by the Joint Waste Owners do not extend past 300 years. The additional amounts would be heavily discounted in the present value calculation, but are not insignificant.

The Team's assessment explicitly allowed for differing views on both the extent and the likelihood of significant cost variations as well as the importance of such variations to the overall economy and to the ability to finance each method.

3.6.10 CONSIDERATION OF ECONOMIC REGIONS⁴⁶

The three assessed methods all require that used nuclear fuel storage or disposal activity take place in a specific location or locations. The NFWA requires that the NWMO use the definition of "economic region" as the defining parameter for location. An economic region is a grouping of census divisions for analysis of regional economic activity. There are 76 economic regions in Canada.

Facility siting requires both technical information and social and political processes. The Seaborn Environmental Assessment Panel recommended that only communities that volunteer be considered as potential hosts. The Assessment Team's analysis covers only general considerations regarding how communities respond to the issue and recognizes that different communities may have very different attitudes. The assessment is not specific with respect to choice of economic region for a central storage facility or geologic repository.

The reactor-site extended storage option would take place, by definition, in the economic regions that contain Canada's nuclear reactors. For this option, there would be no transportation of used nuclear fuel. For the deep geological repository option, the broad region that is technically suitable is the Canadian Shield, containing 21 economic regions and located within six provinces and two territories. For the Provinces of Quebec and Ontario and the Territory of Nunavut, the majority of their land consists of the Canadian Shield. Geologic criteria would dominate in the initial stages of a geological repository site selection process.

In the absence of specific siting criteria, there are few restrictions regarding the siting of a centralized storage facility and hence specific criteria would have to be developed. These may include minimizing transportation distance, maximizing distance from populated areas, specifying required geologic or hydrologic conditions, obtaining support from a potential host region and/or community, and/or minimizing costs.

⁴⁵ NWMO Background Paper 7-6. Comparative Overview of Approaches to Management of Spent Nuclear Fuel and High Level Wastes in Different Countries. Charles McCombie and Bengt Tveiten.

⁴⁶ NWMO Background Paper 5-1. An Examination of Economic Regions and the Nuclear Fuel Waste Management Act. Richard Kuhn, University of Guelph and Brenda Murphy, Wilfred Laurier University.

Ultimately, the storage or disposal of used nuclear fuel may take place in several economic regions. For example, a management strategy could be envisioned that progresses from on-site storage to centralized storage to the construction of a disposal facility either adjacent to the centralized storage facility or in a different location.

3.6.11 EXPERIENCE IN OTHER COUNTRIES

In the next few years, significant policy decisions will be taken in some countries with respect to the status of used nuclear fuel management. These include: France, which in 2006 must formulate its policy concerning long-term surface or underground storage, transmutation, and geological disposal; and the U.K., which, like Canada, has decided to open a public discussion on all potential long-term used nuclear fuel management options. Both Canada and the U.K. have ambitious initiatives in place intended to ensure that the policy finally chosen by the respective government will be firmly based on an analysis of public views on this important issue. By contrast, in the U.S., Congress has already decided, in spite of State of Nevada opposition, that a licensing application should be prepared for the Yucca Mountain repository project in Nevada.

In Finland and Sweden, deep repository programs are advanced and moving towards decisions regarding dates for implementation. The consultation and decision-making processes that have been implemented in these countries have been influential in gaining social acceptance for the repository approach.

Countries with small quantities of used nuclear fuel, or wastes from nuclear applications in medicine, research or industry, also need safe and secure long-term management options. For some of these countries the cost of separate national radioactive waste management facilities would be much higher than if joint facilities were built. Shared facilities might come into operation either because a country with a large nuclear program agrees to accept wastes from smaller programs or smaller countries agree to cooperate in implementing a regional facility.⁴⁷

The following tables summarize what other countries are doing with respect to interim storage⁴⁸ of used nuclear fuel as well as the development of centralized storage facilities and deep geological repositories.

Table 3-13 Interim Storage of Used Nuclear Fuel⁴⁹

COUNTRIES USING ONLY WATER POOLS FOR INTERIM STORAGE	COUNTRIES USING OR CONSTRUCTING DRY FACILITIES FOR INTERIM STORAGE	COUNTRIES WITH BOTH WET AND DRY FACILITIES FOR INTERIM STORAGE
Finland Republic of Korea Mexico Pakistan Russia Slovak Republic Sweden	Argentina Czech Republic Hungary Italy Romania Spain	Belgium France Germany Switzerland UK United States Canada

⁴⁷ NWMO Background Paper 7-6. Comparative Overview of Approaches to Management of Spent Nuclear Fuel and High Level Wastes in Different Countries. Charles McCombie and Bengt Tveiten.

⁴⁸ Interim storage is a temporary method of maintaining used nuclear fuel in a manner that allows access, under controlled conditions, for retrieval or future activities.

⁴⁹ Adapted from NWMO Background Paper 7-6. Comparative Overview of Approaches to Management of Spent Nuclear Fuel and High Level Wastes in Different Countries. Charles McCombie and Bengt Tveiten.

⁵⁰ Adapted from NWMO Background Paper 7-6. Comparative Overview of Approaches to Management of Spent Nuclear Fuel and High Level Wastes in Different Countries. Charles McCombie and Bengt Tveiten.

⁵¹ Estimate for planning purposes only. Based on: CTECH, CANATOM NPN Inc. and RWE NUKEM Ltd. 2002. Conceptual Designs for A Deep Geologic Repository for Used Nuclear Fuel – Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro-Québec and Atomic Energy of Canada Limited. Report v1106MD18084/REP/01.

Table 3-14 Centralized Storage Facilities and Geological Repositories for Used Nuclear Fuel⁵⁰

COUNTRIES THAT HAVE OR ARE CONSIDERING REGIONAL OR CENTRALIZED STORAGE FACILITIES	PLANNED IN-SERVICE DATES FOR COUNTRIES CONSIDERING UNDERGROUND REPOSITORIES
China France Germany India Korea Netherlands Russia Spain Sweden Switzerland UK USA Canada	Argentina – 2050 China – 2040 Czech Republic – 2065 Finland – 2020 Germany – 2030 Hungary – 2047 Japan – 2035 Russia – 2025/2030 Slovak Republic - 2037 Sweden – 2015 Switzerland – 2040/2050 USA – 2010 Canada – 2035 (est.) ⁵¹

3.6.12**LICENSING PROCESS**

Under the Nuclear Safety and Control Act (NSCA), used nuclear fuel management facilities are considered Class I facilities. The requirements described under Class I Nuclear Facilities Regulations (articles 3 to 8) outline the regulatory requirements for obtaining a license to prepare a site, construct, operate, decommission, or abandon a facility. Any license requires the submission of licensing documentation that describes, in varying details, the characteristics of the facility, its operation and its impact on the environment. The licensing process for fuel management facilities follows consistent guidelines, but remains flexible and adapted to the requirements and needs of each situation and thus, is defined to a certain degree on a case-by-case basis.

The CNSC licensing process focuses on the design, engineering and safety aspects of the proposed facility. Public consultation is not required until the final approval stage. The review of this information is internal to the CNSC and is conducted in conjunction with the proponent. The process is iterative, involving several meetings between the proponent and the CNSC staff to ensure a common understanding on requirements and acceptability criteria.

To obtain a license, projects must satisfy the requirements of the Canadian Environmental Assessment Act (CEAA). In practice, since much of the technical work required for the environmental assessment is also required for the CNSC licensing, this means that the CNSC licensing process for a used fuel management facility is conducted in parallel with an environmental assessment process. The environmental assessment process requires public consultation and can take considerable time.

In preparing a licensing application for a used nuclear fuel management facility, a safety case would have to be prepared. The safety case is the integration of arguments and evidence that describe, quantify and substantiate the safety, and the level of confidence in the safety, of a facility or activity. The challenge in developing the safety case for the long-term management of used nuclear fuel is to address all the phases of activity before and after long-term storage and before and after facility decommissioning. This would include the overall approach to the long-term management solution being addressed, which includes the activities to handle the used fuel, contain and package it, store it on an interim basis, receive it at an extended storage facility or repository and manage it over the long term. Transportation of used nuclear fuel would not be included in the license application for a used nuclear fuel management facility, but would require separate approval under the CNSC Packaging and Transport of Nuclear Substances Regulations. It would also be considered in the environmental assessment process.

Assessment Methodology

4

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4.1 What is an Assessment Methodology?

An assessment methodology is an orderly, systematic way of undertaking an assessment that offers rigour to the process in support of improved decision-making. The Assessment Team was charged with undertaking a comparative assessment of alternative technical methods for the long-term management of used nuclear fuel in Canada. Such a comparison is normative in nature because what is sought is the identification of which is best amongst alternatives.

If the methodology that is chosen follows rules that have been tried over the years, peer reviewed, refined as experience has been gained, and become accepted as practice, it is considered a “formal” methodology. Formal assessment methods are frequently used in both the public and private domain to investigate, analyze and compare the alternatives that are being considered within a decision-making process. Examples include: the estimation of risks and benefits of alternative medical treatments; facility siting decisions such as for airports, hospitals, or transportation infrastructure; and the weighing of alternative approaches for reducing greenhouse gas emissions.

These methods can help to improve decisions in a variety of ways. For example, they can help to:

- Identify information and judgments that are needed or useful for decision-making.
- Ensure that important considerations are not overlooked.
- Promote a consistent and defensible logic for comparing alternatives.
- Identify actions that are more likely to achieve objectives.
- Express, in an open and transparent way, all of the factors that contribute to the decision.

4.2 Tasks within an Assessment Methodology

An assessment methodology includes several distinct tasks. These tasks differ depending on the nature of the assessment methodology, but often include structuring the decision problem, characterizing alternatives, estimating the likelihood of risky events, forecasting the consequences of various choices, and valuing those consequences. Taken together, the various tasks and how they are discharged comprise an analytic model.

Analytic models are particularly useful in situations where it is impossible or undesirable to actually “try out” alternative courses of action, exactly the case with used nuclear fuel. Instead, an assessment methodology provides a model for “testing” the options without actually implementing them. If the assessment model is a good one, an alternative that looks good from the standpoint of the model is likely to be a good choice in the real world.

4.3 Challenges for Building an Assessment Methodology

Creating an assessment methodology for evaluating alternative approaches for dealing with Canada’s used nuclear fuel presents some major challenges. A number of these challenges – complexity, long time-horizon, and uncertainty – have already been discussed in Chapter 2. In addition, the following three challenges are especially pertinent to the design of an assessment methodology.

Addressing the Diversity of Current Values and Preferences

A major challenge for the assessment methodology is to be responsive to the diversity of Canadian values. Because of such variations, Canadians may well differ on selecting an appropriate course of action. The reason for this is that no single alternative is likely to be indisputably superior in every way. Making a choice among approaches that have individual strengths and weaknesses requires trading off competing objectives, and this requires value judgments regarding the relative importance of those objectives. Different values lead to differences in willingness to make such trade-offs. In spite of such differences, NWMO has confirmed through work it has commissioned that there is also much common ground in the values held by Canadians. NWMO has made a significant effort to understand the nature of Canadian values and use that as a foundation for its work. The details of how this foundation has been fed into the assessment process are described in Chapter 5.

Addressing the Diversity of Values and Preferences over Generations

Another complication is the fact that we cannot know the preferences of Canadians not yet born – the future generations who will have to live with the results of today’s actions. Since it is not possible to specify a single set of values that represents what all current and future Canadians want, a challenge for the assessment methodology is to be able to explore how well the different approaches serve the differing values that may be held not only by today’s Canadians, but tomorrow’s as well. This issue is further explored in Chapter 5.

Revealing All of the Important Assumptions

When an assessment is complex, many assumptions are built into the assessment model. Often, the more complicated a decision is, the more complex the underlying assumptions. To ensure that decision-making takes place with a full understanding of these assumptions, the assumptions must be explicit. In this way, they can be reviewed, debated, and either accepted or rejected, making the decision transparent to those not directly involved in the process. It is a challenge to describe all of the underlying details and assumptions in a manner that can be easily communicated.

4.4 Goals of the Assessment Methodology

To guide the comparative assessment process, and recognizing the above challenges, the Assessment Team began by establishing the goals of the assessment methodology listed in Table 4-1.

Table 4-1 Goals of the Assessment Methodology

- **Discriminates among the options:**
Facilitates the identification and understanding of the important differences among the three alternative technical methods that are subject to this assessment.
- **Accounts for all issues and builds on the available information base:**
To the extent possible, accounts for all of the issues and concerns that have been identified as important to Canadians, as well as the technical information and understanding that has been collected regarding the alternative approaches.
- **Effectively conveys Assessment Team opinions:**
Enables the Assessment Team to efficiently express and effectively communicate opinions based on the broad base of information that has been developed by and supplied to NWMO.
- **Facilitates an assessment of both contributing elements and an aggregated whole.**
- **Is sensitive to alternative values:**
Explicitly shows the weighting of choices and thus facilitates sensitivity analyses to explore the degree to which the choice among the alternatives depends on the value judgments that are made. This is critical because of the inevitable trade-offs required in judging the relative importance of achieving various objectives and coming to an integrated result.
- **Is effective in its ease of understanding, transparency, and communicability:**
Is intuitively easy to understand, transparent and effective in its capacity to communicate.
- **Provides a credible and defensible analysis.**

4.5 Choosing an Assessment Methodology

To support the selection of a specific methodology, NWMO commissioned a review of potential assessment methodologies.⁵² The review included several dozen social, technical, environmental and economic assessment methods.

Choice of the methodology was guided by the goals described above and influenced by a need to explicitly address multiple objectives in developing Canada's approach for dealing with used nuclear fuel. These multiple objectives are clearly demonstrated in NWMO's first discussion document, *Asking the Right Questions? The Future Management of Canada's Used Nuclear Fuel*. The Ten Questions that are offered there cover a broad range of objectives, including, for example, the maintenance of public health and safety, safeguarding environmental integrity, ensuring human health and safety, and maintaining security. Because of these multiple objectives, attention was restricted to a class of assessment methodologies known as "multi-objective" or "multi-criteria" decision tools. These tools are distinguished by their capacity to explicitly represent and work with such multiple objectives.

4.6 The Selected Assessment Methodology

From the sub-group of "multi-criteria" decision tools, the methodology known as multi-attribute utility analysis (MUA) was selected.

Multi-attribute utility analysis provides a step-by-step process for constructing and applying a decision model. It can be used to help identify a most preferred option, to rank options, to screen options down to a short list for more detailed analysis, or to distinguish acceptable from unacceptable choices. The foundations of multi-attribute utility analysis were originally developed in the 1940s and '50s by von Neumann and Morgenstern,⁵³ and Savage.⁵⁴ It is the subject of many books and professional papers.⁵⁵ Many technical requirements (governing scoring, scaling, weighting, and aggregating) must be satisfied to ensure that quantitative rankings produced by the model logically follow from the judgments of the Assessment Team. The long experience, careful reliance on mathematical logic, and overall evolved theory together provide a strong foundation for this methodology.

Over the past two decades, numerous applications of multi-attribute utility analysis have been conducted on a wide variety of decision problems in Canada, Great Britain, the United States and in many other countries, in both the private and public sectors. Examples include decision-making related to railways,⁵⁶ land use planning,⁵⁷ computer networking strategy,⁵⁸ energy,⁵⁹ choosing sites for hazardous facilities,⁶⁰ and many utility-related applications.⁶¹

⁵² Background Paper 7-11. Methodologies for Assessing Spent Nuclear Fuel Management Options. ETV Canada Inc., OCETA, Risk Wise Inc. and Science Concepts International.

⁵³ Von Neumann, J. and O. Morgenstern. *Theory of Games and Economic Behavior*, Second Edition. Princeton NJ: Princeton University Press, 1947.

⁵⁴ Savage, L. J. *The Foundations of Statistics*. New York: Wiley, 1954.

⁵⁵ See Keeney, R.L. and H. Raiffa. *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. New York: Wiley, 1976.

⁵⁶ Bana e Costa, C., F. Nunes da Silva, and J. C. Vansnick. "Conflict Dissolution in the Public Sector: A Case Study." *European Journal of Operational Research* (2000).

⁵⁷ Beinat, E. and P. Nijkamp (eds.). *Multi-Criteria Evaluation in Land-Use Management*. Dordrecht: Kluwer Academic Publishers, 1998.

⁵⁸ Brooks, D. G. and C. W. Kirkwood. "Decision Analysis to Select a Microcomputer Networking Strategy." *Journal of the Operational Research Society* 39 (1988): 23-32.

⁵⁹ Hope, M., Hope, C. and R. Hughes. "A Multi-Attribute Value Model for the Study of UK Energy Policy." *Journal of the Operational Research Society* 41 (1990): 919-929.

A key characteristic of multi-attribute utility analysis (as well as other multi-objective approaches), is its emphasis on the judgments of the decision-making team that the analysis is intended to serve. This is sometimes interpreted as a weakness, in the sense that applications may appear overly subjective. Judgment, however, is inherent in most important decisions, and this is especially so in the case of Canada's choice of an approach for managing used nuclear fuel. The fact that multi-attribute utility analysis makes those judgments open and explicit is an advantage. Since the judgments and assumptions are represented as inputs to a decision model, interested parties can explore whether changes would alter conclusions.

4.7 Components of the Assessment Methodology

There are four basic steps for applying multi-attribute utility analysis, including:

1. Identify objectives.
2. Estimate performance against objectives.
3. Assign value weights.
4. Combine performance estimates and weights, and conduct sensitivity analysis.

Identifying and Designing the Objectives

The basic premise of the selected assessment methodology is that the best approach for dealing with used nuclear fuel is the approach that best achieves Canadians' objectives. Thus, the first step is to identify what the objectives of the decision are. Objectives answer the question, "What do you want?" It is generally useful to classify objectives according to their level and to display them as a hierarchy. This is because some objectives ("higher-level objectives") can only be achieved if other objectives ("lower-level objectives") are achieved. Several issues are important for selecting and structuring these objectives. These are summarized below as a set of rules for governing the choice and design of objectives.

Rule 1. The objectives should span all the issues important for the decision.

Every effort should be made to ensure that all distinct, fundamental objectives critical to decision-making are included. This does not mean, however, that every fundamental objective that people can think about needs to be included. A useful question for determining whether an objective needs to be included is the following: Do the alternative approaches differ in the degree that they achieve this objective? We might all agree, for example, that "accessibility of public education" is an important objective. However, unless we thought that Canada's choice of an approach for managing used fuel would somehow affect public access to education, we would not want to include this objective in the objectives hierarchy. There are some exceptions to this; for example, when a concern applies to all options and does not help to differentiate between alternatives. A case in point is the need to ensure legal and regulatory compliance. Although an objective of society, ensuring legal and regulatory compliance is taken as a given and therefore is not used as a differentiating objective within the analysis.

⁶⁰ Merkhofer, M.W. and R. L. Keeney. "A Multi-attribute Utility Analysis of Alternative Sites for the Disposal of Nuclear Waste." *Risk Analysis* 7(2) (1987): 173-194.

⁶¹ For example, integrated resource planning using multi-attribute utility analysis is mandated by the British Columbia Utilities Commission. British Columbia Utilities Commission. "Resource Planning Guidelines." December 2003. <http://www.bcuc.com/PUB/MiscDocs/RPGuidelines_12-2003.pdf>

Rule 2. The objectives should be “fundamental choice objectives,” not “process objectives.”

The relevant objectives for the assessment methodology are those that capture what we desire to achieve as an end-point (e.g., secure facilities, environmental integrity), not how to achieve it (e.g., collaborative decision-making).

Rule 3. The objectives must be chosen and designed to avoid “double counting.”

Doing so ensures that the importance of achieving any objective does not depend on the degree to which any other objective is achieved. Oftentimes these requirements can also be met if the objectives relate to end-point choices rather than the means to those ends as described in Rule 2. Note that avoiding double counting does not preclude two or more objectives being influenced by the same factor. For example, an alternative that has the propensity to release hazardous materials into the environment can harm both the ecosystem and people. Thus, it is not double counting to conclude that such an alternative would perform poorly on both a human health objective and an environmental objective. This is appropriate counting, not double counting. The avoidance of double counting is particularly important for ensuring that weights are applied correctly.

Rule 4. The objectives must be amenable to either “maximizing” or “minimizing.”

This rule ensures a direction of preference in a quantitative way. In contrast, “optimize performance” is not an appropriate expression of an objective for this exercise.

Estimating Performance

Once objectives have been identified, the next step is to estimate the degree to which each available technical method would achieve each objective. In other words, for each objective and each approach, a best-effort is made to answer the question, “How well would this approach achieve this objective?” These assessments are made based on data, performance models, and through the application of best professional judgment; for example, as recorded on scoring scales. With scoring scales, more preferred options score higher on the scale, and less preferred options score lower.

Weighting

If one of the alternatives is judged through applying the methodology as performing best on every one of the objectives, then that alternative would be identified as being the preferred method. On the other hand, as is often the case, some alternatives may be estimated as performing best on some objectives, while others do better on other objectives. In such cases, it may be helpful to explore trade-offs. This is achieved by applying various weights to the objectives and exploring alternative preferences by examining our willingness to make trade-offs among the objectives. For example, a high weight assigned to “public health and safety” would mean society would be willing to accept a relatively large loss in the extent to which other objectives are achieved for a relatively small gain in public health and safety.

As described in Chapter 5, the Assessment Team has assigned a number of sets of illustrative weights to explore trade-offs and demonstrate the effects of doing so to the outcome of the assessment. Thus, the methodology includes sensitivity analyses that investigate whether different levels of emphasis on, for example, security or environmental integrity vs. cost might cause the approaches to be ranked differently.

To facilitate such sensitivity analysis, care must be taken to ensure that certain technical conditions are met in the way that the objectives are structured and in the way performance against those objectives is measured. Various techniques and tests come with multi-attribute utility analysis to ensure that the necessary requirements for assigning weights can be met.

Aggregating

Multi-attribute utility analysis provides a means of mapping out all of the factors that influence each objective, scoring individual factors, and then aggregating the result in an overall assessment of performance. In this way, insight on the many aspects of the decision (often the subject of specialized technical expertise) can be brought to bear in an organized and transparent way so that the underlying assumptions and driving values are explicit.

4.8 Cautionary Notes

In the next two chapters, the methodology described in general terms in this Chapter is applied in detail to the task facing the NWMO Assessment Team. In considering the process and results of this assessment, two cautionary notes should be kept in mind.

First, the assessment process documented in this report leads to a result that reflects the considered beliefs and judgments of the Assessment Team. These results are intended to help provide a strong foundation for the design of the recommendation that NWMO must ultimately put to the Government of Canada. However, in coming to its recommendation, NWMO will inevitably take into account social and political factors and other considerations outside the scope of the model. Some of those inputs will come from the public engagement following release of this report. As NWMO moves towards the design of its recommendation, the identification of strengths, weaknesses and other insights related to the three assessed technical methods may be as useful as the specific results of the completed assessment reported here. In sum, the results of this assessment provide an aid to, and not a replacement for, decision-making.

Second, as described in Chapter 2, the issue facing NWMO is a complex public policy issue and in many ways without precedent. Building a decision model for aiding Canada's choice of an approach for managing used nuclear fuel presents significant challenges not normally encountered in applications of any formal assessment methodology. In taking on this challenge, the Assessment Team has made its best effort to accurately apply the methodology while taking into account the concerns and values of Canadians. At the same time, it recognizes that its judgment reflects only what Team members can bring to the deliberations. The Team is hopeful that its work will be seen not only as an assessment but as an aid to others in coming to their own conclusions.

Application of the Assessment Methodology

5

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5.1 Introduction

Following on the generic discussion in Chapter 4 of the methodology used by the Assessment Team, this Chapter turns to the specific comparative assessment facing the Nuclear Waste Management Organization. First, the issue of building from a foundation provided by the values and concerns of Canadians is addressed. Second, the eight objectives that were chosen to guide the assessment are identified and their linkage to the original Ten Questions shown. Next, dealing with the concerns of both current and future generations is discussed and the time horizons for analysis are identified. The eight objectives are then explored in detail, factors influencing the performance of alternative management approaches for each objective are identified, and the process and logic of the assessment used by the Team is laid out. In a short summary note, three key assumptions underlying the assessment are identified.

5.2 Building from a Foundation of Canadian Values and Concerns

Since its inception, NWMO has continued to explore the values of Canadians as they relate to the long-term management of used nuclear fuel. With the release of its first discussion document *Asking the Right Questions? The Future Management of Canada's Used Nuclear Fuel* (available online at <http://www.nwmo.ca>), NWMO was able to reflect back to Canadians what it had heard through the first phase of its engagement activities and seek further input.

Subsequently, NWMO initiated a formal Citizens' Dialogue, a major initiative aimed at enhancing the understanding of Canadian values related to the issue of long-term management of used nuclear fuel in Canada. The Dialogue included twelve workshops held in different centres across the country and

involved more than 450 participants chosen to generally reflect Canadian society. This process took place in parallel with the work of the NWMO Assessment Team. The final Dialogue report will be released following completion of this report and will be posted online at <http://www.nwmo.ca>.

NWMO has been guided by the insight and advice of its Roundtable on Ethics which, through its early deliberations, helped set the frame for NWMO's approach to the inclusion of ethical considerations in its study. Integral to this advice, and as reflected in the first discussion document, was that rather than a separate stream of activity, ethical and value considerations need to be embedded in all aspects of the study, including the decision-making process and the outcome. The Roundtable continues to provide advice concerning an ethical and social framework within which to consider the management of nuclear wastes.

To take advantage of all inputs as the foundation for its work, the Assessment Team developed a synthesis of Canadian values drawing from all available inputs including early insights from the Dialogue and the Roundtable on Ethics. The result is listed in Table 5-1 below. The values captured in this table serve to re-enforce the values and concerns captured by the original ten questions articulated in NWMO's first discussion document.

In seeking to be responsive to these values in the assessment, the Assessment Team recognized that it is unlikely that all values which Canadians consider important can be reflected in their entirety in a single set of objectives. Nor can all the values which have been identified be satisfied equally by a single technical method or management approach.

Table 5-1 A Synthesis of Canadian Values Relevant to Used Nuclear Fuel

1. **Safety from Harm** – people's health and the environment upon which health depends are not unduly harmed.
2. **Responsibility and Respectfulness** – efficient use of natural resources, with due attention to long-term effects and consequences, the workings of the ecosystems and the rights of other forms of life; recognition of obligations to future human generations without having taken away their freedom to make their own decisions in the future; consideration of what may be the impacts of a decision about used nuclear fuel on other aspects of energy, scientific, industrial, or international issues.
3. **Flexibility and Adaptability** – confidence in the capacity and opportunity to benefit from new knowledge, improved technologies, or to deal with unanticipated events or situations.
4. **Accountability and Transparency** – confidence that decisions made will be executed and commitments fulfilled, with authorities and responsibilities clearly identified and assigned and results made available to the public.
5. **Progressive Learning** – expectation that research, experience, new perspectives will lead to improvement on results of decisions made in the light of current knowledge.
6. **Security** – confidence that there is a system and mechanism to identify and address threats from deliberately disruptive, violent, or unauthorized actions.
7. **Fairness** – host communities, segments of society that may be disturbed or impacted, do not suffer disadvantages in comparison with Canadians as a whole.

Because of competing values, a balancing is necessarily required that will involve weightings and trade-offs. The nature of the Assessment Team's efforts to appropriately balance competing values needs to be transparent to allow for examination and scrutiny by interested Canadians. Some of the competing values and preferences which have come to light through NWMO engagement activities, and which the Assessment Team attempted to address through the assessment, include:

- **Security vs. Accessibility.** The management approach selected must maximize safety and security but yet provide for retrieval if the wastes could be used in the future. There may well be a trade-off between reducing security risk versus the degree of accessibility to the used nuclear fuel that is maintained.
- **Remote location vs. Minimal handling and transportation of the waste.** Some Canadians feel used nuclear fuel should be removed from population centres; however, some Canadians would like to see handling and transportation of the waste be minimized to reduce possibility of accident. An additional challenge here is to allow for the inevitable migration of population over the time horizon that requires consideration.
- **Assume responsibility today vs. Provide flexibility to future generations.** Some feel strongly that the generation which enjoyed the benefits should implement a solution and not transfer this problem to future generations. However, some feel that whatever decision we make today should not preclude future generations making their own decisions. A central issue here is whether or not the institutional arrangements can be created that would allow the generations that create the problem to put aside enough funds to cover future costs if a management approach is chosen that involves on-going maintenance and operation.
- **Making a decision vs. Managing uncertainty.** Although there is a desire for Canada to find a waste management solution now, there is also a desire to embed a strategy for managing uncertainty over a long timeframe in whatever decisions are made.

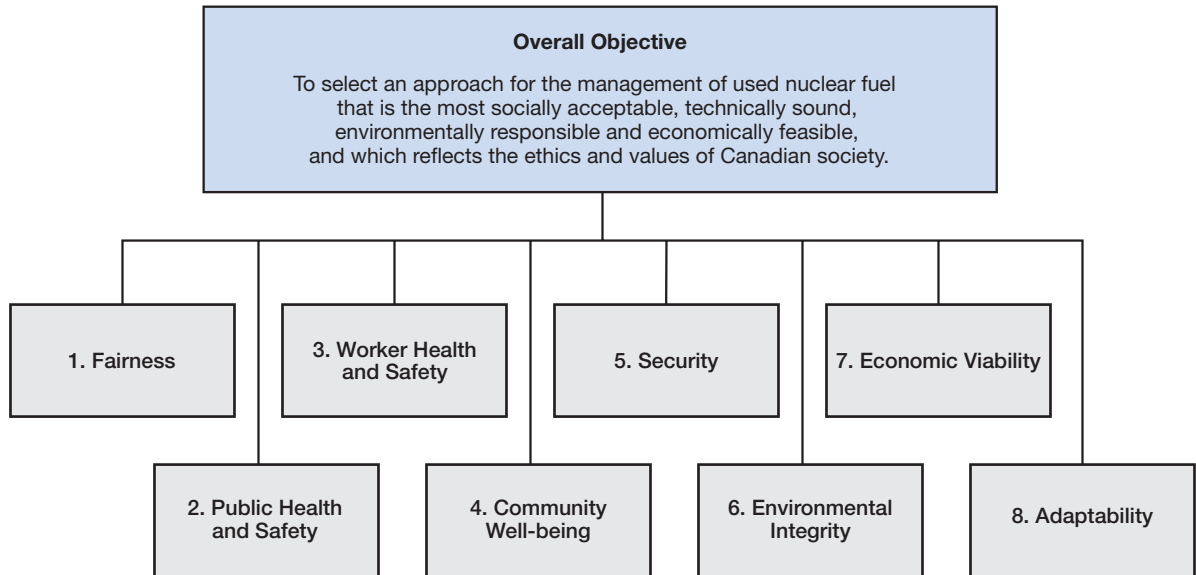
5.3 Choosing the Objectives

Following the rules articulated in Chapter 4, and guided by the Ten Questions from *Asking the Right Questions?*, the Assessment Team designed a multi-level hierarchy to guide its assessment process. At the highest level is found an overarching objective: “to select an approach for the management of used nuclear fuel that is the most socially acceptable, technically sound, environmentally responsible, and economically feasible, and which reflects the ethics and values of Canadian society.”

In the second level, the eight objectives are identified that capture the Assessment Team's views on what must be accomplished in order that this highest level objective be achieved. Below each objective lie more detailed influencing factors. In this way, the overarching objective cascades into progressively more detailed components in a hierarchical form. Each of the detailed factors can be assessed individually and then drawn together following the mapping provided by the hierarchy to facilitate an overall aggregated assessment, first by each of the eight objectives and then for the overarching objective as a whole.

Figure 5-1 shows the overarching objectives along with the eight second-level objectives. Lower level details are discussed later in this chapter.

Figure 5-1 Objectives Hierarchy Showing the Top and Second Levels of the Hierarchy
Below Each of the Eight Objectives Lies a Detailed Set of Influencing Factors.



5.4 The Link to the Original Ten Questions

NWMO initiated its work in 2002 with a program of engagement to learn about the concerns and values of Canadians. Based on the initial phase of engagement, the Ten Questions described in NWMO's first discussion document were offered for discussion as a starting point for an Analytical Framework to be used by NWMO in considering alternative management approaches. In subsequent discussions with Canadians, broad support has been indicated for the substance contained within the Ten Questions. This support has been further re-enforced by the study of Canadian values discussed in Section 5.2.

The Assessment Team was charged with the task of refining the foundation provided by the Ten Questions for practical application. The Assessment Team took great care to work from this starting point. However, the rules and insight brought by the multi-attribute utility analysis methodology led to a re-arrangement of how the values and concerns were expressed in the eight objectives.

Figure 5-2 Elements of the Objectives Hierarchy Plotted Against the Original Ten Questions

Note that the numbers assigned to each of the ten questions and eight objectives do not imply a prioritization of concerns. All are equally important.

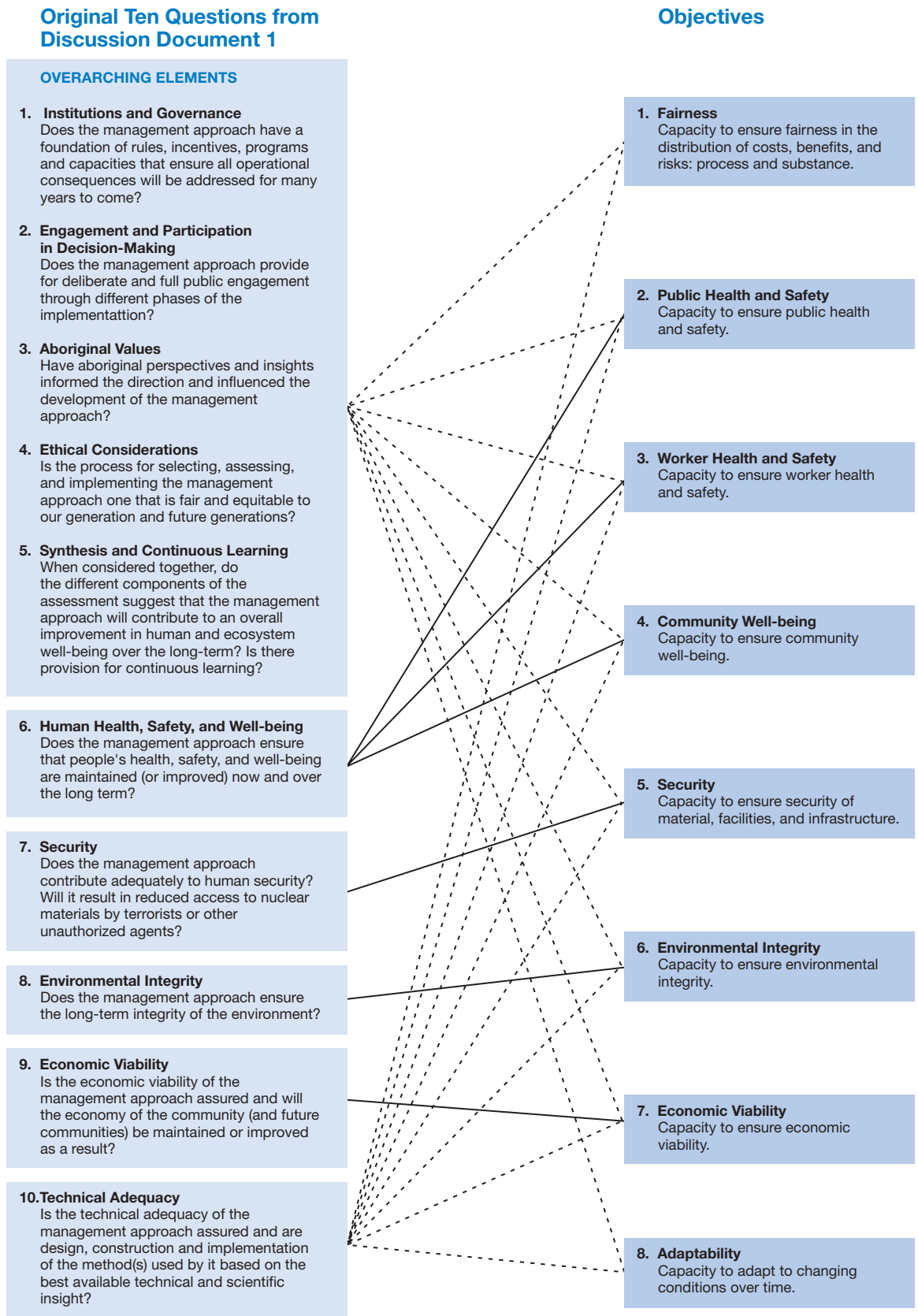


Figure 5-2 shows the relationship between the original Ten Questions and the components of the objectives hierarchy used in the comparative analysis. Variations between the original Ten Questions and the Elements of the Objectives Hierarchy arise for the following reasons:

1. Some aspects of the original Ten Questions are generic and apply across the entire assessment methodology, including all of the elements as well as the aggregated result. This applies to the issue of Aboriginal Values (Question 3), Ethical Considerations (Question 4), parts of Institutions and Governance (Question 1) and Synthesis and Continuous Learning (Question 5). The implementation plan will be dealt with in detail in the Draft Final NWMO report that is scheduled for release in early 2005.
2. Some aspects of the original ten questions require a higher degree of specification to be useful in a comparative analysis than was provided by the original questions. An example here is the split of Human Health, Safety and Well-being (Question 6) into three components (Public Health and Safety, Worker Health and Safety, and Community Well-being).
3. Each objective sits at the top of a pyramid of factors that become progressively more detailed towards the base. When this detail was laid out, certain aspects of the original Ten Questions translated more logically into more detailed objectives in the third level underneath the eight objectives. Examples here are: (1) the adequacy of institutions and governance mechanisms; and (2) availability of necessary capacity, mechanisms, and resources for the long term, both of which are found beneath Objective 8, Adaptability (see Appendix 4).
4. Some aspects of the original Ten Questions apply to more than one objective. For example, public participation is an influence on Objective 1, Fairness; Objective 3, Community Well-being; and Objective 8, Adaptability.

5.5 Current and Future Generations: Setting the Time Horizon of Analysis

The Ten Questions clearly articulate a concern for both current and future generations and how to best address this issue was a significant topic of discussion for the Assessment Team. While those now living can justifiably attempt to speak for current generations – at least we are of that generation and we can try to allow for a wide range in any case – we cannot know or assume the values, concerns, and thus the objectives that will drive the decisions of future generations, particularly given the long time-horizon that is before us.

The Team however, remained cognizant of the fact that while it is not possible to know those future objectives, the present generation has an obligation to do what is possible within its means to:

1. Take steps to ensure that choices made today do not impose undue risks, obligations, or burdens on future generations.

2. Facilitate choice for future generations rather than foreclose options. Such choices may be related to, for example: the use of materials that might be today considered hazardous waste and tomorrow a valuable resource; use of future generations' own resources for addressing their own priorities rather than costs related to management of waste generated today; or the ability to experience healthy people and a healthy environment uninhibited by stress imposed as a result of today's human activity.

As a result, the Assessment Team opted to proceed as follows. It focused on a comparison of the various technical methods using today's perspective as reflected in the eight objectives described in Section 5.3. After discussion and consideration of the information and inputs from other NWMO activities (Background Papers, Dialogue with Canadians, Traditional Knowledge Workshop, the Roundtable on Ethics, and the Scenarios Team), the Assessment Team found it useful to consider the assessment of alternative management approaches in two time periods as follows:

Period 1. From the present until 175 years from now.

This period roughly corresponds to the "seven generations" used by Canadian Aboriginal peoples as a target or goal for assessment or evaluation of benefits or consequences of current issues. It covers the period that would include construction, filling, and initial operation of the selected facility; the period when institutional and economic structures and activities may have some continuity to those of the present; when engineering predictions and the characteristics of human-made objects can be reasonably firm; when environmental and ecological aspects, although undoubtedly changing, can have some reasonable similarity to the present. It is also the period when the radioactive wastes produced from 1950-2010 will have cooled to near-ambient temperatures and many of the activation products produced in the fuel will have significantly decayed.

Period 2. Beyond 175 years.

Beyond seven generations and up to 10,000 years, Aboriginal perspectives and future scenarios work conducted by NWMO suggest that continuity from the present conditions and situations cannot be assumed, socially, institutionally, or environmentally. Although the geological characteristics can be predicted with some confidence, the vagaries of physical environmental conditions and human-induced or natural stresses on the ecosystem make any assessment of the human-ecological interactions extremely speculative. The radioactivity of nuclear fuel wastes will continue to decay, but isotopes of chlorine, cesium, strontium and plutonium will remain radioactive and pose potential, although declining, risks.

As the above assessment progressed, an attempt was made to include a consideration of whether or not the future choices of future generations were implicated and how. In so doing, the Team tried to stay away from pre-judging future values and concerns.

5.6 The Eight Objectives in Detail

Each of the eight objectives is described in detail below. To ensure that each objective and its interpretation reflects the values of Canadians, a general principle is articulated to guide the assessment in each case. These principles provide a means of testing against both capacity to achieve the objective as well as measuring progress over time. The principles are not standards or criteria which must be met. Rather, they are statements of what the actions within that objective should strive for. In this way, the general principles should guide, not specify, the assessment of the alternative management approaches.

Objective 1: Fairness

The selected approach, among other things, should produce a fair sharing of costs, benefits, risks and responsibilities that is regarded as being as fair as possible now and in the future.

General Principle for Guiding the Assessment of Fairness

The management system and technologies used should ensure that the persons and communities likely to be most directly affected by any activities or consequences of the management of the used fuel have opportunity to participate in decisions in advance of the establishment of the used nuclear fuel management facility; that characteristics of the distribution of short-term and long-term health, environmental, or economic costs and obligations are understood and accepted at the time of decision; and that adequate attention is given, as far as is possible by the current generation, to intra-generational, inter-generational and inter-species aspects of the system selected.

Objective 2: Public Health and Safety

Public health ought not to be threatened due to the risk that people might be exposed to radioactive or other hazardous materials. Similarly, the public should be safe from the threat of injuries or deaths due to accidents during the transportation of used nuclear fuel or other operations associated with the approach.

General Principle for Guiding the Assessment of Public Health and Safety

The management system and technologies employed should be such that the direct or indirect risk to the health and safety of individuals or communities in areas that could be affected by the used nuclear fuel management facilities in the near future is fully acceptable according to current safety standards; that the possibilities of unplanned events that could present unexpected risks or stresses have been considered and appropriate contingency action provided for; and that there is no foreseen possibility of greater risks to the public from the used nuclear fuel facility at any time in the future.

Objective 3: Worker Health and Safety

Construction, mining, and other tasks associated with managing used nuclear fuel can be hazardous. It is desirable that the selected approach not create undue or large risks to the workers who will be employed to implement it.

General Principle for Guiding the Assessment of Worker Health and Safety

The management system and the technologies used, the design, the construction methods and the operational and monitoring procedures should be such that, in addition to complying with good engineering practices and all industrial safety regulations, workers in any way involved with the used nuclear fuel facility will not be subject to risks or harmful exposures, chronic or accidental, greater than those acceptable to Canadian or international authorities at the time of construction; and that workers engaged in future monitoring or maintenance activities will not be subject to risks greater than those acceptable today.

Objective 4: Community Well-being

The approach that is selected and the way it is implemented will determine the specific communities that are impacted and the nature of those impacts. For example, towns near the facilities required by the approach may be affected economically through impacts on jobs and property values. Differing attitudes within a community can lead to polarization that can severely degrade the social fabric. Nearby communities are not the only ones, however, that may be implicated. Many groups may feel that their shared interests are affected regardless of whether they live physically close to used nuclear fuel management facilities. Depending on the sites that eventually are proposed for consideration, Canada's Aboriginal peoples may have a particularly significant stake.

General Principle for Guiding the Assessment of Community Well-being

The organizational system and the technologies selected for management of used nuclear fuel should be such that the nearby communities and all those in the region that could be involved in, or affected by, the construction, filling, maintenance or monitoring of the used nuclear fuel management facility, or by the transport, manufacture of containers or other related industrial activities, will not be adversely affected through chemical contamination or other environmental disruption, but will benefit as much as possible from the economic activity; and at the same time not be handicapped socially or culturally by virtue of being host to used nuclear fuel which other parts of the country do not want. Implications for the well-being of all communities with a shared interest are to be considered in the selection and implementation of the management system and related infrastructure.

Objective 5: Security

The selected management approach needs to maintain the security of the nuclear materials and associated facilities. For example, over a very long timeframe, the hazardous materials involved ought to be secure from the threat of theft despite possibilities of terrorism or war.

General Principle for Guiding the Assessment of Security

Without infringing on the freedoms of individual Canadians, the used nuclear fuel management system and the technologies selected should be such that unauthorized access to the used nuclear fuel management facility will be exceedingly difficult, and that attempts at unauthorized access will be detected within a system that ensures appropriate action; it should assure Canadians that their health, safety and the integrity of the environment will not be compromised over time because of the presence of the used nuclear fuel and their potential for being involved in social disruption or institutional changes.

Objective 6: Environmental Integrity

The selected management approach needs to ensure that environmental integrity over the long term is maintained. Concerns include the possibility of localized or widespread damage to the ecosystem or alteration of environmental characteristics resulting from chronic or unexpected release of radioactive or non-radioactive contaminants. Concerns also include stresses and damage associated with new infrastructure (such as roads and facilities) and operations (e.g., transportation).

General Principle for Guiding the Assessment of Environmental Integrity

The management system should be designed and technologies selected such that the physical, chemical and biological stresses on the environment imposed by the used nuclear fuel management facility, including cumulative effects, changes over long time periods, and the potential consequences of failure of any part of the containment system, are within the natural capacity of environmental processes to accept and adjust, thus ensuring the long-term integrity of the environment.

Objective 7: Economic Viability

Economic viability refers to the need to ensure that adequate economic resources are available, now and in the future, to pay the costs of the selected approach. The cost must be reasonable. The selected approach ought to provide high confidence that funding shortfalls will not occur that would threaten the assured continuation of necessary operations.

General Principle for Guiding the Assessment of Economic Viability

The system for managing used nuclear fuel, including the selection of technologies, must have cost estimates that are thorough and reasonable, include financial surety that covers the full facility life-cycle including construction, filling and long-term maintenance as required. All of this must be undertaken in a way that is fully transparent and accountable.

Objective 8: Adaptability

If something is adaptable, it means that it can be modified to fit new or unforeseen circumstances. Although this is an attractive feature for a selected approach, the objective of adaptability as defined here is broader. Adaptability is regarded as a fundamental objective for selecting an approach for the long-term management of nuclear fuel, not just a means to help ensure that the other objectives identified in the hierarchy can be achieved.

The reason that adaptability was identified as a fundamental objective derives from the very long time-frame over which the approach must operate. Generations in the distant future may see things differently than we do today. They may have different objectives than those represented in Figure 5-1, or, at least, they may place very different weights on those objectives. It is desirable, therefore, that we facilitate the ability of future generations to pursue and attain their own objectives, whatever those objectives may be. Thus, adaptability reflects our desire for an approach that provides flexibility to future generations to change decisions. It also includes our desire not to place burdens or obligations on future generations that will constrain them. Furthermore, adaptability, as defined here, includes consideration of the degree to which the selected approach is able to function satisfactorily in the event of unforeseen “surprises.”

General Principle for Guiding the Assessment of Adaptability

The system for management of used nuclear fuel should be adaptable and flexible, and capable of adjusting technologies and procedures if new information is obtained or new equipment or materials become available that will assure or improve the integrity of the management system and, possibly, reduce the costs of establishment, maintenance, and monitoring. Similarly, the system should preserve the ability of future generations to make decisions that they see as being in their best interests.

5.7 Factors Influencing the Achievement of Objectives

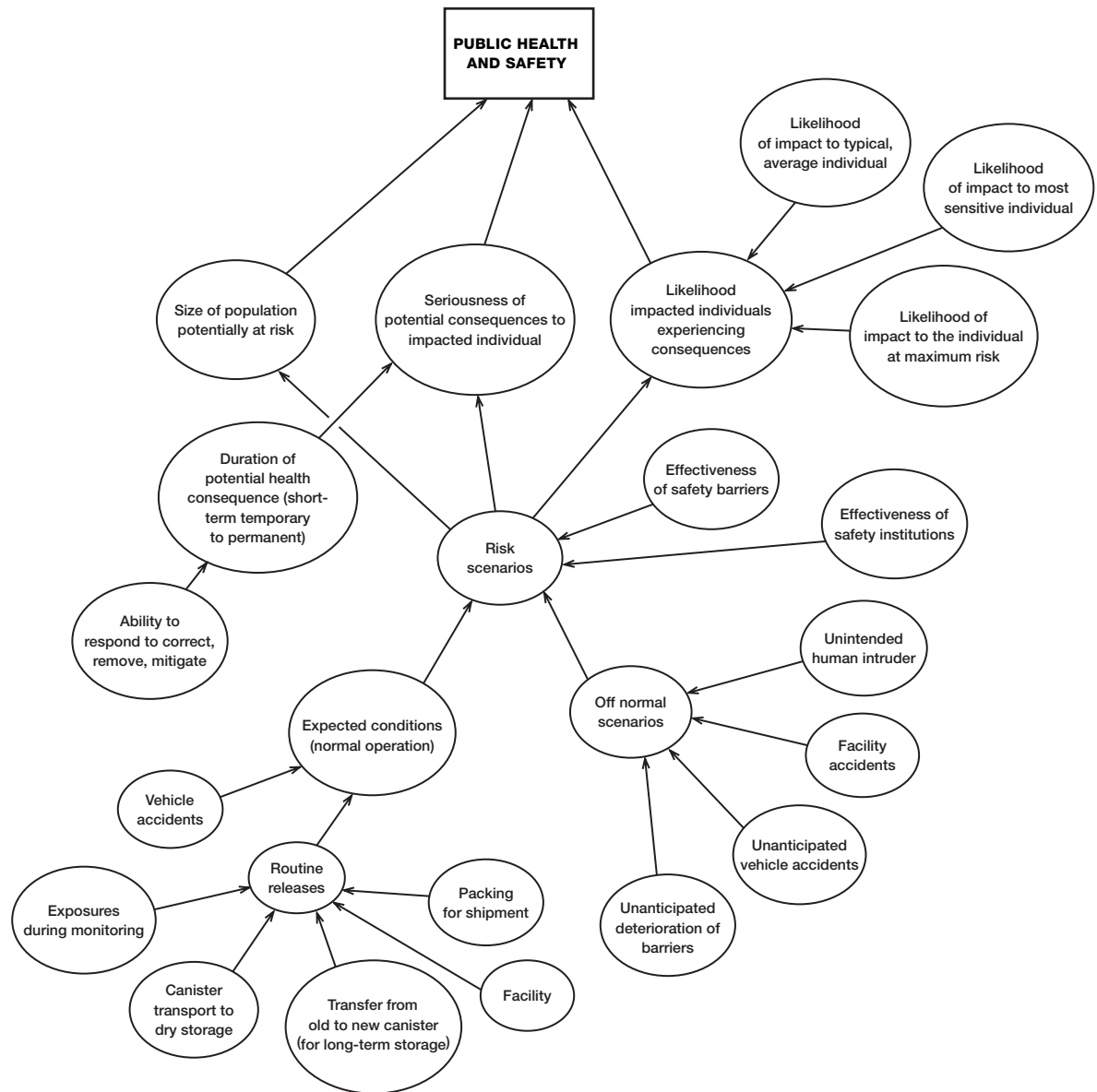
Within each of the eight objectives lies a complex mix of interacting factors that will influence the capacity of any given technical method to perform well on that objective. A significant task of the Assessment Team was to identify and map these influencing factors. The resulting “influence diagram” represents the third, lower level of the hierarchy that comprises the analytic model being used by the Assessment Team.

Figure 5-3 provides an example of an influence diagram, in this case for public health and safety, and Appendix 4 contains the influence diagrams for all of the eight objectives. In these diagrams, influencing factors are shown within a bubble and the dominant direction of influence is signalled by the connecting arrow.

The influence diagrams for each objective were used to systematically guide each individual’s assessment of each alternative technical method, for each time-horizon of analysis.

Influence diagrams are most easily interpreted “from the top down”. For example, in Figure 5-3 there are three “top-level” factors with arrows going directly into the box representing the degree of public health and safety achieved with any technical method: (1) the size of the population potentially at risk;

Figure 5-3 Sample Influence Diagram Showing Factors Judged to Influence the Degree of Public Health and Safety Provided by an Approach



(2) the seriousness of the potential consequences to an impacted individual; and (3) the likelihood that an impacted individual would experience the adverse consequence.

Interestingly, these factors are exactly the factors that a risk assessor would need to know in order to quantify risk (the third factor is commonly referred to as “individual risk”, while the product of the first and third factors are typically referred to as “population risk”). The factors influence the degree of public health and safety risk. An approach that (1) places a larger number of people at risk, or (2)

subjects people to more serious consequences (e.g., death as opposed to injury), or (3) makes it more likely that an individual within the population at risk would experience that adverse consequence, would, other things being equal, create a higher public health and safety risk.

The factors with arrows going into the top three bubbles identify the factors judged to influence each. For example, each of the top bubbles is influenced by a “risk scenario”. The concept is that the assessment of health and safety risks requires identification of possible sequences of events or “risk scenarios” that result in people being exposed to hazardous materials or other dangers. Thus, the logic identified in the influence diagram is that the risk scenarios that might occur under a given approach determine the populations potentially exposed, the nature of the potential adverse consequences, and the likelihood that the exposed individuals will experience those consequences, which, in turn, determine the risk associated with the approach.

When the three approaches are compared on this objective, the one that most effectively addresses the risks aggregated from all factors is assessed to perform better. The topic of “risk scenario” is discussed in greater detail in the next section.

5.8 The Concept of Risk Scenarios

The term “risk scenario” appears often in the influence diagrams constructed to guide the assessment of the approaches against the various objectives. The reason is that for many of the objectives, it is possible to envision future events or possibilities that could significantly influence how well an approach performs against an objective. However, the use of the word “scenario” in this case is different than its usage for example by the NWMO Scenarios Team in its exploration of alternative futures (see Chapter 6). It is also different than its use by those who would “project” a given condition (temperature under various conditions of climate change) or level of activity (such as the future use of nuclear energy) into a “high”, “medium” and “low” scenario.

Typically, a risk scenario involves some sort of external event (e.g., earthquake, severe transportation accident) that could trigger a non-normal response (e.g., loss of containment of radioactive materials) followed by the potential for creating harm (e.g., dispersion of released material and exposures of people or environmental resources). Generally, there is not one single risk scenario that is relevant, but a range of scenarios about future possibilities. These scenarios are not “forecasts”, for no one can say with any certainty whether or not such future events will occur. Rather they represent possibilities (often based on a kind of “gut feeling”) about what could happen to our society in the future.

Because of the very long timeframes involved, the risk scenarios account for two quite different possibilities not typically addressed in risk assessments. The first relates to the significant changes that may occur in the natural environment, especially climate change (and the chance of increasingly extreme weather events such as severe storms), but also including the possibility of other major, catastrophic events, such as earthquakes or meteorite impacts. As all Canadian nuclear power plants are on large rivers, lakes or sea coasts, significant changes in water or sea-level could be very important.

The second type of risk scenario relates to changes that may occur in human societies and their institutional arrangements: will the kind of society we have now persist into the future, with nations as we know them with strong democratic governance and administrative structures intact? Or, should we allow for at least the possibility of social breakdown, even social chaos, leading to the abandonment of modern governance institutions? If such events are possible, the potential consequences on the performance of the approaches need to be considered through the use of risk scenarios.

Two important dimensions need to be considered – expected frequency and expected consequences – into one’s reasoning: We ought to worry less about potentially catastrophic impacts, for example, if we are guessing that there is a negligible probability the event will occur. Similarly, if impacts are rated as negligible, we don’t have to worry too much even if we estimate that there’s a good chance the event may occur.

On the other hand, the types of risks usually referred to as “low-probability, high-consequence” events are genuinely worrisome. Relatively rare natural events (such as severe earthquakes in regions of high population density) or social catastrophes (such as major terrorist attacks) have huge consequences, in terms of both economic and psychological impacts. Risk management authorities spend a lot of time in assessing such risks and, where possible, in taking specific precautionary steps to reduce both the likelihood and the consequences of their occurrence. The elaborate multi-barrier engineering designs for storage and disposal of used nuclear fuel provide another illustration of this type of precautionary approach.

In this type of reasoning, our expectations about the future are properly referred to as “subjective estimates”. (This is another way of expressing what was earlier called “gut feelings”.) It is impossible for anyone to say what type of management approach might be best suited to securing used nuclear fuel, over thousands of years, without making some kind of judgments about what is most likely to happen in the future.

Assessment Team members used the above kind of thinking to guide their assessments. Thus, the resulting judgments reflect each person’s subjective assessment of the likelihood and seriousness of the risk scenarios under each objective that impact the performance of the alternative approaches.

5.9 Assessment Logic: Scoring the Performance of Alternative Methods

The influence diagrams (of which Figure 5-3 is an example) served as “logical road maps” for each Team member as they undertook their assessment of how well each alternative approach would likely perform with regard to each influencing factor under each objective. In this way, consistency was achieved in the logic of the assessment process and in the discussions of how well each alternative approach would perform with respect to each of the eight objectives as represented by each of the eight influence diagrams. This analysis was performed for the two time periods (the present to 175 years, and from 175 years onwards). The exception was the Fairness Objective which did not allow scoring for separate time periods because it compares performance across generations.

Qualitative Assessments

To simplify the development and assessment of judgments, the “colour scale” shown in Table 5-2 below was used. Working with each influence diagram from the bottom up, colours were assigned first to each influencing factor and subsequently to each of the eight objectives based on a synthesis of qualitative reasoning and expert judgments against the descriptions provided in the table. For example, if an influencing factor was not a significant issue it would be coloured green and if it was an issue of high concern, it was coloured red.

Table 5-2 Colour codes used in the assessment

COLOUR CODE	DESCRIPTION
GREEN	Not a significant issue or problem; essentially no impact or effect; about as good as could be expected; in the top 1% of possibilities.
Green-Aqua	Between green and aqua
AQUA	A small issue or issue of lesser significance; very low impact or effect; the factor cannot or ought not to be ignored but it is not as important as it is in other contexts or alternatives; it is at the more favourable (say 25%) range of possibilities.
Aqua-Blue	Between aqua and blue
BLUE	A moderate or moderately important issue; the factor represents a magnitude or level of importance in the middle (say 50%) of possibilities; although it may be of a magnitude to raise concerns, the factor is a bigger or more important concern in other alternatives or contexts.
Blue-Yellow	Between blue and yellow
YELLOW	A relatively high or adverse magnitude; within the higher, more adverse (say 75%) range of possibilities but not necessarily extreme or unacceptable in and of itself.
Yellow-Red	Between yellow and red
RED	Very high or among the most extreme (say top 99%) of possibilities or alternatives; deserving of significant attention. Depending on related or interacting considerations, possibly unacceptable.
Un-coloured	Information insufficient for assessment or for differentiating the alternatives; not formally assessed.

Assessments were performed for each approach for each of the applicable time periods for each objective. Each Assessment Team member presented to the team as a whole his or her qualitative assessments and described the rationale underlying the assessment. Differences of opinion were then discussed, and the sharing of views and rationale often resulted in individuals changing their individual assessments. Chapter 6 provides a summary of the rationale and the assessment developed for each alternative under each objective.

Quantifying the Qualitative Assessment

The colours assigned to each objective (based on a synthesis of each person's qualitative reasoning and judgments) were then transformed to a quantitative score using a scale of 0–100 as follows. An assessment of “Red” on the colour scale was given a score of zero corresponding to a definition of “an extremely poor, unacceptable level of performance on the objective”. An assessment of “Green” was given a score of 100, consistent with a definition of “an ideal performance with respect to the objective (e.g., a situation where absolutely no adverse consequences would occur)”. The other colours were provided intermediate scores that were distributed linearly on the scales between the unacceptable and the ideal. For example a score of 50 was interpreted to represent a level of performance whose value was halfway between the (negative) value of an unacceptable performance and the (positive) value of ideal performance.

A representation of the Team's collective opinion was developed in the form of a range of scores and an average for use in the comparative assessment. The range reflects differences in the judgements and reasoning among the individual members of the Team and provides an indication of the uncertainty and complexity that exists. The ranges of scores were plotted on bar graphs to allow visual comparison and the average was marked. All of these results are provided in Chapter 6.

For computing the ranges of scores, single outliers were dropped. That is, the highest and lowest scores when assigned by only one person were dropped. Thus, the ranges reported in Chapter 6 extend from highest to lowest scores, excluding such outliers. For computing averages, single outliers were rolled back to the second highest and second lowest scores, respectively. At any time during this process, each Team Member could change his or her scores as a result of discussion.

Dealing with the outliers in this way promotes fair scoring. It ensures that no single individual can bias either the range or average by assigning unrealistic scores. Although this process, in some cases, reduced the range in the scoring, the Team members were satisfied in the end that the resulting scores and ranges reflected their collective views.

5.10 Key Assumptions Underlying the Assessment

The next Chapter provides a summary of all the assigned scores as well as the overall assessment that resulted. In making its assessment, the Team made the following three key assumptions:

- 1. The Analysis Assumes that the Approaches can be Built and Implemented.** Each of the technical methods listed in the mandate of NWMO has had thorough engineering analysis. For the purposes of its assessment, the Assessment Team felt it reasonable to assume that each of the approaches could, if chosen, be built and implemented from a technical perspective. Clearly, there are reasons why implementation might not occur – failure to achieve legal or regulatory requirements, failure to achieve political support, or lack of public acceptance, for example.
- 2. Assurance of Safe Performance is Yet to Come.** The Assessment Team anticipated that assurance of safe performance will be examined in detail through subsequent phases of the decision-making process, including environmental assessment and licensing. Demonstration of performance over long periods of time is obviously impossible, but ability to assess likely long-term integrity is continually improving.
- 3. Performance Against Design Specifications not Necessarily Assumed.** Although it is assumed that each of the three alternative approaches could be implemented, it is not assumed that each approach would necessarily always perform according to its design specifications. In other words, in each case the risks that a selected approach may not perform well are explicitly considered as part of the assessment.

Assessment Results

6

CONTENTS

- 6.1 Assessing the Eight Objectives
- 6.2 Sensitivity of Results to Alternative Weighting Judgments
- 6.3 Exploring the Implications of Future Scenarios
- 6.4 Summary
- 6.5 Comments

The discussion which follows summarizes the results of Assessment Team work, including:

- Scoring of the three methods on each of the eight objectives.
- Efforts to explore various approaches to weighting of the objectives to create an overall score for each method.
- Conclusions based on the scoring exercise.

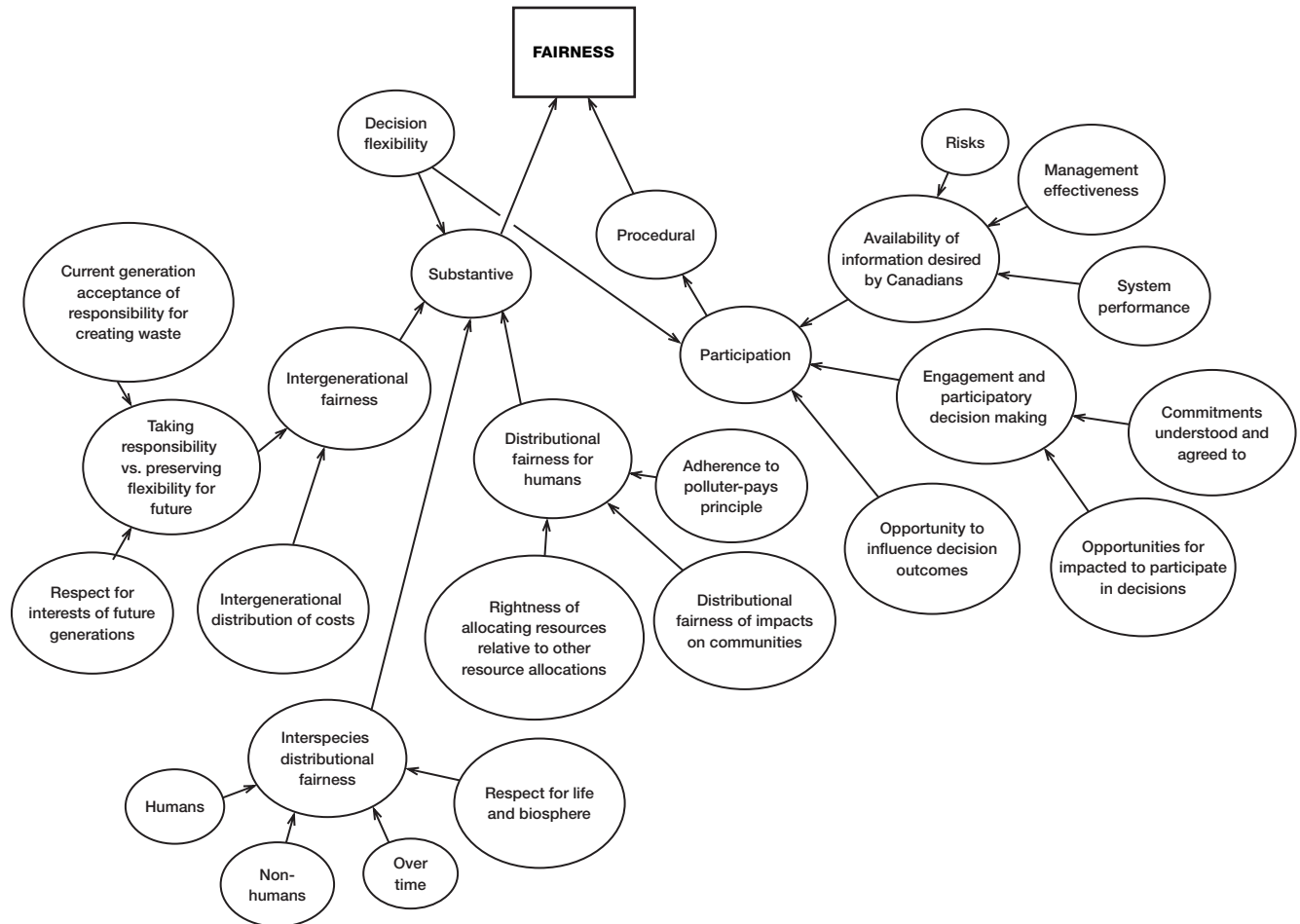
6.1 Assessing the Eight Objectives

Fairness

In its assessment of fairness, the Team considered issues of both substantive and procedural fairness. Substantive fairness includes consideration of how the costs and benefits associated with the approach would be distributed across various people and between humans and other species. It also includes consideration of inter-generational fairness. A key question for inter-generational fairness is the balance struck between the desire that the current generation take responsibility for resolving the problem once-and-for-all versus the desire not to overly constrain future generations by the choices we make today. Procedural fairness is mainly a function of the degree to which the approach would allow for the participation of concerned citizens in key decisions about how the approach would be implemented. This, in turn, depends in part on the opportunities for decision-making provided by the approach and the availability of information that would be helpful for driving those decisions. The complete list of influences considered is notionally identified in Figure 6-1.

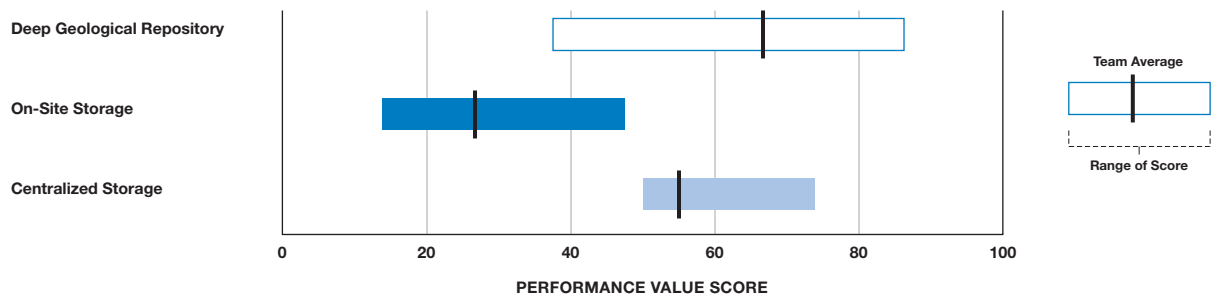
The fairness scores assigned by the Team are shown in Figure 6-2. As indicated, on average, the Assessment Team viewed the deep geological repository (DGR) approach as the most fair, followed by centralized storage and on-site storage. On-site storage was viewed as least fair for several reasons. Perhaps most importantly, the on-site storage approach would obligate existing reactor sites with on-going, long-term management of used nuclear fuel. This function was not envisioned when the reactor

Figure 6-1 Fairness Influence Diagram



sites were initially chosen, nor was it understood by the communities and businesses that have chosen to locate in the vicinity of these facilities. By contrast, the centralized storage and DGR approaches involve facilities that could be located away from existing communities, thus lessening the unfairness of involuntarily subjecting many people to additional risks. Indeed, the opportunity for public participation in the locating of a centralized storage or DGR facility was seen to be a positive attribute with regard to fairness, assuming that the siting process would be a voluntary one.

Another fairness concern with the on-site storage approach is that it would force future generations to take responsibility for dealing with the fuel consumed by this generation through the requirement to actively manage the waste to ensure safety. If not managed properly, a burden of risk has been shifted to future generations. The centralized storage approach also requires future generations to continue to maintain the facility. However, the costs and other burdens would likely be higher in the case of on-site storage given that multiple facilities would be involved.

Figure 6-2 Fairness Scores

Although DGR was rated highest for fairness, the range of scores assigned to DGR was, as shown in Figure 6-2, relatively wide, indicating disagreement among the members of the Assessment Team. Those that scored DGR very high felt that a major fairness advantage of DGR was the fact that it would remove the burden on future generations to take further actions. Those that scored it less highly were concerned that DGR removed too much flexibility from future generations to make their own choices about how the waste should be managed, and provided too little opportunity to monitor the performance of the system and take corrective action. Another disadvantage of DGR is that it would provide less opportunity for citizen participation over the long term, since DGR, by its nature, provides little flexibility for making fundamental changes without considerable additional costs.

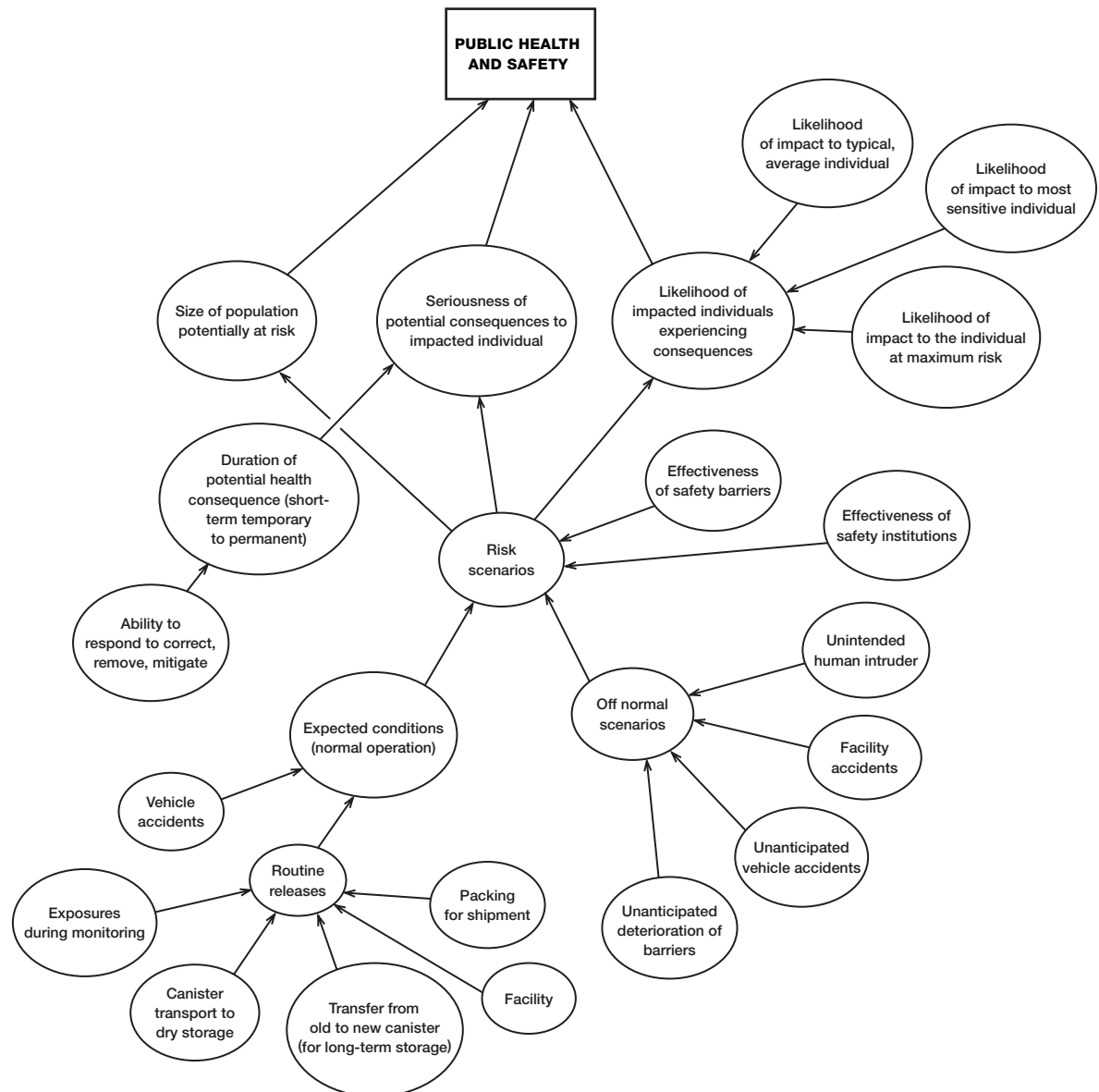
Nevertheless, nearly every member scored DGR higher than the other two approaches. Other advantages cited for DGR included the fact that the current generation would bear most of the costs, which was regarded as fair since our generation also obtained the most immediate and direct benefits from using the fuel. Another fairness advantage of DGR is that, because the costs would need to be “paid up-front,” there is more assurance that those costs would be paid by the utilities, consistent with the “polluter pays” fairness principle. While it is true that DGR makes it more difficult for future generations to have flexibility to shift to another approach, it is also possible that on-site or centralized storage may limit future flexibility. For example, if at some point in the distant future it was decided that used fuel should be buried, it might at that point be impossible to find a site with suitable geology that was not already highly populated with people and/or insufficient monies may remain to fund it.

Public Health and Safety

The public health and safety afforded by each approach was assessed under both the short (0-175 year) and long (>175 year) timeframes. Risks were estimated under normal, expected operating conditions and under “off-normal” scenarios in which members of the public might be inadvertently exposed to hazards associated with the various approaches. The complete list of influences considered is notionally identified in Figure 6-3.

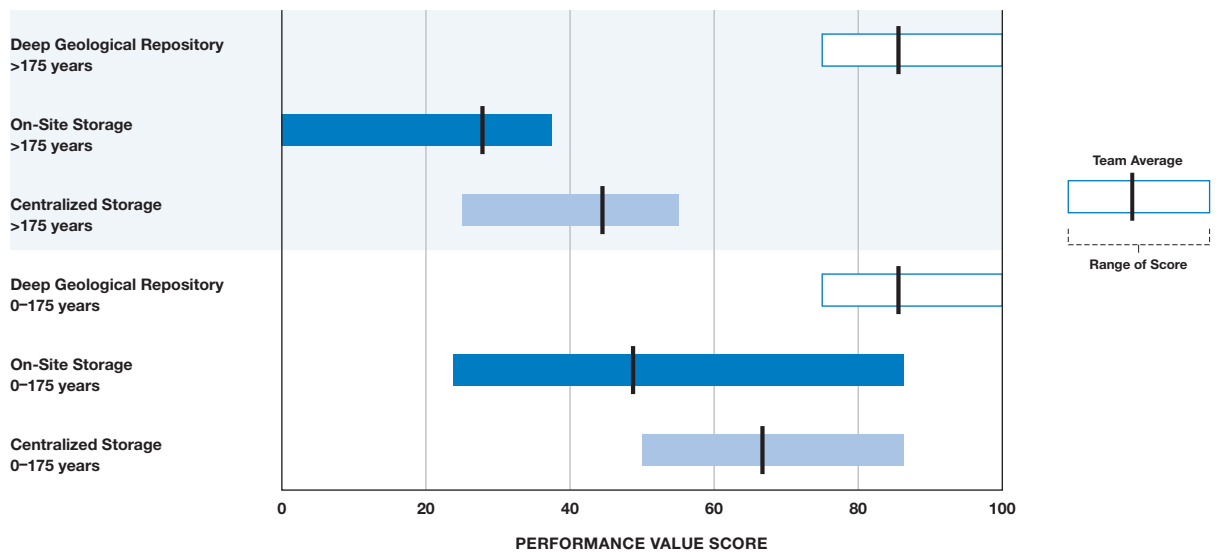
Under normal operating conditions, risks associated with the following operations were considered: packing for shipment, transfer from old to new canisters, vehicle accidents, canister transport to dry storage, and exposures during monitoring. None of these risks was estimated to be large with any of the approaches. However, with DGR or a centralized approach, large quantities of used fuel would need to be transported away from the reactor sites. Even though the risk of release of radioactive material was judged to be low, the vehicles involved might contribute to collisions and

Figure 6-3 Public Health and Safety Influence Diagram



other traffic-related accidents that could cause injuries to the public. The main “off-normal” risk scenarios considered included unanticipated deterioration of the natural and engineered barriers constructed to isolate the fuel, large-scale transportation accidents (e.g., the wreck of a train carrying used nuclear fuel), facility accidents, and unintended human intrusion.

Figure 6-4 shows the range of scores assigned by the Assessment Team. As indicated, on average, on-site storage was estimated to pose the most public health and safety risk, both in the short and long terms. The primary reasons are reflected in the influence diagram of Figure 6-3. With the on-site storage approach, used nuclear fuel continues to be stored at the existing reactor sites. Since these sites are typically in industrial, populated areas, a mishap could potentially expose a larger

Figure 6-4 Public Health and Safety Scores

number of people. Over the long time-period involved, the potential for events that might trigger exposures increases. For example, there is some chance that extreme natural events such as very high winds, rise in sea level, global warming or cooling, and earthquakes could damage the facility, particularly given the location of many of these facilities on large bodies of water. The broad range of scores assigned to on-site storage reflects differences of opinion among the Team over the likelihood and consequences of these and other such events. The centralized storage approach suffers these same concerns, however, since it would require only one facility that would likely be remotely located, the risks are considered not quite so great.

The on-site and centralized storage facilities lack the natural barriers afforded by burying the waste deep underground, and for this reason the security of the facilities depends primarily on maintaining institutional controls that prevent or restrict access. This may be increasingly difficult over the long term, because, for example, of the possibility that social instabilities might occur at some future time period. As well, although we have a safety conscious society now, the same cannot be guaranteed for the future. Since on-going facility operation will become routine, there is a danger that safety operations may become lax over time. Again, the risks may be lessened somewhat under the centralized storage approach. Since all of the fuel would be located in a single location and since the facility will be expressly sited and designed to facilitate security, it was judged to be less risky.

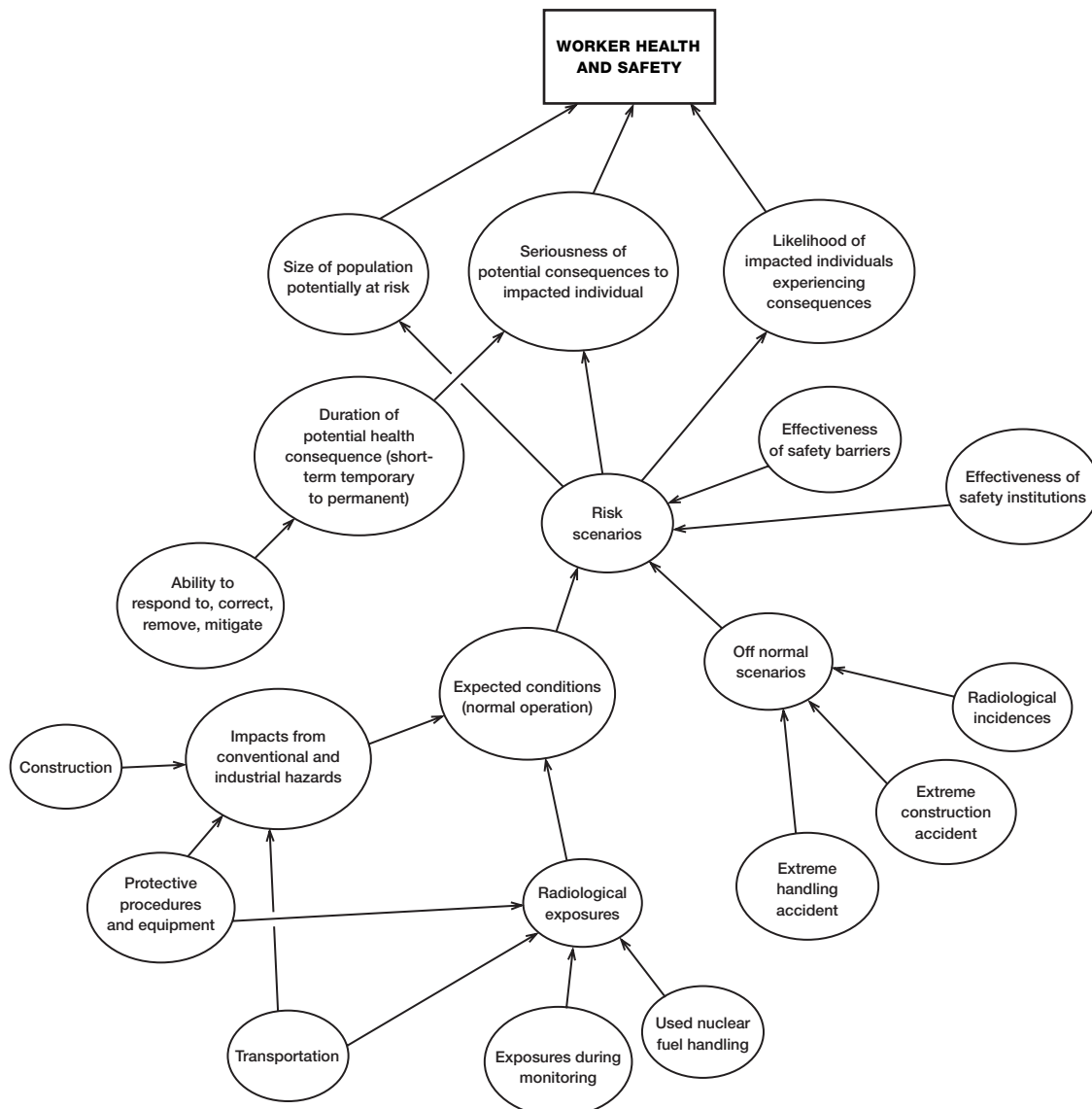
As shown, on average DGR was estimated to provide the least public health and safety risks. The facility would be located in a remote region selected to minimize the likelihood that any material released would come in contact with people. Unlike the centralized or on-site storage approaches, security does not depend on human institutions. Being located deep underground, the radioactive materials would be very difficult to access. The Assessment Team believed that burying the waste caused DGR to have a public health and safety advantage relative to on-site and centralized that would increase over time even though, in the unlikely event of a containment breach, the breach would be relatively more difficult to detect and address.

Worker Health and Safety

The considerations for assessing worker health and safety were in many ways similar to those used to assess public health and safety. Risks were separately estimated for the same two time periods. They were also estimated based on normal, expected operating conditions and under “off-normal” scenarios in which workers might be inadvertently exposed to hazards associated with the various approaches. The complete list of influences considered is notionally identified in Figure 6-5.

Under normal operating conditions, worker risks associated with the following operations were considered: construction, transportation, fuel handling, and monitoring. None of these risks was estimated to be unusually large compared to the normal risks experienced by workers in construction and other industrial settings. All of the approaches involve some risks associated with handling of the fuel, but the use of robotics minimizes the chance of workers being exposed to radioactivity. Although DGR would require the relatively dangerous tasks of mining and earth moving, much of the work would be

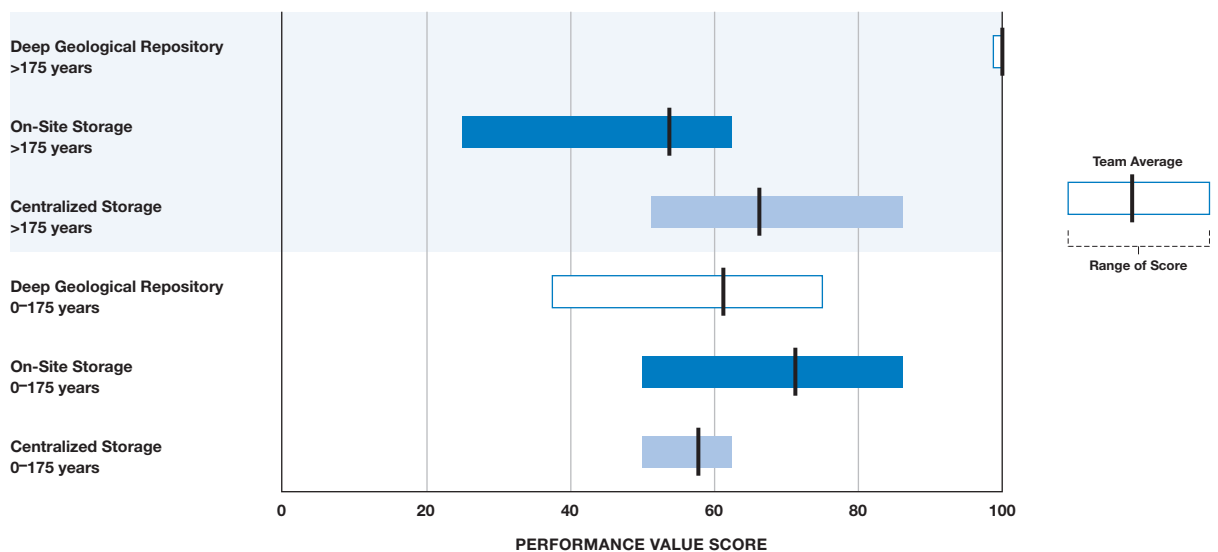
Figure 6-5 Worker Health and Safety Influence Diagram



mechanized and a relatively small number of workers would be directly involved. Both DGR and a centralized storage approach would involve transportation of used fuel, with the attendant risks of traffic accidents and other dangers to drivers. The main “off-normal” risk scenarios considered included an extreme construction accident, accidental radiological exposures, and extreme fuel handling accidents.

Figure 6-6 shows the range of scores assigned by the Assessment Team. Overall, on average the risks to workers were judged to be relatively low. In the short term, the risks to workers arise mainly from construction and transportation requirements, and are non-radiological in nature. Even though radiological exposures may well occur, based on the safeguards present, they are unlikely to cause serious health consequences. As indicated, on average, centralized storage was estimated by the Team to pose the most worker health and safety risk in the short term. The primary reason for this is that the centralized storage approach produces worker risks during the construction of the facility, during fuel transportation, and then repeatedly as the containers degrade and the fuel must be repackaged. Thus, the risks are greater than with DGR because more handling and packaging would be required. Also, workers will encounter a wider range of conditions compared with DGR, potentially increasing the chances of mishap. Furthermore, construction risks extend into the long term, due to the fact that the facility will essentially need to be rebuilt roughly every 300 years.

Figure 6-6 Worker Health and Safety Scores



On-site storage was scored best in the short term, largely because it involves minimal construction risks and no transportation risks, but highest in the long term, because it has all of the worker risk problems associated with the centralized storage approach plus would require continuing operations involving more workers at multiple sites with differing conditions. Like the centralized storage approach, institutions must continue to function well to ensure that the safe practices that protect workers (and others) do not decline. If something goes wrong, workers will be called upon to correct the problem. However, so long as institutions remain effective, serious exposure risks to workers are unlikely.

On average, DGR was scored almost as low as centralized storage in the short term, and some Team members scored it even lower. The primary reason for this is potential for a large-scale mining accident. Other members did not consider this risk serious, however, arguing that Canada has much experience in mining. Furthermore, the trend toward robotic mining decreases the likelihood of a major disaster. DGR was scored highest (at the “ideal” level) on long-term worker risk because there are essentially no workers beyond the 175-year period. Once the DGR is closed, it does not require additional worker activities.

Security

An approach must ensure the security of both nuclear materials and the facilities that manage them. Although a loss of nuclear material would likely pose health and safety risks to Canadians, maintaining security would be an objective even if the lost fuel was sure to be transported out of Canada. Canadians would not want the people of other countries to be at risk from radioactive materials stolen from Canada. Thus, security is a fundamental objective, not merely a means objective for protecting the health and safety of Canadians.

To assess security, the vulnerability of each approach to various risk scenarios was considered. The risk scenarios included terrorism and potential “insider” threats focused on theft, diversion, sabotage, and “seize and hold” strategies. The adequacy of contingency plans and the robustness of the approach under scenarios involving societal breakdown and civil disobedience were also considered. The complete list of influences considered is notionally identified in Figure 6-7.

Figure 6-7 Security Influence Diagram

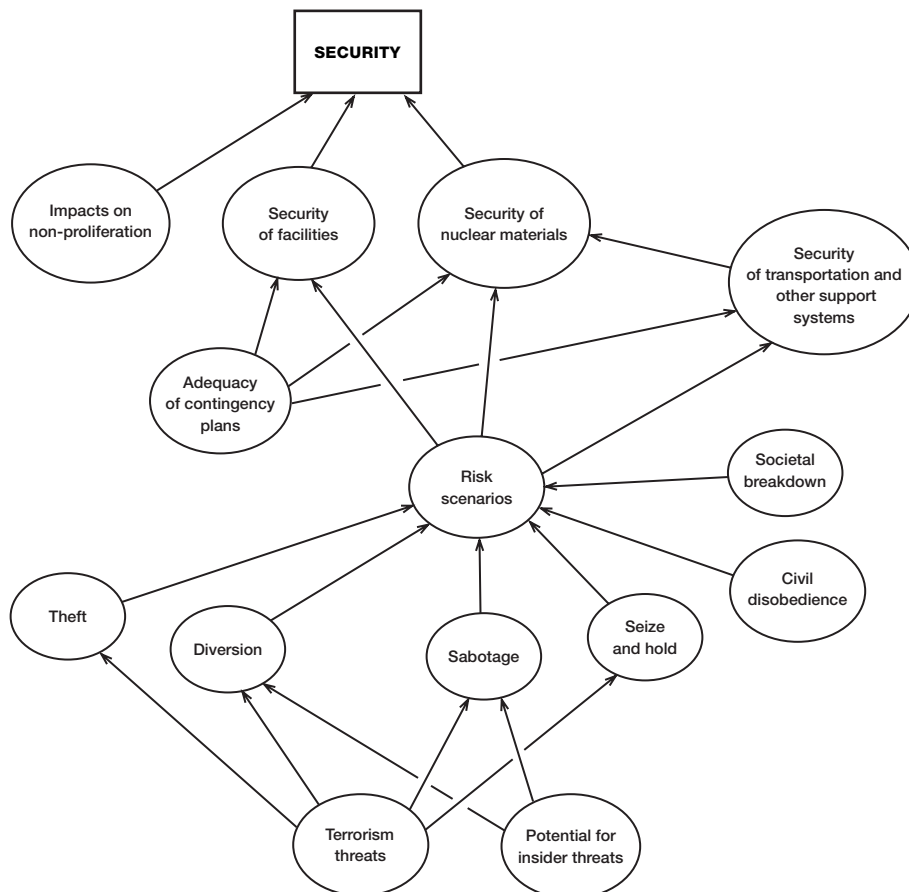
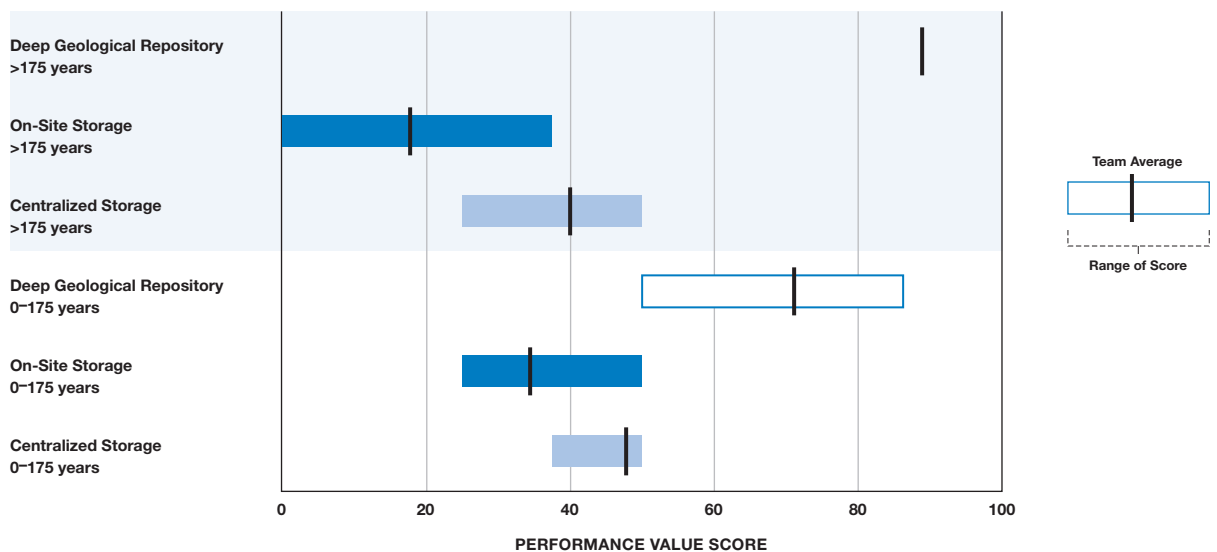


Figure 6-8 provides the security scores assigned by the Team. The nature of spent fuel (e.g., its high radioactivity) makes it difficult to steal during the first several hundred years. Nevertheless, the Assessment Team concluded that security risks do exist and are likely most significant during transportation and repackaging. As indicated by the average scores, in the short- and long-term time periods, the on-site storage approach was estimated to be the least secure. Locating sensitive materials on the surface is inherently less secure than placing them underground. After roughly 300 years, radiation levels will drop to the point that the waste is no longer self-protecting, thus increasing the security risk. Because the on-site storage approach involves multiple facilities in populated areas, it must rely heavily on the integrity of institutions to maintain security over the long term. Although on-site storage does not require transporting the fuel, the need to periodically repackage the wastes at multiple sites was estimated to create a significant challenge for ensuring security.

Figure 6-8 Security Scores



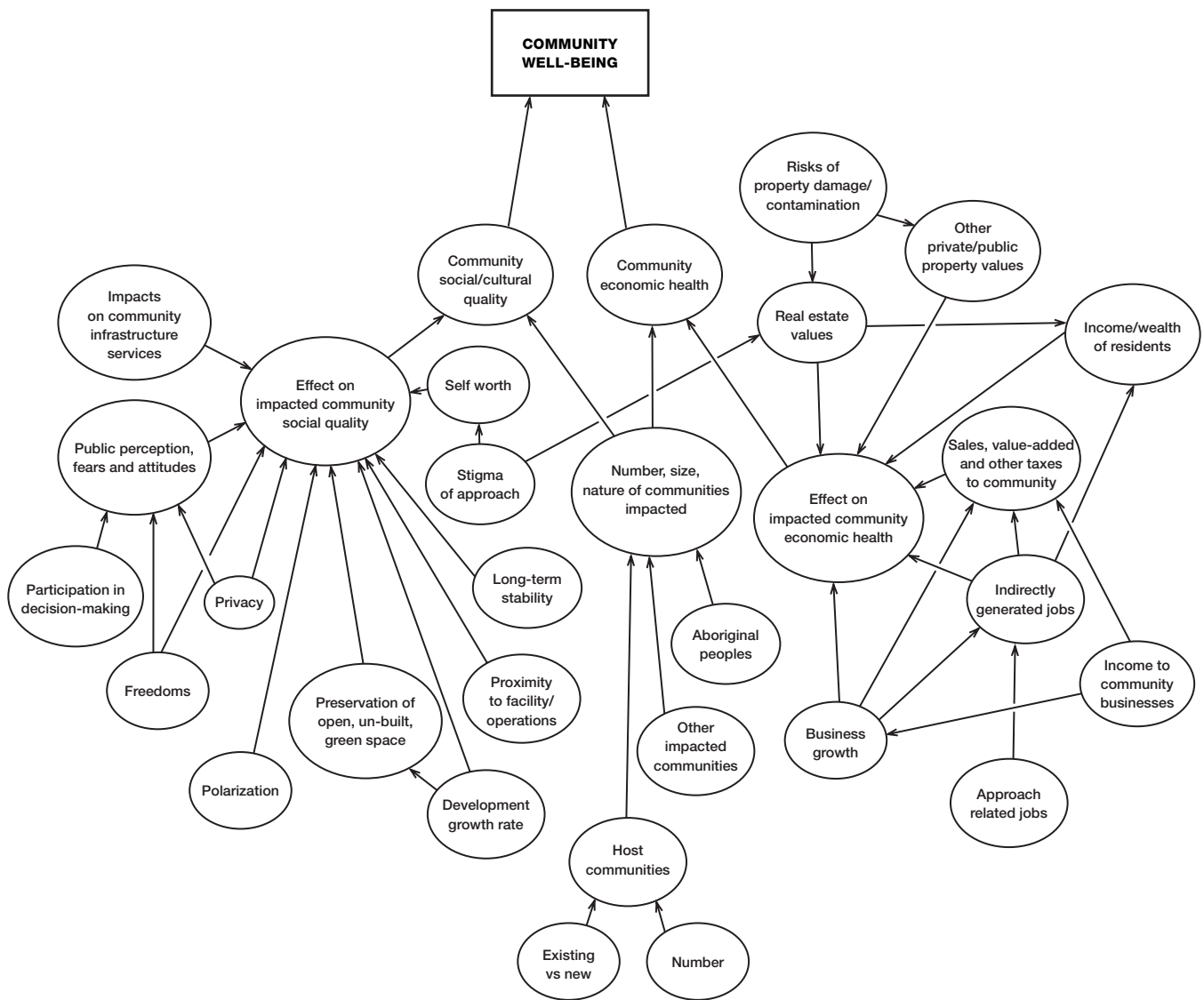
The centralized storage approach was estimated to do somewhat better, due to the fact that the facility could be sited in a location and setting which would facilitate providing security. However, because the waste would be concentrated in one location, it might be a more attractive target for terrorist activities. Also, there is the near-term threat of a security breach during transportation of the material to the facility.

DGR was estimated to provide the greatest security, because, once underground, the waste would be difficult to access. Thus, DGR was rated highly with respect to security in the post-175-year time period. Even then, however, security concerns would still exist. Indeed, a closed DGR would in many respects be similar to a plutonium mine. In the short term, before the waste has been emplaced, security risks for DGR would likely be greatest during waste transportation. Security risks could also be increased if the facility became a target for civil disobedience.

Community Well-Being

The assessments with respect to community well-being considered both the likely economic impacts of the approach and the potential effects on social and cultural qualities of impacted communities. On the economic side, consideration was given to potential effects on property values, jobs and businesses. Potential social and cultural impacts include raising fears and concerns of citizens and the potential for community polarization (e.g., contrasting beliefs between those who support and those who oppose locating a facility near their community). Some may see living near a radioactive waste management facility as placing a stigma on their community. The complete list of influences considered is notionally identified in Figure 6-9.

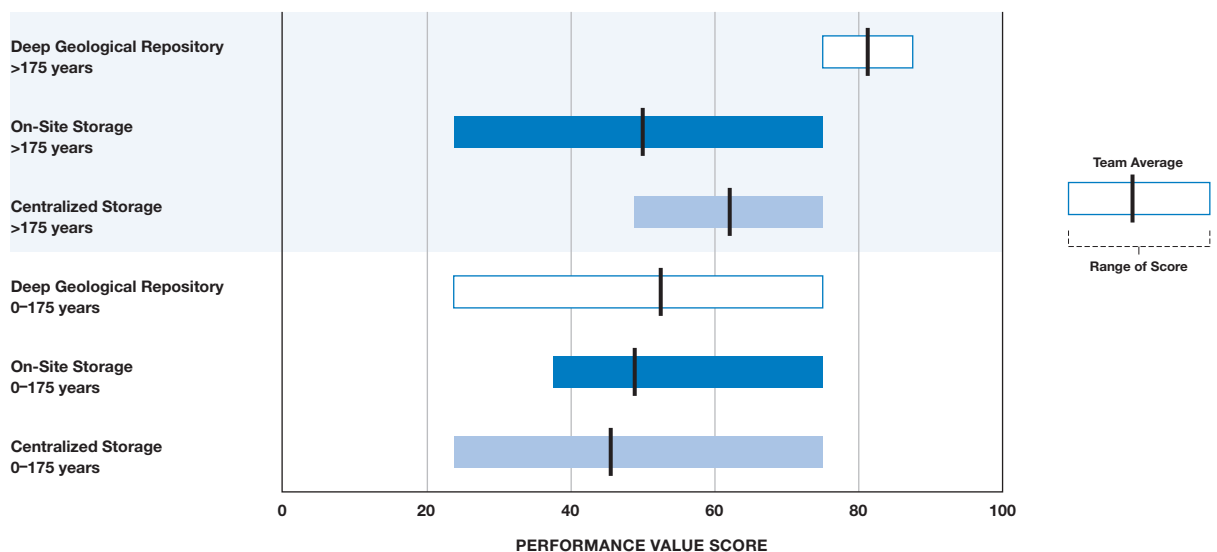
Figure 6-9 Community Well-being Influence Diagram



The nature of the community impacts will depend, in part, on the nature of communities that are impacted. Smaller, more remote communities may be more vulnerable to impacts. A key determinant of the community impacts in the case of any newly constructed facility will be whether or not the community is a voluntary host. Also important will be how the community manages the opportunities created by having the facility in their midst. Constructing a new facility in a lightly populated area could produce a “boom and bust” cycle with serious adverse effects. On the other hand, the relative permanence of a radioactive storage facility should lead to other development in the local area. It is anticipated that whatever approach is implemented, the local communities would be offered benefits that would at least partially mitigate or compensate for the adverse impacts that would otherwise occur.

As noted previously, to be impacted, a community does not necessarily need to be physically close to a waste management facility. The approaches that require transporting waste away from existing reactors would likely raise the concerns of communities along the transportation routes. Many other communities, including Aboriginal peoples, may be socially or culturally impacted based on their unique values and perspectives, irrespective of where they live.

Figure 6-10 Community Well-being Scores



The community well-being scores assigned by the Team are shown in Figure 6-10. The approaches were rated similarly in the initial time period. The reason for this is that each of the approaches has its own advantages and disadvantages, and these tend to average out so that it is difficult to argue (at least within the near-term time-period) that one approach is significantly better than another with regard to impacts on communities. Furthermore, whatever approach is taken, the fact that a long-term solution is being implemented is expected to have a positive impact on Canadians in general.

The ranges in the initial time period are also similar. All three are quite wide. This is because the community impacts under each approach depend on similar, very significant uncertainties, such as the processes by which choices are implemented, the technical performance of the facilities involved, and

the effectiveness of political and social systems that promote community welfare. However, as illustrated, the low end of the ranges for the centralized storage and DGR approaches are below that for the on-site storage approach. This is because some Team members believe that creating a new facility in a new location will necessarily create more adverse impacts on communities than leaving the waste where it is.

The on-site storage approach provides a good example of the tendency for positive and negative characteristics to balance out. Although on-site storage would involve multiple facilities near existing, relatively highly populated areas, the Team reasoned that local communities have become more accustomed to nuclear materials and, therefore, would experience less social disruption than would be the case for a community dealing with a newly constructed facility. Changing the role of the reactor storage sites from temporary to long term would involve significant facility upgrades. Some might see the project positively, for example, as an improved and more robust facility. On the other hand, there is potential to polarize the more immediate community because some people may feel betrayed by the change of status of the facility from interim to long-term waste management. Furthermore, the proximity of a facility that is acknowledged to involve risks may be a target for citizen legal action.

The centralized storage and DGR approaches have the advantage of allowing a voluntary process for picking the site of the respective facilities, although there is less flexibility for choosing a site in the case of DGR because of its requirements for the host geology. Being more remote, fewer communities and fewer people might be directly impacted. However, the centralized storage facility might well be located closer to people than DGR, and might therefore impact more people.

In the case of the centralized storage and DGR approaches, the economic impacts that do occur would have some positive attributes, for example, the construction of improved roads and other infrastructure as well as generating high-tech jobs. However, most of the effects would be relatively short-lived. Also, the social impacts of such changes could be perceived by many as negative, given that remote communities are often populated by people who have made deliberate choices to live in private, largely un-built, natural environments.

Both the DGR and centralized storage facilities require waste transportation, which may raise concerns for those who live near or travel on the transportation routes. On the other hand, when the DGR facility is closed, its physical nature will not create the same visual reminder and associated stigma that a surface facility may.

While the importance of factoring in and addressing the concerns of Aboriginal peoples is recognized in general, and specifically concerning this objective, the Assessment Team did not feel capable of anticipating the perspective of Aboriginal peoples. The perspective of Aboriginal peoples will need to be understood and brought in to the assessment in regard to assessing the methods on community well-being, as well as on each of the other objectives identified in this assessment.

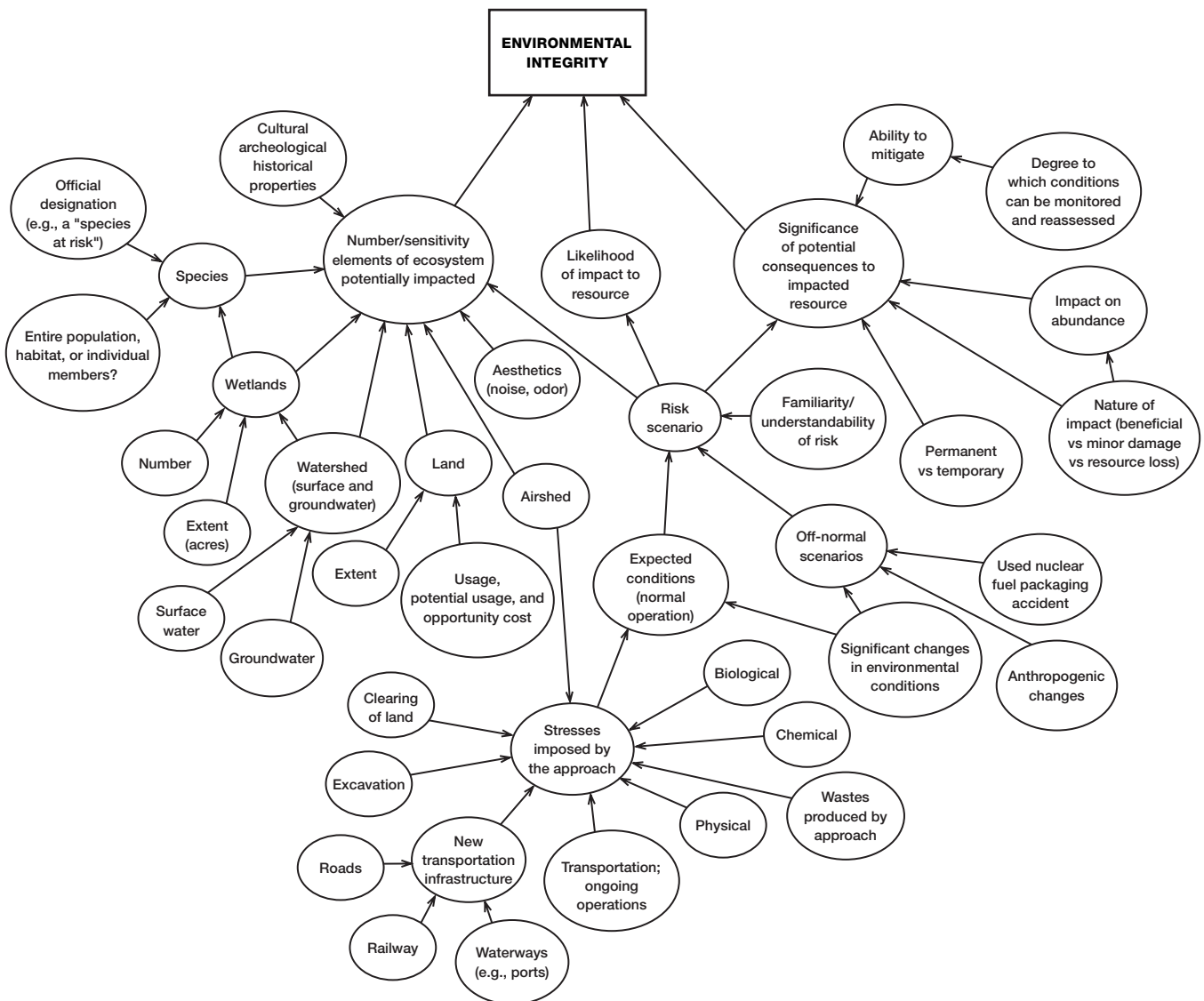
Over the longer time period, the Team agreed that DGR would create the least adverse community impacts. No significant long-term operations are required under DGR, making it likely that the facility would be largely forgotten in the long term. As indicated in the health and safety scores presented previously, DGR, in the long term, is expected to be safer, which brings the additional benefit of reducing the likelihood that adverse performance will be a source of community concern. However, the limited opportunity to demonstrate this performance may be a source of lingering concern among some in the community.

The larger uncertainty regarding the performance of on-site storage over the long term reflects the greater challenge posed by the need to successfully manage multiple facilities. Inadequately managing a facility in one community, for example, would likely raise serious concerns on the part of other communities within which facilities are located.

Environmental Integrity

Assessing the degree of impact each approach would have on the natural environment required consideration of many factors, including the number and sensitivity of elements of the ecosystem that would potentially be impacted, the likelihood of impact to each type of resource, and the significance of the potential consequences to impacted resources. Many different types of valued environmentally sensitive resources could be affected, including plants and animals, land, surface water bodies and groundwater, and the air (e.g., through air pollution created during the construction of a new facility). Also included in the assessment were various aesthetic impacts, such as noise, possible odours, and visual changes to the natural scenery. As in the case of other objectives, it is necessary to consider

Figure 6-11 Environmental Integrity Influence Diagram

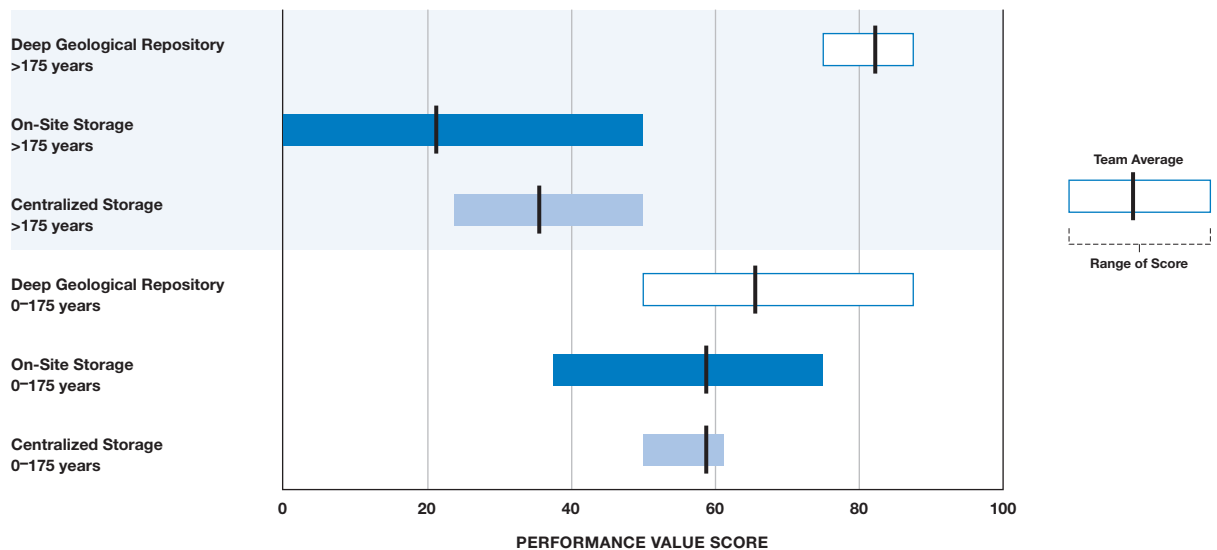


not only the stresses that each approach would produce assuming that the approach performs as expected, it is also necessary to consider the possibility of off-normal risk scenarios. The complete list of influences considered is notionally identified in Figure 6-11.

It is, of course, very difficult to be precise regarding the environmental impacts of the various approaches. This is especially true in the cases of the DGR and centralized storage approaches because the impacts on the environment that each approach would produce depend greatly on where the new facilities would be located, something which is not yet known. The long timeframes involved also add to the difficulty of being precise for all three of the approaches.

Figure 6-12 provides the environmental scores assigned by the Team. As indicated, the DGR approach was estimated on average to perform the best with regard to the environment, particularly in the long time period. Multiple and robust barriers below-ground which do not require institutional controls lead the Assessment Team to score DGR much higher than the other methods in the long term. In the shorter term, for which there is more overlap in the range of scores assigned the three methods, excavation of the DGR facility would produce adverse impacts, however these impacts are expected to be localized and relatively short-lived. Unlike a centralized or on-site storage approach, there is no need for periodic repackaging and other operations at the facility that might place the environment at risk. DGR, like the centralized storage approach, requires waste transportation, but the environmental effects of this were not regarded to be substantial.

Figure 6-12 Environmental Integrity Scores



In the near-term period, the range of scores for the on-site storage approach extends to fairly low values. This is due to the greater susceptibility that multiple facilities would have to extreme weather and other natural events, plus the severe consequences that might occur should social instabilities occur that result in a site being abandoned. Even though the current reactor sites are in industrial areas, which are less sensitive from an environmental standpoint, they are located near water bodies (many are on the Great Lakes). Releases from the facilities could result in those water bodies

becoming damaged. These concerns multiply in the longer timeframe. These are the primary reasons that the on-site storage approach shows a wider range of scores, both in the short- and long-term time periods. On the plus side, the on-site storage approach provides opportunities for monitoring facility performance, and the proximity to people and accessibility on the surface may mean that any environmental problems that develop might be more quickly noticed and fixed.

The centralized storage approach is expected to have better and more predictable environmental performance than the on-site approach, both in the near- and long-term periods. Not only is there just one facility, which puts less environmental resources at risk, that facility can be purposely located and built to reduce environmental risks. However, the fact that a centralized storage facility would likely be built in a remote location could be a disadvantage in terms of ensuring effective and continuing maintenance of its infrastructure.

Economic Viability

Assessing the economic viability of the approaches required considering the likelihood that financial resources would be available to pay the costs, recognizing that these costs are uncertain and, especially in the case of the on-site and centralized storage approaches would continue over a very long timeperiod. The complete list of influences considered is notionally identified in Figure 6-13.

The scores assessed by the Team are shown in Figure 6-14. In the initial time period, on average on-site storage was estimated to be most economically viable. It presents the least up-front costs with the least cost-uncertainty, since Canada has much experience with the type of technology required and costs involved through on-going interim storage of used nuclear fuel. Over the initial time period

Figure 6-13 Economic Viability Influence Diagram

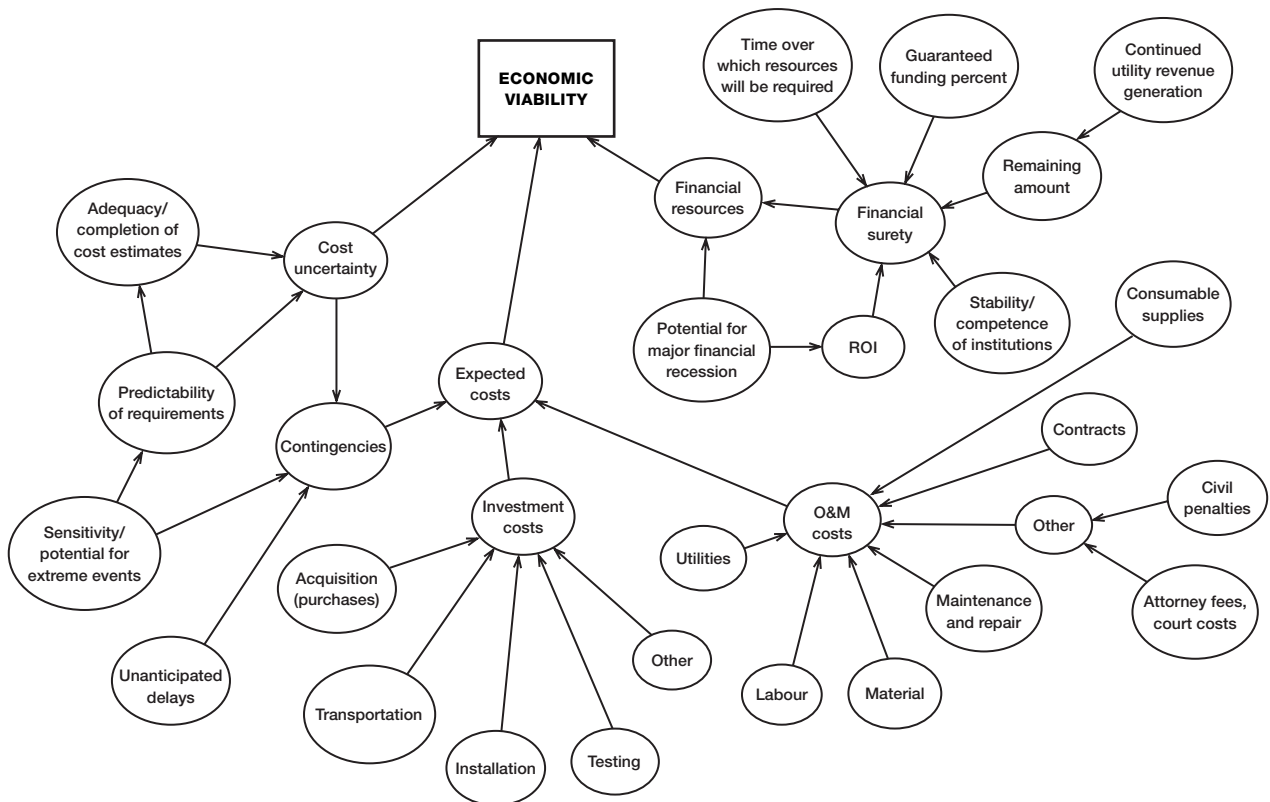
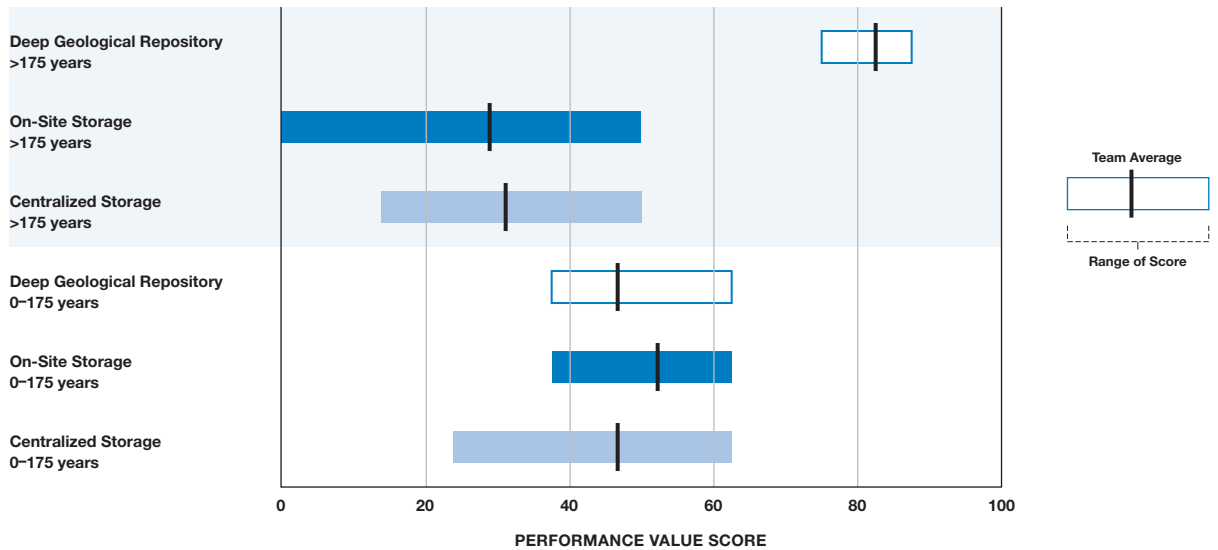


Figure 6-14 Economic Viability Scores



especially, there is reasonable confidence that continued sales of electricity will provide sufficient funds for financing the approach. There was less confidence in the economic viability of the centralized storage and DGR approaches. Since such facilities have not been previously constructed, there is much more potential for problems and delays, which would raise costs. The technology required for the centralized storage approach is, perhaps, better known than for DGR, which might make it easier to estimate and control costs. On the other hand, at least the mining costs associated with DGR (ignoring the potential for delays) are relatively predictable. Many of the costs would be similar to that of a standard small mine, and Canada has considerable experience estimating such costs.

DGR would create the highest upfront costs, and experience in other countries indicates that the selection and characterization of a potential site can be expensive. The possibility also exists that an unforeseen breach of containment would produce future costs, including clean-up costs, but the likelihood was estimated to be substantially less than in the case of the above-ground approaches.

Even though the up-front costs with DGR would be very large, the fact that they would be over and done with relatively quickly gave most Team members more confidence in the financial surety of the DGR approach. Nevertheless, some Team members believed that the very large, required upfront expenditure could not be managed. Experience with other large projects undertaken by the nuclear industry indicates that the costs of such projects can be greatly underestimated. Others, however, viewed the total costs as manageable, since they will likely represent only a small percent of electricity revenue although government guarantees would be necessary.

By comparison, the centralized storage approach might be less costly initially, but there are significant uncertainties. Like DGR, there would be substantial costs incurred in finding and characterizing a site. Also, like DGR, transport costs may be significant, and could increase if there are major delays. However, unlike DGR, there would continue to be significant cost requirements going into the future,

as in the case for on-site storage. In fact, the range of scores assigned to on-site storage in the long-term time period extends all the way to zero, indicating that some members of the Assessment Team were very concerned about its long-term financial viability. In part, these low scores were related to concern over the possibility that localized or wide-scale political or economic problems might result in inadequate funding being provided to one or more of the on-site storage facilities.

The very high score for DGR in the long-term time period reflects the fact that DGR requires very few on-going operations following the closure of the facility. Once it is built and implemented, costs are essentially complete. This is an important advantage, given the difficulty of assuring adequate financial resources in the long term.

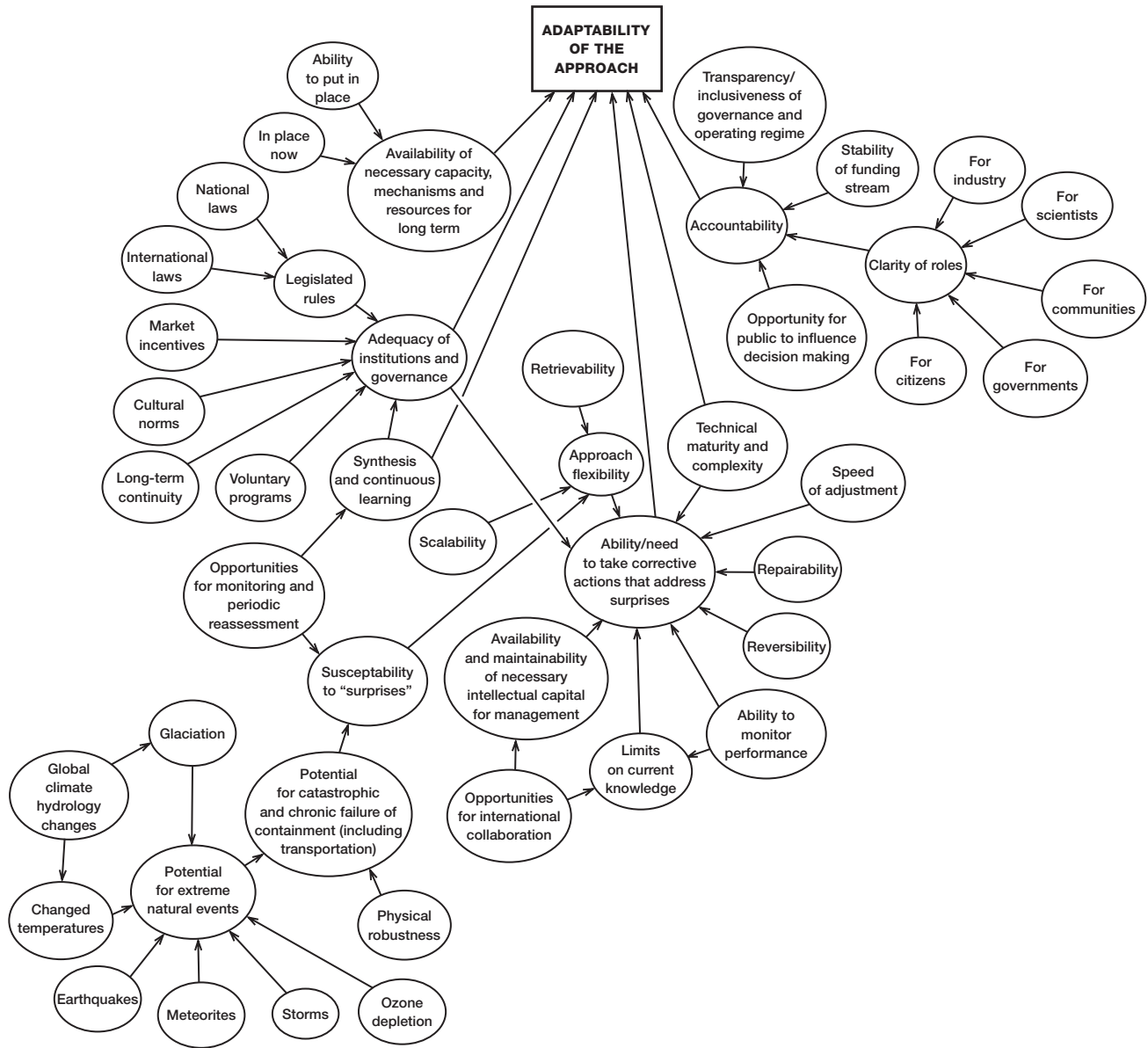
Adaptability

As indicated previously, the Assessment Team adopted a broad definition of adaptability when scoring the approaches against this objective. Adaptability includes not just the flexibility allowed by the approach for making changes, but also consideration of the need for potential changes. An approach that is more resistant to surprises (e.g., less potential for catastrophic and chronic failure of containment), for example, is less likely to need to be changed. In addition, consideration was given to information that would be available for supporting changes and to the likely availability of mechanisms and resources for making such changes over the long term. Finally, the degree of accountability provided by the approach was also regarded as a factor influencing adaptability. As with some of the other objectives, how the selected approach is implemented would have a significant bearing on its adaptability. Regardless of which technical approach is selected, the management approach needs to be designed to achieve adaptability. The complete list of influences considered is notionally identified in Figure 6-15.

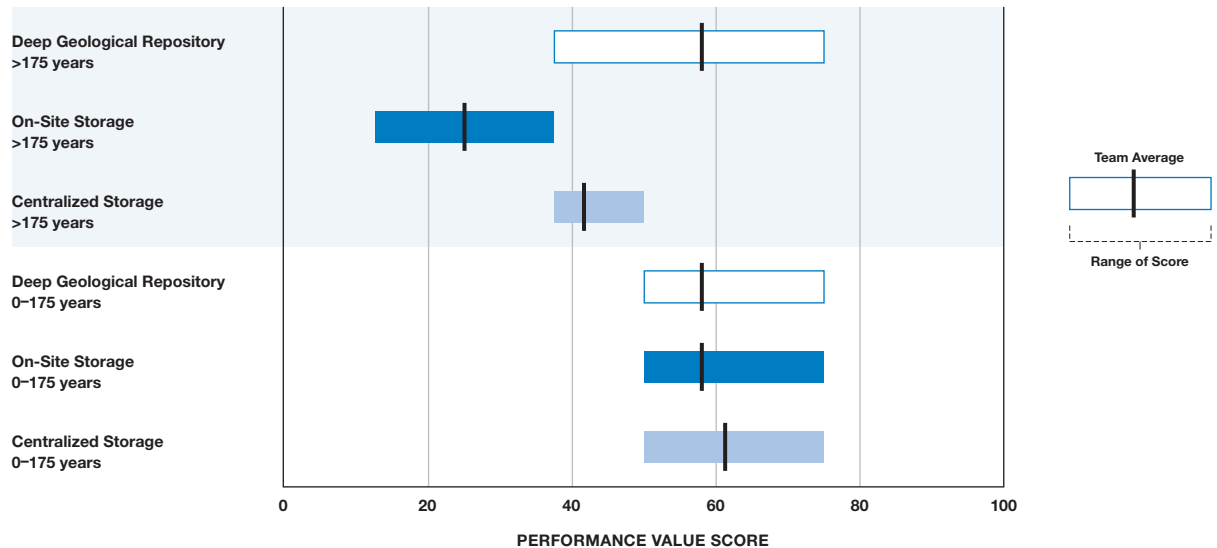
The adaptability scores assessed by the Team are shown in Figure 6-16. As indicated, in the initial time period, the approaches were rated as roughly equal in terms of adaptability. The reason for this is that the different aspects of adaptability considered by the Team tended to balance out. For example, the centralized storage and on-site storage approaches offer easier access to the waste, facilitating the ability to make changes. On the other hand, these approaches were regarded as more vulnerable to various risk scenarios compared to the DGR approach. One could argue that flexibility is really only important when it is necessary to ensure safety. DGR may be less flexible, but flexibility may be less needed given its lower susceptibility to surprises. In the short-term, at least, the relative advantages and disadvantages tended to balance out.

Even though DGR ultimately reduces flexibility to move the waste, the Assessment Team felt that making the decision in the short run to move toward DGR does not foreclose much flexibility within the first 60 years or so before the repository would be closed. The decision of whether and when to close the facility would be made by a future generation, presumably aided by advances in science and technology, providing some measure of adaptability. By comparison, on-site storage provides no flexibility to select the locations for the facilities, and some constraints would naturally be placed on the designs that could be used. Thus, DGR was not scored significantly lower in the near-term period than the other approaches.

Figure 6-15 Adaptability Influence Diagram



Once built, a DGR facility is likely to be loaded with waste and eventually closed, thus constraining options and reducing flexibility available to future generations. However, as indicated by the scores assigned in Figure 6-16, on average the Assessment Team was more confident in DGR. It effectively takes the hazardous material out of the accessible environment. Thus, it is less vulnerable to extreme events than the other approaches. The centralized storage approach, and to an even greater extent the on-site storage approach, create long-term costs and institutional requirements that would burden future generations, and which would compete for resources with other valued objectives of the time. For these reasons, on-site storage, in particular, was rated relatively poorly with regard to long-term adaptability.

Figure 6-16 Adaptability Scores

6.2 Sensitivity of Results to Alternative Weighting Judgments

A review of the above scores shows that, on most objectives DGR is expected to perform better than on-site or centralized storage, especially over the longer timeframe. Using the average of the scores assigned by the Assessment Team, the only objectives for which DGR was not estimated to be superior are (1) near-term worker health and safety, (2) near-term economic viability, and (3) near-term adaptability. In these cases, DGR was generally estimated to perform only slightly below one or both of the other approaches. At the same time, DGR was estimated to be significantly better than on-site or centralized storage with respect to meeting the objectives of (1) fairness, (2) security, (3) public health and safety, (4) long-term worker health and safety, (5) long-term adaptability, (6) long-term community well-being, (7) long-term economic viability, and (8) environmental integrity.

The dominance of DGR with respect to the great majority of objectives was somewhat unexpected. The result lessens the sensitivity of conclusions about overall preferences to the choice of weights, or relative degrees of importance that might be assigned to the objectives (see Section 4.7 for definition). Nevertheless, the Team elected to conduct the exercise of assigning weights so as to further analyze the implications of its scores.⁶²

Figure 6-17 shows some illustrative weights. The weights are averages based on the team members' personal values. The two time periods (initial 175 years and beyond 175 years) have been combined.

⁶² For technical reasons, each weight is defined to represent the improvement in going from the lowest score (score of zero) to the highest score (score of 100).

Figure 6-17 Initial Illustrative Weights

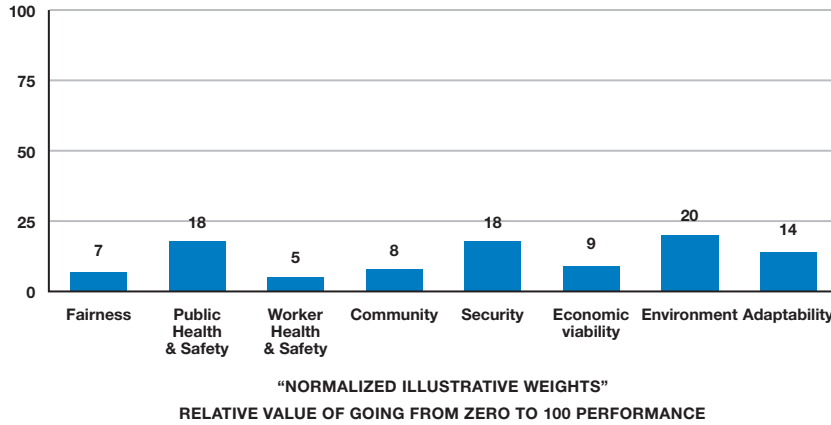


Figure 6-18 shows weighted scores using the weights of Figure 6-17. In Figure 6-18 the weights are fixed, while performance scores vary among three choices, labelled "nominal figure of merit," "minimum figure of merit," and "maximum figure of merit." The nominal figure of merit is based on the average performance scores obtained from the Assessment Team. The minimum figure of merit is the result when the minimum (low end of the range) scores are used. The maximum figure of merit is the result when the maximum (high end of the range) scores are used.

Figure 6-18 Results of Combining the Illustrative Weights with the Performance Scores

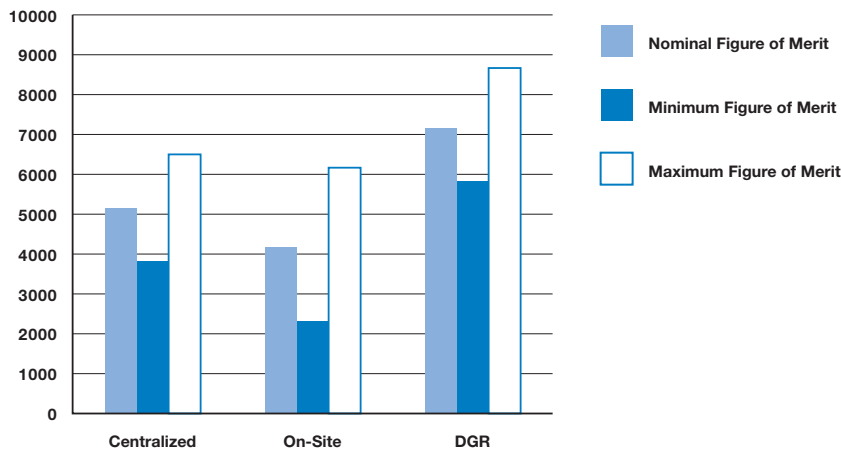


Figure 6-18 shows that, for the assumed set of illustrative weights, DGR is the preferred option for each choice of Figure of Merit.

The Team also tested several alternative illustrative weighting systems. The alternative weighting systems are shown in Figure 6-19 and include (1) high emphasis on security concerns; (2) high emphasis on environmental concerns; (3) high emphasis on economic concerns; (4) high emphasis on community and fairness concerns (combined).

Figure 6-19 Alternative Weights

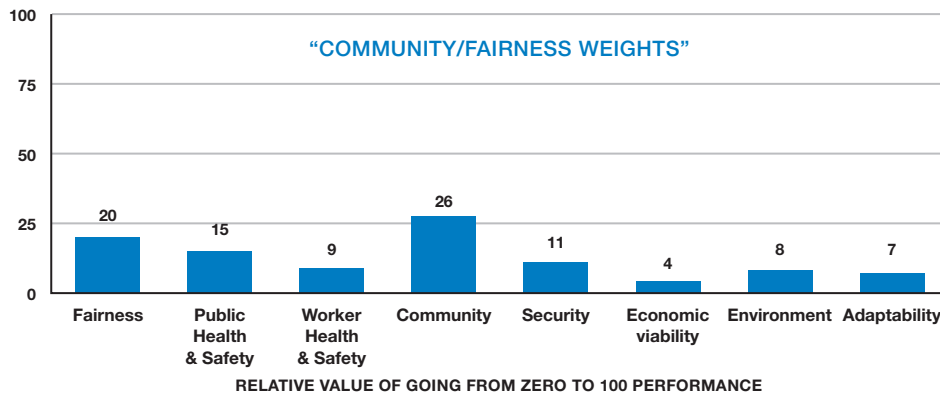
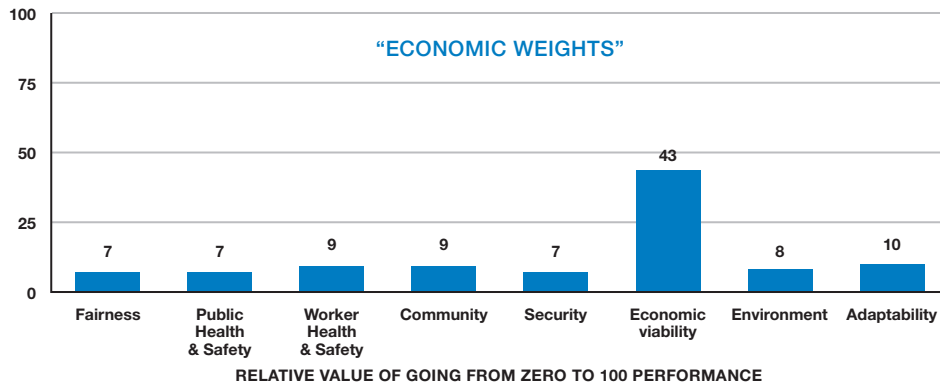
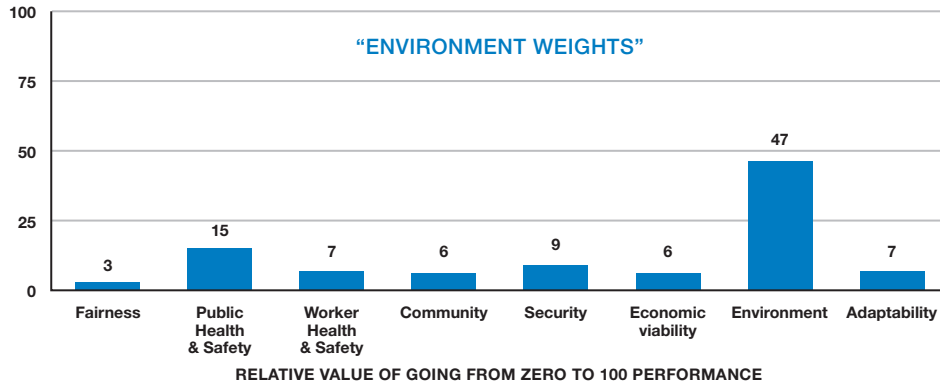
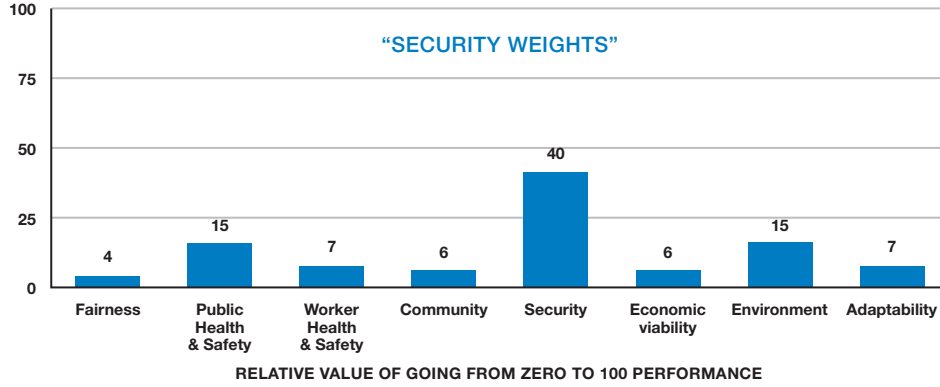


Figure 6-20 Results of Combining the Alternative Weights with the Performance Scores

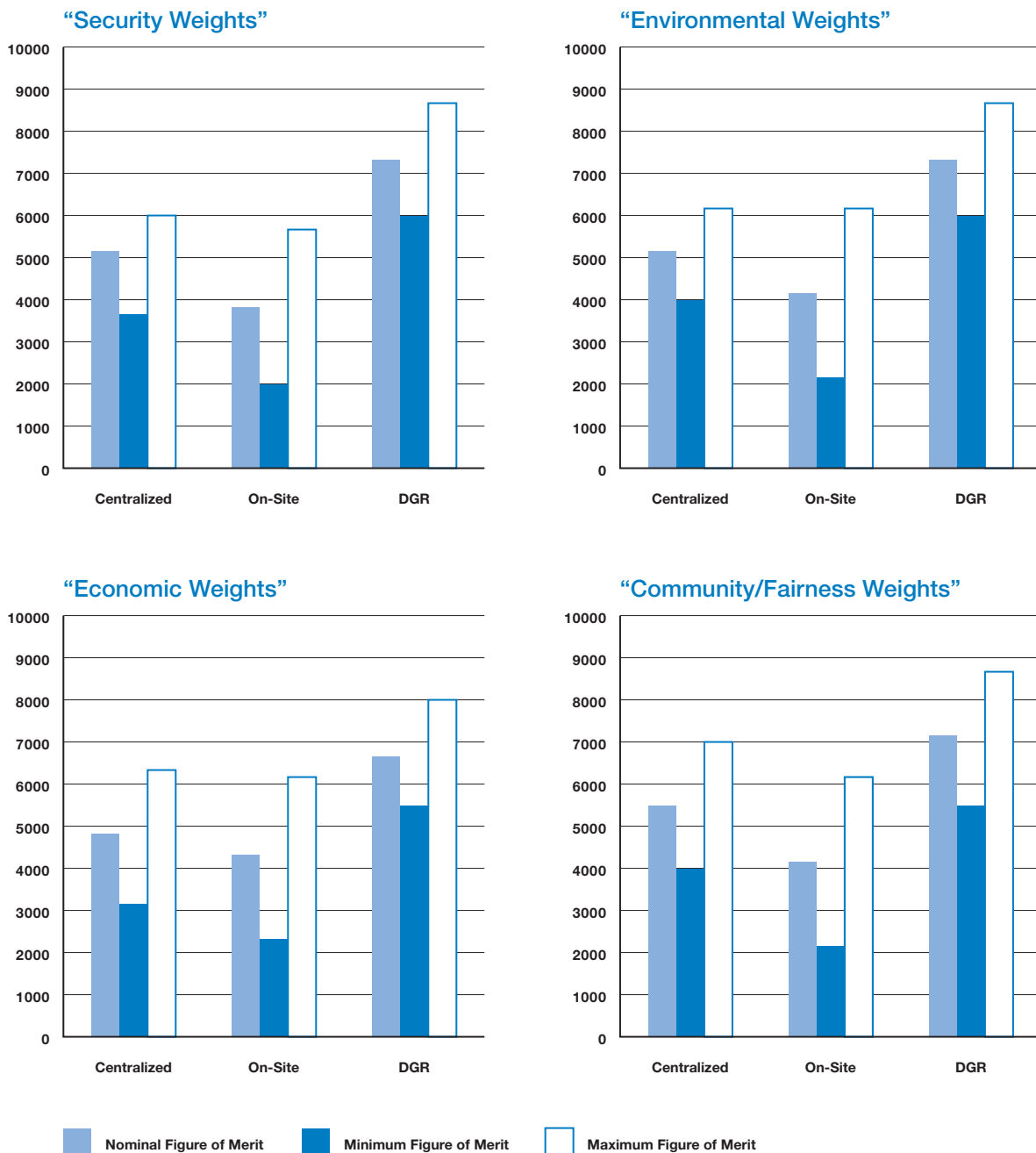


Figure 6-20 shows the results of using these weights, assuming Nominal Figure of Merit for performance scores. In all cases, the results show that DGR is preferred. The various cases illustrate the Team’s conclusion that, given the average performance scores assigned by the Team, only an extreme weighting system would cause a storage option to be preferred over DGR. This conclusion follows mathematically from the dominance of DGR with respect to the great majority of objectives. In particular, assuming the average scores assigned by the Team, it would be necessary to weight near-term

performance far more than the long-term performance and to place nearly all weight on worker health and safety, near-term economic viability, and near-term adaptability in order for a storage approach to be preferred to DGR.

The insensitivity of the results to alternative sets of weights suggests that differences in weights may not be a major source of disagreement over the selection of Canada's approach for dealing with used nuclear fuel. Rather, any disagreement is more likely to be associated with differences of opinion over what sort of conditions are likely to exist in Canada over the long term and how well the alternative approaches would perform under these future conditions. Accordingly, the analysis described in the next section was conducted to explore the sensitivity of the estimated performance of each approach to possible future scenarios.

6.3 Exploring the Implications of Future Scenarios

In the assessment summarized in Section 6.1, a broad range of scores is compiled under almost all objectives. From discussion amongst team members, it is clear that score ranges are to some degree, the result of different assumptions about the future condition of our world. To explore the significance of these assumptions, the Assessment Team undertook an analysis of how the three management options would fare in different assumed future circumstances – some optimistic and some more challenging.

Appendix 5 provides a more detailed discussion of the analysis that was completed. Three alternative futures were considered selected from a number of scenarios developed previously by the NWMO Scenarios Team.⁶³

Test Scenario 1 is an optimistic scenario in which institutions remain strong, stable, respected, and vigilant in perpetuity. The generation of used nuclear fuel ends with the current facilities working to their design life and not beyond. No new technical solution is found for treating the used fuel. Thus, in an overall sense, while care must be taken in perpetuity, society's overall capacity to address the issue of used nuclear fuel is high. For the analysis, this Scenario is split into two sub-scenarios. In Scenario 1-A, the "polluter pays" principle is adhered to for all three management approaches. In Scenario 1-B, the principle is only truly maintained for the Deep Geological Repository. For the storage options, resources from future generations are eventually required to cover the cost of repackaging and maintenance thus the polluter pays principle is not fully respected.

Test Scenario 2 is more pessimistic than Scenario 1. Here, nuclear energy is abandoned because of a loss of public trust, there is extreme social, political and institutional instability, mass migration of populations, fossil fuel use rises, climate change goes to the extreme, food costs rise, population shrinks by half and many are driven to subsistence lifestyles.

Test Scenario 3 is also pessimistic. While the economy is strong, energy demand is high, and nuclear dependency is also high; weapons proliferate and security issues are grave; the gap between rich and poor widens and social instability results; totalitarian rule is imposed greatly reducing personal freedoms; the threat of nuclear war is real but doesn't occur; society teeters.

⁶³ Fully reported in Global Business Network, 2003. Looking Forward to Learn: Future Scenarios for Testing Different Approaches to Managing Used Nuclear Fuel in Canada. Report prepared for the Nuclear Waste Management Organization. Available on-line at <http://www.nwmo.ca>

In summary, two overall significant conclusions arise. First, it is clear from this analysis that assumptions made about future conditions heavily influence how any given alternative management approach will score as well as the relative positioning of the three alternatives assessed. Second, DGR performance is less sensitive to future conditions than the storage options. This lack of dependency on future conditions implies a degree of robustness not shared by the others.

This analysis thus serves to re-enforce the overall conclusions arrived at by the Assessment Team. However, it has brought to light sets of conditions which would result in more favourable scoring for the storage options. These conditions include:

- Strong, stable, respected, and vigilant institutions must remain in place in perpetuity;
- Climate change must be limited to the very low end of what is now projected; and
- The polluter pays principle must be entrenched in a way that provides for an indefinite stream of resources to cover costs of the storage options in perpetuity such that those receiving the benefit from the generation of used nuclear fuel would truly shoulder the burden of providing the resources for its management over the long term.

6.4 Summary

1. On nearly all objectives, especially for the long term, the collective opinion of the Team is that the repository concept is likely to perform better than the other alternatives.

DGR scored significantly better on eight objectives. It was estimated to be significantly better than on-site or centralized storage with respect to meeting the objectives of (1) fairness, (2) security, (3) public health and safety, (4) long-term worker health and safety, (5) long-term adaptability, (6) long-term community well-being, (7) long-term economic viability, and (8) environmental integrity.

DGR scored only slightly below the storage alternatives on three objectives. Using the average of the scores assigned by the Assessment Team, the only objectives for which DGR was not estimated to be superior are (1) near-term worker health and safety, (2) near-term economic viability, and (3) near-term adaptability. In these cases, DGR was generally estimated to perform only slightly below one or both of the other approaches.

2. Over the long term, the performance of the Deep Geological Repository is more robust in the face of long term uncertainties than the storage alternatives. Leaving the used fuel at reactor sites is the most vulnerable to these uncertainties.

Some uncertainties arise because of the specifics of a given approach (e.g. where a new facility would be located) as well as the decision-making process (e.g. the likelihood that necessary federal-provincial-local agreements will be reached to enable a facility to be built). These kinds of uncertainties will be resolved one way or the other as Canada progresses down a chosen path.

However, a more significant group of uncertainties relate to the performance of the various approaches over the long term. They arise from the complexity of the issue, the limits to our present knowledge about the technical performance over the long term, and the environmental and social change that will occur in the future. Decisions to proceed must be made in the context of these uncertainties.

3. The wide ranges among the scores assigned by individual members of the Assessment Team for all three of the options should be noted.

The ranges in the scores for the three options are quite wide, in most cases, and as well almost always overlap at their extremities (low or high ends). The large range assigned to the scores on many objectives reflect differing views among members of the Assessment Team concerning future environmental and social conditions in Canada as well as questions regarding how well the approaches might actually perform.

In reflecting on the results of its own work, the Assessment Team is of the view that such wide variation is to be expected and indeed, that similar variations might be obtained by others should they conduct their own exercise.

6.5 Comments

Within the limits of the analysis, not only did the deep geological repository generally score better than the other alternatives, but it also generally scored at a level that suggests it will perform well in meeting the eight objectives not only in comparison to the others but also on its own merits, particularly over the long term. The favourable results for the deep geological repository derive largely from advantages realized over the long time period during which any management approach must perform.

In addition, three important points should be borne in mind in considering the results of the Assessment Team's analysis and in considering a way forward:

- No alternative perfectly addresses all the values and objectives important to Canadians, although the deep geological repository concept comes closest;
- A practical real-world strategy must take factors into account that are outside the scope of this analysis such as financial costs and political climate; and
- Without delaying a decision to proceed, the strategy should seek a balance between realization of a preferred solution in a timely manner while remaining open to utilizing new learning as it emerges.

These issues will be further addressed in Chapter 7.

Additional Insights

7

CONTENTS

- 7.1 Broadening the Perspective
- 7.2 Strengths and Limitations of the Methods
- 7.3 Towards a Staged Approach
- 7.4 The Need for a Decision Now
- 7.5 Meeting the Objectives

7.1 Broadening the Perspective

The *Nuclear Fuel Waste Act* of 2002 represents a decision by Parliament that reflects the sentiment of Canadian society – that the generations of citizens benefiting from nuclear power and creating the associated wastes have an obligation to provide a lasting means for managing that waste. Likewise it is clear that there is a desire to preserve options for future generations to make decisions that they believe are in their own best interests.

The Assessment Team supports this concept and believes that a decision establishing a formal commitment to a specific management approach, but which also preserves flexibility, is of critical importance. This perspective is supported by the following major themes from the preceding chapters:

1. The many, interrelated factors involved in nuclear waste management;
2. The extended time-frame for any implementation plan;
3. The need for Canada to make a timely decision;
4. The desirability of preserving some flexibility for future generations in the implementation of a preferred management option for used nuclear fuel; and
5. The strengths and weaknesses of each of the assessed approaches.

Over the decades of program development and implementation, the selected approach will encounter changes in society, technology, economics, and the environment. These changes will be further influenced by the evolving political and institutional landscape and more. The Assessment Team therefore suggests that an adaptable management approach ought to be considered, one that is staged to include periodic sequential decision points.

The assessment highlights the breadth of objectives that need to be considered and optimized. It concludes that among the three used nuclear fuel management methods, when considered separately and in isolation from each other, the deep geological repository option is expected to perform better than either reactor site extended storage or centralized extended storage. This judgment is consistent for the majority of the key objectives that the assessment explicitly addresses, while noting that the storage options do provide benefits in the short term, that is, in the first 175 years.

In the course of its work, the Assessment Team came to recognize features of the three management methods that are not mutually exclusive, and in fact overlap with each other. This is primarily because any process of implementation will necessarily stretch out over an extended period of time, at least many decades.

Recognition of the exceedingly long time period over which any management approach must perform is key to the design of effective implementation. This long time frame combined with the necessary overlap of certain aspects of the different methods facilitates adoption of a staged approach that would preserve flexibility and facilitate continuous learning as new experience generates new knowledge. It would also help ensure that the preferred management approach is implemented and adapted in an effective manner.

For example, a timely decision to pursue the geological repository option would require several decades of continued temporary storage, either at reactor sites or in centralized storage, before the repository is operational. Even at that point, additional decades would elapse as the repository is being filled and monitored until it is decommissioned, allowing for some flexibility in future choices.

Examining the three methods together can provide insights into the principal characteristics of an appropriate, integrated management approach, including the process of its implementation that can best meet Canadian objectives in both the short and long terms. The defining features of the three methods are described below.

7.2 Strengths and Limitations of the Methods

The assessment made it clear that each method possesses both strengths and limitations. Examining the three methods together can provide insight into the principal characteristics of a management approach, including the process of its implementation, which can best meet Canadian objectives in both the short and long terms.

At-Reactor Storage

Advantages: No transportation of used nuclear fuel would be required, as the used fuel would remain next to where it is generated. Each of these sites already houses nuclear installations, so there is nuclear expertise on site and in the existing communities. These communities are familiar with the presence of nuclear facilities, including storage of used nuclear fuel. Further, the ability to monitor the performance and the flexibility to adapt to changing conditions should be facilitated. The science and technology required are well in-hand.

Limitations: The key disadvantage, shared with centralized storage, is the need for continuing administrative controls and operations, including the necessary funding, for the thousands of years the used nuclear fuel remains hazardous. Unlike centralized storage, at-reactor storage means continued management at a number of sites, each of which has as its primary focus, the production of power, not the long term management of used nuclear fuel. These reactor sites were selected for their suitability for reactor operation, not for very long term storage of used nuclear fuel. The used nuclear fuel will remain hazardous well beyond the almost certain shutdown and ultimate abandonment of the nuclear reactor sites. At-reactor storage would result in very long term used nuclear fuel management at a number of sites located next to important bodies of water. This raises security, environmental and safety issues and adds significant uncertainty given the potential for changes in institutions and governance and the likelihood of extreme natural and human induced events over such an extended time.

Centralized Storage

Advantages: Centralized storage, either above-ground or shallow below-ground, would allow for the site selection solely on the basis of used nuclear fuel management. If done well, siting can be achieved with community participation. These are both key potential advantages compared to at-reactor storage and apply to the siting of a deep-geological repository as well. Such a site could be either at an already existing nuclear site, if suitable, or at a different site should that prove more advantageous. With the option of shallow below-ground storage, some of the security concerns can likely be abated. As with at-reactor storage, the required science and technology are well in hand.

Limitations: Centralized storage shares with the at-reactor storage option the key disadvantage of requiring effective and continuing administrative controls and operations, including the required funding, for thousands of years. It also would require the identification and development of a site with potentially contentious community involvement. Transportation of the used nuclear fuel to the site would be required with its attendant risks and costs.

Deep Geological Repository

Advantages: The deep geological repository option results in the eventual permanent emplacement of the used nuclear fuel which reduces or may eliminate the necessity for long term institutional and operational continuity and financial surety. As a consequence, after emplacement and closure, provision of long term resources and funding are not required, although further actions are not precluded. The site is chosen with specific features as a requisite and, if done well, can be achieved with community participation. The intrinsic geologic, hydrologic and other features of the site, in combination with engineered features such as long-lived waste packages and material buffers, isolate the used nuclear fuel from the accessible environment for the very long time periods that they remain hazardous. Deep emplacement reduces security concerns both before and after closure.

Limitations: Advance “proof” that such a system works is not scientifically possible because performance is required over thousands of years. Detailed scientific studies, models and codes form the foundation of the assurances of performance provided to regulatory authorities and interested organizations and individuals. Monitoring becomes more difficult as the used nuclear fuel is emplaced deep underground and as the site is backfilled and closed. At this stage adaptability and flexibility are also reduced as retrieval of the used fuel, for example, becomes much more difficult, costly, and hazardous. Siting must pay particular attention to intrinsic geologic features, perhaps limiting options more than for storage alternatives. As with centralized storage, community participation in regard to siting could be contentious and transportation of the used nuclear fuel will be required.

7.3 Towards a Staged Approach

A staged approach guided by the two complementary objectives of providing a solution and preserving future options, would:

- Enhance trust by establishing a stepwise commitment to Canada's used nuclear fuel management program and giving greater opportunity for stakeholders, and specifically the affected communities to participate in the design, and evaluation of the program status for progressive decision-making;
- Allow for sequential decision making on whether, when and how fast used nuclear fuel is moved to final disposition;
- Allow for an extended validation and optimization program, so that full advantage can be taken of early repository system operation to justify confidence in performance or permit necessary additional measures to be taken.
- Provide a viable storage capability that can be adapted to facility progress and used fuel emplacement while providing flexibility for waste emplacement rates or potential retrieval; and
- Promote continuous learning, allowing careful, controlled improvements in operations and design that enhance performance, reduce uncertainties, and improve economics.

In the event that the Government of Canada agrees with and accepts the deep geological repository as the preferred technical approach, implementation in a staged manner might include the following stages:

- A formal commitment to embark on a long-term decision making process aiming at eventual emplacement of used nuclear fuel in a deep geological repository;
- Initiation of the process to site, license, and develop the deep geological repository;
- Continued storage until the deep geological repository can be sited and constructed;
- Design of the deep geological repository in such a way that is open for an extended indefinite period of time, to allow for both monitoring and possible fuel waste retrieval;
- Inclusion in the design, the development of a modular, expandable storage capability, which may be located at the deep geological repository site, at the reactor sites or at some other site, to store the waste prior to disposal and to permit extended storage should there be a subsequent desire by future generations to reverse the process and/or retrieve the used nuclear fuel from the deep geological repository.
- Careful review and implementation of the best possible interim action plan.

- Careful review – and adjustment if necessary – of the financial viability plan designed to ensure that adequate funds are available, as required, to finance the implementation of the management approach over the long term.

7.4 The Need for a Decision Now

There is definite merit in not delaying a decision. Taking a decision now can define a direction for action and provide a framework within which progress can be made and measured. Delaying a commitment may inadvertently result in limiting future options. In addition, the danger of indefinitely extending at-reactor-site storage is that the worst alternative would be entrenched; we would be defaulting into a solution that is the least effective at managing the attendant risks.

Further, not taking a decision now would severely limit the extent to which those benefiting from nuclear energy will in fact shoulder the responsibility for addressing the issue of used nuclear fuel. Inaction would almost certainly ensure that the resources of future generations would be required for managing a used nuclear fuel problem created today, thus constraining their choices. In short, opting for inaction would be inconsistent with the intent and spirit of the 2002 *Nuclear Fuel Waste Act* and be inconsistent with the values and concerns of Canadians.

7.5 Meeting the Objectives

Choosing a method of managing used nuclear fuel for the long term is not an easy task. Experience over the past decades in many countries suggests that implementation is also difficult. Preferred methods may vary from country to country depending upon nuclear experience, culture, values, or political and institutional structures, economics, and the physical environment. As well, the process by which a selected method is implemented is as important as the method itself. Canada is fortunate. It has a wealth of relevant scientific and technical expertise, a strong nuclear background, the necessary resources, and a set of responsible organizations capable of putting priority on societal values.

The process by which a management approach is implemented, and the institutions and systems which are put in place, will be important determinants of the overall effectiveness of the approach and the extent to which it is and continues to be responsive to societal needs and concerns. Whatever technical method is ultimately selected for implementation, the implementation process must invite and achieve the involvement of citizens at key decision points throughout the process. It must also involve the identification and configuration of institutions and systems, likely at multiple levels of government and administration. The assessment suggests it will be necessary to ensure there is a clear and transparent path for decision making and a mechanism in place to provide assurance that commitments made will in fact be met, and that contingency plans are known and available should they be required, at least for the period in which active management of the waste is needed to ensure safety.

That there should be differences of opinion and residual uncertainties is to be expected. Through this process, Canadian society is making up its mind. The assessment and analysis suggests that a practical and fair approach to managing used nuclear fuel can be established, taking advantage of the best technology and experience available and designing in flexibility to reflect future advances in capabilities or changes in values.

Reactions and responses to this approach should also form an important element in reaching a final recommendation. Success will depend much on the process of moving forward and the meaningful engagement of citizens and stakeholders. This is critical to meeting the Seaborn Panel conclusion that, "Broad public support is necessary in Canada to ensure the acceptability of a concept for managing nuclear fuel wastes."

Glossary & Acronyms

Actinides are nuclides of heavy elements in the series beginning with actinium in the periodic table of the elements. Some absorb neutrons, but do not split. The main actinides in used fuel are: Uranium-235, 236, 238; Plutonium-239, 240, 242; Neptunium-237; Americium-241; Thorium-232.

Activation Products comprise the radioactive isotopes resulting from neutron reactions with materials in the fuel cladding as distinct from the fuel itself. They are called activation products since they arise from non-radioactive materials that have been made radioactive (activated) by fission neutrons. Some of them are Carbon-14, Chlorine-36, and Zirconium-93.

Alpha Radiation is a particulate radiation which can be stopped by a sheet of paper or the outer layer of human skin.

Atom is the smallest unit of an element that maintains the properties of the element.

Basket is a sealed container designed to maintain the geometry of a used nuclear fuel bundle arrangement inside a cask, canister or vault.

Becquerel is a unit of measurement for the rate of decay of a radioactive substance.

Beta Radiation is particulate radiation which can be stopped by a three centimetre thickness of wood.

Cask is a robust, re-usable container used for transportation of highly active radioactive material such as used fuel, designed according to the requirements of CNSC's Packaging and Transportation of Nuclear Substances regulations. The cask provides containment, heat dissipation, radiation shielding, and protection of the contents in normal operation and in the case of a transportation accident. An internal structure, baskets, or module is used to constrain the fuel bundles within the cask.

Centralized Extended Storage (CES) facility is a facility used for the extended storage of used nuclear fuel. The facility will be located at a single, central location and would accept used nuclear fuel from all reactor sites in Canada.

Centralized Facility means a facility used for the extended storage or geologic emplacement of used nuclear fuel. The facility would be located at a single, central location and would accept used nuclear fuel from all reactor sites in Canada.

Daughters are decay products of a radioisotope.

Decay is the process whereby a radioactive element changes into another element, releasing alpha, beta or gamma radiation.

Dilute and Disperse involves dissolving the used nuclear fuel in acid, neutralizing the solution and discharging it slowly down a pipeline into the sea. Dilute and disperse is not included in any national or international R&D programs.

Direct Injection involves the injection of liquid radioactive waste directly into a layer of rock deep underground. Current published assessments indicate no substantive advantages of this method and it is not being pursued in any country as a means of dealing with an entire national inventory of used nuclear fuel.

Disposal is method of isolating used nuclear fuel from humanity and the environment that is conclusive and without the intention of retrieval or reuse.

Disposal at Sea involves placing packaged used nuclear fuel on the bed of the deep ocean. It is prohibited by international conventions and is not included in any national or international R&D programs.

Disposal in Ice Sheets involves placing containers of used nuclear fuel in very thick, stable ice sheets, such as those found in Greenland and Antarctica. Disposal in ice sheets is not included in any national or international R&D programs.

Disposal in Space would permanently remove the used nuclear fuel from the Earth by ejecting it into outer space. Considerable further processing of the used nuclear fuel would be required. This method has never been included in any major research and development program.

Disposal in Subduction Zones involves placing the used nuclear fuel in a subducting or descending plate of the earth's crust. No national or international program is currently examining this option in any way.

Dose is radiation exposure.

Electron is a negatively charged particle orbiting around the nucleus of an atom.

Element is any substance that cannot be separated into different substances except by radioactive decay or nuclear reactions. All matter is composed of elements.

Extended Storage means storage for periods of time significantly greater than 50 years from the time the facility is placed into service. In the context of this study it means permanent or indefinite storage.

Fissile refers to a nuclide which can be induced to fission by an incoming neutron of any energy. Only a few nuclides can fission (i.e., the splitting of a nucleus with the release of energy) and there is only one naturally occurring fissile nuclide, ^{235}U . Other fissile nuclides are ^{233}U and some isotopes of plutonium (^{239}Pu and ^{241}Pu), but none of these occurs in nature to any appreciable extent.

Fission is the splitting of uranium atoms.

Fissionable refers to nuclides that can be induced to fission. This can only happen if the incoming neutron has an energy level higher than a certain threshold. Examples of fissionable, but not fissile, nuclides are ^{238}U and ^{240}Pu .

Fission Products are formed when neutrons hit and split uranium-235 atoms. In the splitting process, several dozen different isotopes are formed. The most significant fission products are: Krypton-85, Strontium-90, Technetium-99, Tin-126, Iodine 129, Cesium-135, and Cesium-137. Fission products generate large amounts of radiation and heat, so fuel bundles must be handled remotely, and they must be shielded and cooled when first removed from the reactor.

Gamma Rays is the most penetrating electromagnetic radiation.

Half-life The time it takes for half the atoms of a given sample of an isotope to decay.

Interim Storage is a temporary method of maintaining used nuclear fuel in a manner that allows access, under controlled conditions, for retrieval or future activities.

Ionizing Radiation is radiation that causes atoms to gain or lose protons and so develop a net electrical charge. When ionization occurs in tissue, it can change the chemical makeup of the tissue and lead to cancer and congenital malformation and possibly to genetic damage.

Isotopes are atoms of an element with the same number of protons but different numbers of neutrons. Most are manmade and are radioactive. Radioactive isotopes are called radioisotopes.

Loading means placement of used fuel in a transportation cask, and carrying out all draining, flushing, backfilling, sealing, bolting etc. activities needed to ensure continuation of containment, shielding and protection of used fuel.

Management in relation to used fuel is all of the activities necessary for long-term care, including the handling, treatment, conditioning or transport of nuclear fuel waste; institutional requirements; and associated planning & decision-making processes.

Management Approach is strategy for the long-term care of used nuclear fuel which encompasses a particular technical method or sequence of methods, and all of the conditions necessary for its successful implementation, including societal requirements, related infrastructure, institutional and governance arrangements.

Method is a technology, technique, technical process or procedure for handling used nuclear fuel.

Module Canister is a sealed container holding a number of modules for loading into a SMV storage vault.

Module is a rack system for holding fuel bundles currently used by OPG for storage in fuel bays and in DSCs. 96 fuel bundles are stored in horizontal tubes held in a rectangular framework.

Natural Background Radiation is naturally occurring and unavoidable radiation from sources around us including the earth, the sun, our bodies etc.

Neutron is a particle in the nucleus of an atom which has no charge.

Neutron Radiation is a very penetrating form of radiation, made up of neutrons ejected from the nuclei of uranium atoms during nuclear fission.

On-site Transfer System is the system of transportation casks, tractors, trailers, rail trolleys, cask transporters etc required to move the fuel between the processing and storage buildings.

Partitioning is the separation and segregation of certain radioisotopes from used nuclear fuel.

Preparation for Shipment means cask decontamination, monitoring, attaching impact limiters if used, labeling and documenting. Placing the cask on or in the transport vehicle, securing tie downs, inspection and placarding and all other activities needed prior to release of the vehicle from the nuclear site.

Processing Building houses the facilities for receiving the fuel deliveries, offloading the transportation casks, unloading the fuel, transfer to the storage containers and loading the containers onto the on-site transfer system. This is likely to be the main building on site and could incorporate other facilities and amenities.

Proton is a positively charged particle in the nucleus of an atom.

Radiation is energy moving through space as waves or particles.

Reactor Extended Storage (RES) facility is a facility used for the extended storage of used nuclear fuel. The storage facilities will be located at each of the current Reactor sites. Each fuel owner will implement a storage solution selected for the specific circumstances of that site.

Reprocessing is the physical and chemical treatment of used nuclear fuel for the purpose of recovery and recycling of uranium, plutonium and fission products.

Rock Melting involves placing the used nuclear fuel in liquid or solid form in an excavated cavity or a deep borehole. There have been no practical demonstrations that rock melting is feasible or economically viable and it is not being investigated in the national program of any country.

Safety is the protection of individuals, society and the environment, from the harmful or dangerous effects of used nuclear fuel, now and in the future.

Security is a condition in which a referent entity or process is made and kept safe against harmful acts, events and situations (which are not of a social construction). Activities include threat, vulnerability and consequence assessments, and mitigation activities. Includes both physical and policy considerations.

Storage is a method of maintaining used nuclear fuel in a manner that allows access, under controlled conditions, for retrieval or future activities.

Storage Building provides the environment for the long-term storage of the fuel, in the alternatives constructed at ground level. The buildings will be essentially modular and constructed over time to match fuel arrival on site. The buildings will be close together and interconnected to form a Storage Building Complex.

Storage Cavern provides the environment for the long-term storage of the fuel in the below ground alternative. The caverns will be interconnected to form a Storage Cavern Complex, which will have access ramps to the surface for transporting the fuel casks to the caverns.

Storage Chamber provides the environment for the long-term storage of the fuel in shallow trenches. Each chamber comprises two storage bays. The chambers will be interconnected modular concrete structures constructed in an open trench and mounded over to form a complex accessible by a ramp from ground level.

Sub-seabed Disposal involves the burial of used nuclear fuel containers beneath the deep ocean floor. Research on sub-seabed disposal effectively ceased in the early 1990s when it became clear that there would always be intense political opposition.

Transmutation is the further processing and transformation of radioisotopes using nuclear reactions initiated by neutrons, protons, or photons from lasers.

Treatment refers to processes applied to used nuclear fuel that change its characteristics.

Transportation Package means a package designed for transportation of radioactive materials and meeting the requirements of the Canadian Nuclear Safety Commission's Packaging and Transport of Nuclear Substances Regulations. The transportation package for used fuel is usually referred to a cask.

Transportation System in this document means a system for retrieving used fuel from the current storage facilities, and transporting it to a centralized site. It includes all facilities, handling equipment, test equipment, casks, vehicles, tie-down systems, maintenance provision, management provisions, emergency response provisions, communications, security, safe guards, contingency provisions, ancillary facilities, and all other items required for safe and effective functioning.

Used Nuclear Fuel means the irradiated fuel bundles removed from commercial or research nuclear fission reactor.

Waste is a fuel bundle from a commercial or research nuclear reactor that has served its intended purpose and has been removed from the reactor.

Acronyms

ACR	Advanced CANDU Reactor	DGR	Deep Geological Repository
AECL	Atomic Energy of Canada Limited	DP	Douglas Point
CANDU	CANada Deuterium Uranium Reactor	DSC	Dry Storage Containers
CEAA	Canadian Environmental Assessment Agency	DSCTP	Dry Storage Container Transportation Package
CES	Centralized Extended Storage	EA	Environmental Assessment
CNSC	Canadian Nuclear Safety Commission	EU	European Union
CRC	Casks in Rock Caverns	KASAM	Swedish National Council for Nuclear Waste
CRL	Chalk River Laboratories	IAEA	International Atomic Energy Agency
CSB	Casks in Storage Buildings	IFB	Irradiated Fuel Bay
CSIS	Canadian Security and Intelligence Service	IFTC	Irradiated Fuel Transportation Cask
CST	Casks in Shallow Trenches	IFTC/BM	Irradiated Fuel Transportation Cask for Baskets or Modules
CVSB	Casks and Vaults in Storage Buildings	MUA	Multi-attribute Utility Analysis
CVST	Cask and Vaults in Shallow Trenches		

NEA	Nuclear Energy Agency	SMV	Surface Modular Vaults
NBP	New Brunswick Power	SSB	Silos in a Storage Building
NFWA	Nuclear Fuel Waste Act	SST	Silos in a Shallow Trench
NPD	Nuclear Power Demonstration	UFC	Used Fuel Containers
NSCA	Nuclear Safety and Control Act	UFTS	Used Fuel Transportation System
NWMO	Nuclear Waste Management Organization	URL	Underground Research Laboratory
OECD	Organization for Economic Co-operation and Development	VST	Vaults in Shallow Trenches
O&M	Operations and Maintenance	WS	Whiteshell Laboratories
OPG	Ontario Power Generation	WRA	Whiteshell Research Area
PLGS	Point Lepreau Generating Station		
RCMP	Royal Canadian Mounted Police		
RES	Reactor Site Extended Storage		
R&D	Research and Development		

Appendix 1
NWMO Assessment
Team Biographies

A1

Michael Ben-Eli (Chair)

Michael Ben-Eli is a cybernetician and international consultant on management and organization. His work is focused on strategy development, organizational design, sustainability, and change management. He graduated from the Architectural Association in London, received his Ph.D. from the Institute of Cybernetics at Brunel University, and was a close associate of R. Buckminster Fuller, with whom he collaborated on a number of projects involving research on advanced structural systems and exploration of issues related to the management of technology and world resources for a sustainable future.

Dr. Ben-Eli pioneered applications of Systems Thinking and Cybernetics to management and organization. Over the years he worked on synthesizing strategy issues in many parts of the world and in diverse institutional settings, ranging from small high technology firms to multinational enterprises, manufacturing companies, financial institutions, health care organizations, government agencies, NGOs, and international multilateral organizations. He is founder of Sustainability Initiatives™, a network of activities established recently in order to facilitate transition to sustainability practices in both the public and private sectors.

John Neate (Secretary)

John Neate is an experienced executive and a hands-on manager in addressing complex challenges and solving problems related to energy and water infrastructure, innovative technology applications and resource management.

Since 1997, as President of Strategies for Change, his skills and expertise have been used by private and public sector organizations in over twenty countries to help them achieve sustainable objectives while anticipating and adapting to change. During this period, he has provided services to the United Nations, the Commission for Environmental Cooperation (CEC), the Canadian Climate Change Action Fund, Environment Canada, the Canadian Department of Foreign Affairs and International Trade, Canada's Natural Sciences and Engineering Research Council (NSERC), Terasen Utility Services, the Globe Foundation, and most recently, NWMO.

From 1990 to 1997, he was responsible for building a private sector employee-owned technology research, development and services company with over 100 employees that was acquired by a publicly-traded firm in the fall of 1997. Prior to this, he served as the Energy and Scientific Policy Advisor for Canada's Environmental Protection Service and was the principal investigator on energy supply alternatives for the Ontario Royal Commission on Electric Power Planning. He was also a founding director of the Ontario Centre for Environmental Technology Advancement (OCETA).

Jo-Ann Facella

Jo-Ann Facella is a student of public opinion and how organizations respond to citizen and market-place needs and wants. Her work has focused on understanding citizen and consumer attitudes on a wide range of policy, corporate and market issues. She has worked for such prominent public opinion firms as the Gallup Poll and Goldfarb Consultants, and more recently on energy issues at Ontario Power Generation.

While at Gallup and Goldfarb Consultants, Jo-Ann conducted strategic research on key issues for the Boards of Canada's largest companies, for provincial and federal governments, and political parties. She has been involved at various times in the development of leading-edge public opinion measurement tools related to satisfaction, loyalty and segmentation. As Senior Advisor at Ontario Power Generation, her areas of focus included public demand for conservation, public perceptions of risk regarding nuclear plant operation, and societal needs and expectations concerning long-term management of used nuclear fuel. She is currently a Senior Advisor for NWMO.

Jo-Ann has a Masters degree in Political Science, where her focus was on the rise of social movements and public policy development.

Anthony Hodge

Anthony Hodge is a geological engineer with a rich and varied career that has included assignments around the world. He served as Director of Research of the B.C. Royal Commission of Inquiry, Environment and Health Safety of Uranium Mining from 1978-1980. In 1987, he became the principal Canadian Researcher in a bi-national state-of-environment review of the Great Lakes region of North America. Anthony served as President of Friends of the Earth Canada from 1989-1992.

In 1992 he was appointed to the Prime Minister's National Round Table on the Environment and the Economy (NRTEE), a position he held until 1996. Through 2001 and 2002, he led a multi-interest U.S.-Canada review of practices in the mining/mineral industry (MMSD – North America). In early 2003, he was appointed Senior Advisor to Canada's Nuclear Waste Management Organization.

Anthony's academic background includes B. A. Sc. (1972) and M. A. Sc. (1976) degrees from the University of British Columbia (Geological Engineering with a specialization in groundwater hydrogeology). He was awarded his Ph. D. (interdisciplinary) in 1995 from McGill. The subject of his dissertation was reporting on progress toward sustainability. From an overarching perspective, his many diverse assignments have a common thread: an interest in recognizing, tracking, understanding, and sparking change such that people and the environment are better off as a result.

Thomas Isaacs

Mr. Isaacs is Director of Policy, Planning and Special Studies at the Lawrence Livermore National Laboratory. This includes responsibility for shaping and outlining the Laboratory's mission, programs, scientific and technical accomplishments, and operational activities. The Laboratory has major national programs in national security, homeland security, energy, environment, biosciences, health care and basic sciences.

Previously, Mr. Isaacs held several senior management positions in the High-Level Radioactive Waste Program of the DOE. As Deputy Director of the Office of Geologic Repositories, he managed the comparative evaluation of candidate sites for the first U.S. repository. Mr. Isaacs also managed the international technical cooperative program with several European nations and Canada, and was the lead U.S. delegate to the Radioactive Waste Management Committee of the Nuclear Energy Agency. He was a member of the 2003 U.S. National Academy of Science committee which released its report making recommendations on the development of used nuclear fuel waste management programs focused on geologic repositories. He serves on the advisory committees for the nuclear engineering departments at Texas A&M and Oregon State universities.

Earlier, Mr. Isaacs was Deputy Director of the DOE Office of Safeguards and Security with responsibility in federal actions to minimize prospects of nuclear proliferation, including establishing the program of technical assistance to the International Atomic Energy Agency for safeguarding nuclear facilities worldwide. Mr. Isaacs graduated cum laude with a B.S. in chemical engineering from the University of Pennsylvania, and was a member of the Tau Beta Pi National Engineering Honor Society. Mr. Isaacs received an M.S. in Engineering and Applied Physics from Harvard University.

William Leiss

William Leiss is a Fellow and former President (1999-2001) of the Royal Society of Canada and Officer of the Order of Canada. He is Professor, School of Policy Studies, Queen's University; Visiting Professor, Haskayne School of Business, University of Calgary; and Scientist, McLaughlin Centre for Population Health Risk Assessment, University of Ottawa.

From 1999 to mid-2004 he held the NSERC/SSHRC Research Chair in Risk Communication and Public Policy in the Haskayne School of Business, University of Calgary. From 1994 to 1999 he held the Eco-Research Chair in Environmental Policy at Queen's University. His earlier academic positions were in political science (Regina, York), sociology (Toronto), environmental studies (York), and communication (Simon Fraser). At Simon Fraser he was also Chair, Department of Communication and Vice President, Research.

He was the founding Chair of the Committee on Expert Panels of the Royal Society of Canada, established in November 1995. This Committee is charged with developing in Canada a consistent and credible procedure for the conduct of expert panel processes, which are used to provide definitive judgments on the state of scientific knowledge relative to issues in the management of health and environmental risks.

He is author, collaborator or editor of twelve books and numerous articles and reports. His most recent book is *In the Chamber of Risks: Understanding Risk Controversies* (2001); two earlier volumes on risk themes are *Mad Cows and Mother's Milk: The Perils of Poor Risk Communication* (co-authored with

Douglas Powell, 1997) and *Risk and Responsibility*, 1994 (all from McGill-Queen's University Press). Earlier books include *The Domination of Nature* (1972), *The Limits to Satisfaction* (1976), *Social Communication in Advertising* (1986, 1990), C. B. Macpherson (1988), and *Under Technology's Thumb* (1990), all of which are currently in print.

He was a member of the Senior Advisory Panel for the Walkerton Inquiry (2000-2002) and in 2000 was Chair of the Task Force on Public Participation for Canadian Blood Services.

Michael Margolick

Michael Margolick is a Senior Associate of GCSI/Natsource and Vice President, Technology of Nai Kun Wind Development Inc. He joined GCSI in 1998, following a 20-year career in the energy sector, including positions in the Corporate Planning Unit at BC Hydro and Executive Director of the BC Energy Council.

Through GCSI, his work has included projects such as Principal Consultant for the National Climate Change Electricity Table, assistance in the development of the post-Kyoto strategy for the Royal Dutch/Shell Group (London, UK), a Bird's-Eye View of Canadian Electricity Supply and Demand, for the Canadian Electricity Association, and a major report Corporate Greenhouse Gas Reduction Targets for the Pew Center on Global Climate Change (Washington, D.C.).

Dr. Margolick has a B.A. in Mathematics from Cornell University and a Ph.D. in Mathematics from the University of British Columbia.

Katherine Moshonas Cole

Katherine Moshonas Cole has had over 17 years' experience in the nuclear industry. Her work in regulatory affairs has included the licensing of nuclear facilities in Canada, the interpretation of CNSC regulations and ICRP/IAEA recommendations, and the management of environmental assessment activities. She has also worked extensively in health physics, radiation protection, and operational and design safety assessment.

Most recently, Katherine served as Managing Director of ITER Canada and was a key member of the team promoting Canada's stake in ITER, a \$14B international fusion energy research project. Prior to this position, she was Director of Regulatory Affairs for ITER Canada and the ITER International Fusion Energy Institute. Before this, she spent six years in Germany and the United States with the ITER Joint Central Team's Safety Environment and Health Group, during which time she led the program for Occupational Safety and Radiation Safety Assessment for the ITER design.

In 1986 Katherine completed her B.A.Sc. in Engineering Science – Nuclear/Thermal Power at the University of Toronto and began her career with the Canadian Fusion Fuels Technology Program. She then spent six years with Ontario Hydro working in the areas of Nuclear Materials Management and Operational Health Physics. From 1993 to 1996 she licensed and managed a nuclear instrument calibration laboratory and performed various performance assessments and incident investigations on operating nuclear facilities in Canada and the United States.

Katherine is a registered Professional Engineer with Professional Engineers Ontario. She is currently a Partner at Candesco, a Canadian company specializing in nuclear licence management, nuclear safety analysis, software development, and quality assurance.

Fred Roots

Fred Roots is a Science Advisor Emeritus to Environment Canada. A meteorologist and geologist, he worked for many years in northern and western Canada and its polar regions, then became involved in the founding of the Canadian Federal Department of the Environment, and the Federal-Provincial Task Force on Radiation (1960-1970), the first serious government concern about radioactive waste in Canada.

Since then he has been involved in environmental impact assessments of nuclear power stations and uranium mining; was Secretary to the group recommending management of used nuclear fuel in Canada (the Hare Report 1977), and a member of the Scientific Review Group of the Nuclear Fuel Waste Management and Disposal Environmental Assessment Panel (Seaborn Panel 1992-1998). He has published about 240 scientific papers and is an Officer of the Order of Canada.

Appendix 2
Terms of Reference

A2

Background

An Assessment Team has been convened to assist the Nuclear Waste Management Organization (NWMO) in undertaking a comparative assessment of alternative approaches for managing used nuclear fuel over the long term. This initial assessment work will be completed in the first six months of 2004 and will provide the substance of NWMO's second major discussion document, *Understanding the Choices*. The Assessment Team will apply an assessment framework for comparing the alternative management approaches – the principal outcome will be an assessment of the specific management approaches referenced in the NFWA.

Assessment Approach

The valuable lessons NWMO is learning from on-going engagement activities will be integrated into the work of the Assessment Team. At the foundation of this are the ten key questions in NWMO's first major discussion document, *Asking the Right Questions?*, which emerged from NWMO's earlier *Conversations about Expectations*. The questions cover a number of overarching aspects of the analysis, including the social, environmental, technical and economic aspects of nuclear fuel waste management. The Assessment Team is being informed by the work of *Scenarios Workshops* previously conducted by NWMO and will test the robustness of the different management approaches against different timeframes.

The Assessment Team will meet a minimum of five (5) times between January and June of 2004. Each meeting will be 4-5 days in duration.

Tasks

The Assessment Team has organized itself to accomplish the following tasks.
The Assessment Team will:

1. Examine the Context of Managing Used Nuclear Fuel.

Review the key factors – ethical, social, environmental, economic and technological – affecting used nuclear fuel waste management. Particular attention will be given to the inherent complexity and interactions of key variables and the implications for policy and decision-making.

2. Describe the Management Approaches.

Fully describe the alternative approaches for managing used nuclear fuel. As required under the NWFA, the management approaches to be assessed include consideration of the following technical methods: deep geological disposal in the Canadian Shield; storage at nuclear reactor sites; and centralized storage, either above- or below- ground. A fourth approach may also be developed as a reasonable alternative to the others. This fourth approach could involve a sequencing of some of the above technical methods or could involve another technical method such as reprocessing.

3. Define Functional Criteria for the Evaluation of the Management Approaches:

For the process of evaluating management approaches, define a set of functional criteria derived from the ten key questions in NWMO's first major discussion document, Asking the Right Questions.

4. Develop an Assessment Framework:

Develop a functional and practical assessment framework which will include: identification of specific sub-tasks that must be completed to address outstanding issues; and development of a work plan for the timely completion of these sub-tasks.

5. Apply the Assessment Framework:

Apply the assessment framework against each of the alternative management approaches and undertake a synthesis of all the required results addressing both quantitative and qualitative aspects as appropriate.

6. Report

Document the refined assessment framework and the results of the preliminary assessment of the alternative management approaches in a concise report. The report will include a synthesis of the Assessment Team's thinking regarding a comprehensive, practical and sensible approach for the management of used nuclear fuel in Canada.

Appendix 3
Methods of
Limited Interest

A3

The following used nuclear fuel management methods have been investigated to varying degrees over the past 40 years and in some cases are still being advocated by a few individuals or organizations. However, none are being implemented, nor are they part of any national program of research and development. In some cases, they are contrary to international conventions. For most of these methods, the used nuclear fuel would be difficult to retrieve.

Dilute and Disperse would involve dissolving the used nuclear fuel in acid, neutralizing the solution and discharging it slowly down a pipeline into the sea. Another possibility would be to transport the used fuel solution by tanker to the open ocean and release it there. The discharge site and rate would be such that radiation doses to people would never exceed internationally accepted limits.

Reasons for screening out – Dilute and disperse differs from all the other used nuclear fuel management methods in that there would be no containment of the waste and isolation from the environment. It has never seriously been proposed for used nuclear fuel because sea disposal is prohibited by international conventions. Dilute and disperse is not included in any national or international R&D programs.

Disposal at Sea would involve placing packaged used nuclear fuel on the bed of the deep ocean. The packaging would consist of canisters designed to last for a thousand years or more. The used fuel would be in a solid form that would release radionuclides into the ocean very slowly when the canisters fail. The site would be one where the water is a few kilometers deep, so that the used fuel would not be disturbed by human activities and there would be substantial dilution of radionuclides before they reach the surface environment.

Reasons for screening out – Sea disposal was investigated by the Nuclear Energy Agency's Seabed Working Group. It would be an extension of the 'sea dumping' method which was used for disposal of solid low level radioactive waste until the early 1980s and which is now prohibited under international conventions. Sea disposal is prohibited by international conventions and is not included in any national or international R&D programs.

Disposal in Ice Sheets would involve placing containers of heat-generating used nuclear fuel in very thick, stable ice sheets, such as those found in Greenland and Antarctica. Three concepts have been suggested. In the “meltdown” concept, containers would melt the surrounding ice and be drawn deep into the ice sheet, where the ice would refreeze above the used fuel containers creating a thick barrier. In the “anchored emplacement” concept, containers would be attached by surface anchors that would limit their penetration into the ice by melting to around 200-500 meters, thus enabling possible retrieval for several hundred years before surface ice covers the anchors. Lastly, in the “surface storage” concept, containers would be placed in a storage facility constructed on piers above the ice surface. As the piers sank, the facility would be jacked up to remain above the ice for perhaps a few hundred years. Then the entire facility would be allowed to sink into the ice sheet and be covered over.

Reasons for screening out – There has been very little work on disposal in ice sheets because there has never been enough confidence about predicting the fate of the used nuclear fuel and because of the potential for release of radionuclides into the ocean. Disposal of radioactive waste in Antarctica is prohibited by international treaty and Denmark has indicated that it would not allow such disposal in Greenland. Disposal in ice sheets is not included in any national or international R&D programs.

Disposal in Space would permanently remove the used nuclear fuel from the Earth by ejecting it into outer space. Destinations which have been considered include the sun and ejection beyond the solar system. This method has been suggested for disposing of small amounts of the most toxic waste materials.

Reasons for screening out – This method has never been included in any major research and development program. Considerable further processing of the used nuclear fuel would be required. Concerns about the risk of an accident have been reinforced by the Challenger and Columbia accidents.

Rock Melting would involve placing the used nuclear fuel in liquid or solid form in an excavated cavity or a deep borehole. The heat generated by the used fuel would then accumulate, resulting in temperatures sufficient to melt the surrounding rock and dissolve the radionuclides in a growing sphere of molten material. As the rock cools, it would crystallize and incorporate the radionuclides in the rock matrix, thus dispersing the used fuel throughout a larger volume of rock. In a variation of this method, the heat generating waste would be placed in containers, causing the rock around the containers to melt, sealing the used fuel in place. Research was carried out on this method in the late 1970s and early 1980s, when it was developed to the level of engineering design. The design involved a shaft or borehole which led to an excavated cavity at a depth of 2-5 kilometers. It was estimated, but not demonstrated, that the used nuclear fuel would be immobilized in a volume of rock one thousand times larger than the original volume of the used fuel. Another early proposal was to use weighted containers of heat-generating used fuel that would continue to melt the underlying rock, allowing them to move downwards to greater depths with the molten rock solidifying above them.

Reasons for screening out – There was renewed interest in this method in the 1990s in Russia, particularly for the disposal of limited volumes of specialized material such as plutonium. Russian scientists

have also proposed that used nuclear fuel could be placed in a deep shaft and immobilized by a nuclear explosion, which would melt the surrounding rock. There have been no practical demonstrations that rock melting is feasible or economically viable. This method is not being investigated in the national program of any country.

Disposal in Subduction Zones would involve placing the used nuclear fuel in a subducting or descending plate of the earth's crust. As subduction zones are invariably offshore, this concept can also be considered as a variant of emplacement in the sea or beneath the seabed. Either tunneling or deep sub-seabed boreholes could theoretically be used to emplace the used nuclear fuel close to an active subduction zone. Free-fall penetrators could also be used.

Reasons for screening out – Lack of confidence in predicting the fate of the used nuclear fuel has been the main reason why little attention has been paid to disposal in subduction zones. Concerns have been expressed that the used fuel might return to the surface environment via volcanic eruptions. It has also been suggested that this method would be seen as a form of sea disposal and hence would be prohibited by international conventions. No national or international program is currently examining this option in any way.

Direct Injection would involve the injection of liquid radioactive waste directly into a layer of rock deep underground. Although used for the disposal of liquid hazardous and low-level waste in the U.S. in the past, this technique has only ever been used for liquid high-level waste in the former Soviet Union, at a number of locations usually close to the waste generating sites.

Reasons for screening out – Direct injection requires detailed knowledge of subsurface geological conditions, as it does not incorporate any man-made barriers. There would be no control of the injected material after disposal and retrieval would be impossible. There are many technical unknowns that would require extensive research to gain the degree of confidence that this method would be appropriate for a specified site. Although the option would not contravene international conventions, it would not be consistent with the spirit of international guidance on the long-term management of used nuclear fuel. Current published assessments indicate no substantive advantages of this method and it is not being pursued in any country as a means of dealing with an entire national inventory of used nuclear fuel.

Sub-seabed Disposal would involve burial of used nuclear fuel containers in a suitable geological setting beneath the deep ocean floor. The disposal sites would be ones where the sediments are plastic and have a high capacity to absorb radionuclides, and where the water is a few kilometers deep. The main sub-seabed disposal concept would use missile-shaped canisters called “penetrators” that hold the solid waste, are dropped from ships, and bury themselves to a depth of a few meters or more in the sediments on the ocean floor. The idea behind the concept is that the waste form, inner canister, penetrator and sediments would provide sufficient protection to prevent the release of radionuclides into the ocean for thousands of years or more. When release finally does take place,

it would occur very slowly and there would be substantial dilution. Another variation of this option would use deep sea drilling technology to stack used nuclear fuel packages in holes drilled to a depth of 800 meters, with the uppermost container about 300 meters below the seabed. An alternative “sub-seabed” option would be to access a location deep beneath the ocean floor via on-land shafts and drifts. In this instance, the ocean itself would serve as a last line of defense. The theory is that if contaminants were to escape and move to the ocean environment, their volume would be small and the buffering and diluting capacity of the ocean would mitigate consequences.

Reasons for screening out – Sub-seabed disposal was investigated extensively in the 1980s, primarily under the auspices of the Seabed Working Group set up by the Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD). Canada participated in this group, as did the U.S., the U.K., Japan and several European countries. Research on sub-seabed disposal effectively ceased in the early 1990s when it became clear that there would always be intense political opposition. Ocean access to a sub-seabed repository is now prohibited by international conventions.

Appendix 4
Influence Diagram
Development

A4

The development of influence diagrams involves two steps undertaken concurrently:

1. Identification of factors significant to the determination of each objective; and
2. Mapping of objectives in a way that demonstrates a direction of influence.

In the case of the Assessment Team, Step 1 began with a review of insight from the original Ten Questions contained in Discussion Document 1 along with the many sub-elements that were used there as examples of knowledge or insight that would help in the development of an answer to each question. The results of this analysis are shown below in a series of tables organized by objective. In each case, the link between each objective and the original ten questions is provided, “influencing factors” are listed, and a number of criteria are offered that serve to differentiate between technical approaches.

Appendix 4.1 Fairness

ORIGINAL TEN QUESTIONS RELATED TO:	INFLUENCING FACTORS
Mainly 2 and 4, also to 1, 3, 5, 6, 8 and 9	<ul style="list-style-type: none"> > opportunities to participate > distribution of impacts among communities > intergenerational distribution of costs > respect for humans and the biosphere > respect for the unknowable interests of future generations
FAIRNESS CRITERIA THAT HELP TO DISCRIMINATE BETWEEN TECHNICAL METHODS	
<p>From Question 2, Engagement and Participation in Decision-Making:</p> <ul style="list-style-type: none"> > communities of interest have the opportunity to participate in the decisions that influence their future > commitments are understood and agreed to by the communities of interest. <p>From Question 4, Ethics</p> <ul style="list-style-type: none"> > the fair sharing of costs, benefits, risks, and responsibilities for humans and non-humans both now and in the future. 	

Appendix 4.2 Public Health and Safety

ORIGINAL TEN QUESTIONS RELATED TO:	INFLUENCING FACTORS
Mainly 6, also 1, 4, 5 and 8	<ul style="list-style-type: none"> > size of population potentially at risk > understanding and control of risks and effect of normal operations > likelihood and consequences of “off-normal” events > allowance for changes in institutions, society, economy > knowledge of mental and cultural stresses and their consequences
PUBLIC HEALTH AND SAFETY CRITERIA THAT HELP TO DISCRIMINATE BETWEEN TECHNICAL METHODS	
<p>From Question 6, Human Health, Safety, and Well-being</p> <ul style="list-style-type: none"> > worker and population health, safety and security are protected over time and stresses imposed on individuals and communities are assessed and managed > social/cultural costs, benefits and risks, including direct, indirect, cumulative and induced effects, are understood and addressed in a manner consistent with the goals of the community > effective organization and capacity are in place or can be put in place within the management facility, the community and within governments at all levels > the level of risk to people and society is understood and addressed > a reasonable degree of certainty exists that the responsibilities and sureties for short and long-term human well-being are fully and fairly assigned. 	

Appendix 4.3 Worker Health and Safety

ORIGINAL TEN QUESTIONS RELATED TO:	INFLUENCING FACTORS
Mainly 6, also 1, 5, 9 and 10	<ul style="list-style-type: none"> > seriousness of potential consequences to affected individuals > likelihood of impacted individuals experiencing consequences > potential of impacts from conventional and industrial hazards > potential for “off-normal” extreme accidents (handling, construction, radiological)
WORKER HEALTH AND SAFETY CRITERIA THAT HELP TO DISCRIMINATE BETWEEN TECHNICAL METHODS	
<p>From Question 6, Human Health, Safety, and Well-being</p> <ul style="list-style-type: none"> > worker and population health, safety and security are protected over time and stresses imposed on individuals and communities are assessed and managed > effective organization and capacity are in place or can be put in place within the management facility, the community and within governments at all levels > the level of risk to people and society is understood and addressed > a reasonable degree of certainty exists that the responsibilities and sureties for short- and long-term human well-being are fully and fairly assigned. 	

Appendix 4.4 Community Well-being

ORIGINAL TEN QUESTIONS RELATED TO:	INFLUENCING FACTORS
Mainly 3 and 6 but to all others as well	<ul style="list-style-type: none"> > effect of the waste facility on economic health of the community > effect of being host to the waste on social and cultural quality > effect of being a focus for high-technology operations > relation of nuclear energy and wastes to other community industries > vulnerability of community and facility to changes in institutions, governance, economic conditions over time
COMMUNITY WELL-BEING CRITERIA THAT HELP TO DISCRIMINATE BETWEEN TECHNICAL METHODS	
<p>From Question 3, Aboriginal Values</p> <ul style="list-style-type: none"> > spiritual and physical aspects of the land, people, wildlife and their habitats are addressed within the aboriginal sense of responsibility and stewardship. <p>From Question 6, Human Health, Safety, and Well-being</p> <ul style="list-style-type: none"> > worker and population health, safety and security are protected over time and stresses imposed on individuals and communities are assessed and managed > social/cultural costs, benefits and risks, including direct, indirect, cumulative and induced effects, are understood and addressed in a manner consistent with the goals of the community > effective organization and capacity are in place or can be put in place within the management facility, the community and within governments at all levels > the level of risk to people and society is understood and addressed > a reasonable degree of certainty exists that the responsibilities and sureties for short- and long-term human well-being are fully and fairly assigned. 	

Appendix 4.5 Security

ORIGINAL TEN QUESTIONS RELATED TO:	INFLUENCING FACTORS
Mainly to 7, but also to 1, 2, 4, 6, 5, 8, 9 and 10	<ul style="list-style-type: none"> > security of facilities, nuclear materials, transportation and other support infrastructure and systems > potential for theft, diversion, sabotage, seize and hold, civil disobedience, societal breakdown > adequacy of legal, surveillance and enforcement systems, awareness of used nuclear fuel as a target and a symbol for social unrest, communication and intelligence systems, programs of communications and participation to build public support, contingency plans > integration of all parts of the waste system for control and response > events in other countries > potential for insider threats > ability for integrity and security to be maintained in the event of political, institutional or social breakdown
SECURITY CRITERIA THAT HELP TO DISCRIMINATE BETWEEN TECHNICAL METHODS	
<p>From Question 6, Human Health, Safety, and Well-being</p> <ul style="list-style-type: none"> > worker and population health, safety and security are protected over time and stresses imposed on individuals and communities are assessed and managed. <p>From Question 7, Security</p> <ul style="list-style-type: none"> > The management approach, facilities, and related support infrastructure will maintain their intended integrity in the face of accidents and failures; acts of terrorism and malice; societal breakdown; and the possibility of war. > Contingency plans are in place or can be put in place to anticipate and adequately address the effects and consequences of security concerns. 	

Appendix 4.6 Environmental Integrity

ORIGINAL TEN QUESTIONS RELATED TO:	INFLUENCING FACTORS
Mainly 8, but all others as well	<ul style="list-style-type: none"> > adequate knowledge of the sensitivity of key elements of the ecosystems to stresses and disturbances caused by construction and presence of a used nuclear fuel facility as well as support systems and infrastructure including transportation > adequate knowledge of ecological processes and consequences of disturbance or recovery > knowledge of the geochemistry of groundwater with regard to elements in used nuclear fuel, and of mechanisms and rates of diffusion or dispersion in solid rock, soil, and water > understanding of the role of micro-organisms in soils, waters, and rocks which may affect the facility > understanding of the risks and consequences of extreme environmental events, and of the trends and events of long-term changes
ENVIRONMENTAL INTEGRITY CRITERIA THAT HELP TO DISCRIMINATE BETWEEN TECHNICAL METHODS	
<p>From Question 8, Environmental Integrity</p> <ul style="list-style-type: none"> > elements of the ecosystem affected by the management method are not compromised in order to meet the needs of current and future generations > the physical, chemical, and biological stresses on the environment imposed by the waste facility, including their cumulative effects and the potential consequences of failure of containment, are understood and mitigation proposed > the risk to the environment is understood and addressed > effective organization and capacity are in place or can be put in place for monitoring and periodic reassessment of changing environmental conditions to allow for improvements > responsibilities for long-term integrity of the ecosystem are fully and fairly assigned. <p>From Question 10, Technical Adequacy</p> <ul style="list-style-type: none"> > the effects of the technical method(s) on natural and anthropogenic processes are understood and addressed over both the short and long term > the potential for catastrophic and chronic failure of containment systems, including those used for transportation, is understood and addressed > the potential for long-term residual impacts is understood and addressed. 	

Appendix 4.7 Economic Viability

ORIGINAL TEN QUESTIONS RELATED TO:	INFLUENCING FACTORS
Mainly 9, also 1, 5, 6, 8 and 10	<ul style="list-style-type: none"> > adequacy of estimates, in the current period, of costs which will be incurred over a very long time-period > range of possible economic, social, and environmental conditions and the capacity for funds set aside to address costs resulting from this range > procedures for management of investment costs over at least two generations, until the facility is filled > surety of funding for operational and maintenance costs for at least seven generations; confidence that funds set aside will cover incurred costs > process for ensuring resources to maintain the facility during financial recession or institutional breakdown
ECONOMIC VIABILITY CRITERIA THAT HELP TO DISCRIMINATE BETWEEN TECHNICAL METHODS	
<p>From Question 9, Economic Viability</p> <ul style="list-style-type: none"> > cost estimates are complete and take into account the magnitude and characteristics of the waste stream and the services required to maintain the facility, reflecting best available social and technical knowledge > adequate funds are set aside and available to finance development of the approach and its implementation > offering secure and sustainable financial arrangements that will endure for the long term > significant social and economic impacts are understood and addressed > the potential financial consequences for the community are understood and addressed > intergenerational transfer issues are understood and addressed > contingencies are established and addressed, for example to deal with transportation accidents, a major economic recession, an extreme natural event such as a major earthquake. 	

Appendix 4.8 Adaptability

ORIGINAL TEN QUESTIONS RELATED TO:	INFLUENCING FACTORS
<p>Mainly 1, 5 and 10 but also to all others</p>	<ul style="list-style-type: none"> > availability of necessary resources and capacity over the long term > adequacy of institutions and governance in terms of both accountability and their capacity to adjust to changing environmental and socio-economic conditions > ability for the management approach to adjust to new or improved knowledge or technologies, and developments in both Canada and other countries > technical maturity and intellectual (research) capacity to maintain the integrity of the facility under changing environments and socio-economic conditions > ability to deal with catastrophic events affecting the facility
ADAPTABILITY CRITERIA THAT HELP TO DISCRIMINATE BETWEEN TECHNICAL METHODS	
<p>From Question 1, Institutions and Governance</p> <ul style="list-style-type: none"> > an efficient and effective mix of legislated rules, voluntary programs, market incentives and cultural norms is in place or can be put in place > national and international laws, regulations, and conventions are respected > capacity, mechanisms and resources are in place or can be put in place to address consequences over the long term. <p>From Question 5, Synthesis and Continuous Learning</p> <ul style="list-style-type: none"> > Continuous learning is embedded in the proposed approach and there is a system for monitoring and periodic reassessment to allow for improvements. <p>From Question 10, Technical Adequacy</p> <ul style="list-style-type: none"> > technical barriers, uncertainties and opportunities are understood and addressed > the potential for catastrophic and chronic failure of containment systems, including those used for transportation, is understood and addressed > the potential for extreme natural events (storms, meteorites, earthquakes, dramatically changed temperature regimes, glaciation, ozone depletion) is factored into the design > the effects of changes in global climate, hydrology and landscape are factored into the design > the potential for long-term residual impacts is understood and addressed > the opportunity exists to undertake technical monitoring and reporting > flexibility and the opportunity for change and improvement is factored into the design. 	

In developing the influence diagrams, insights were drawn from:

- An analysis of social and ethical considerations emerging from the Seaborn Panel Report and discussions of the NWMO Ethics Panel
- Insight that has emerged from the various background and concept papers commissioned by NWMO.

Using the above approach, the influence diagrams shown in Chapter 6 were developed for each of the eight objectives.

Appendix 5
Exploring the Implications
of Future Scenarios

A5

1. Introduction

To examine the implications of assumptions made about alternative futures in the scoring of management approaches, a subgroup of the Assessment Team undertook an analysis drawing from the previously completed Scenarios Exercise.⁶⁴ In that earlier work, four scenarios were developed within a 25-year time horizon, and twelve using a 175-year time horizon. Additional thinking extended out to 500 and 10,000 years but not in the form of fully developed scenarios.

To undertake this analysis, three scenarios were taken from the scenarios developed with a 175-year time horizon. A description of these “test” scenarios is found below followed by a discussion of the results of this analysis.

2. Descriptions of the Future “Scenarios” Used in this Analysis

In this discussion, the term “scenario” is used to describe a set of future conditions in which today’s decisions may be played out. These scenarios are neither predictions nor strategies. They are stories with beginnings, middles, and ends that provide a series of real-life-like tapestries that wind together many variables, including:

- *Care for the environment:* from much care and sensitivity to little.
- *Care for people and their communities:* from much care and sensitivity to little.

⁶⁴ Background Paper 8-5. Looking Forward to Learn: Future Scenarios For Testing Different Approaches to Managing Used Nuclear Fuel in Canada, Global Business Network (GBN)

- ***Future use of nuclear as a source of electrical energy and thus the volume of used nuclear fuel generated:*** from a limit to today's capacity let run to the end of its design life through an intermediate condition of continuing a form of the current technology to the end of the 21st century, to indefinite continuation, to changed nuclear technology allowing for small-scale local sources.
- ***Stability of and respect for governments and political and societal institutions:*** from very stable and respected through loss of respect to total collapse.
- ***Growth of human population:*** from significant growth to significant reduction to total annihilation
- ***The living location of people:*** from current urban centres to a significant migration to rural areas and redistribution of population.
- ***Climatic conditions:*** from current conditions through to significant change in line with projected changes from climate change scientists and beyond to unexpectedly more severe changes.
- ***Health of the economy:*** from very strong to business-as-usual to total collapse.
- ***Overall state of health of the human population:*** from very healthy to collapse.
- ***Need to transport used nuclear fuel:*** from not at all to a major amount.
- ***Degree of unexpected containment deterioration:*** from none at all to its occurrence.
- ***Capacity to transfer specialized knowledge from generation to generation:*** from much to little.

Each scenario brings together a unique set of these variables using a reasonable and plausible logic. How the world actually unfolds will likely be different than any particular scenario conceived of in this way. However, the intent is to provide a means of assessing how the results of current decisions will respond to various potential future conditions, not to predict the exact pathway taken by those future conditions. The three scenarios used in this analysis are summarized below.

Test Scenario 1⁶⁵

Test Scenario 1 is an optimistic scenario. Key characteristics include: respect for institutions is high and they remain strong in perpetuity; climate change occurs but is at the minimal end of projections; a shift away from consumerism; reduction in tension and attendant terrorism; a doubling of the typical human lifespan through biotech and medical advances; significant population increase leading to careful control of birthing; increased conservation coupled with reduced energy demand; the use of alternative energy technologies increases while the use of nuclear ends with the current facilities running to the end of their design life; the used fuel issue becomes an old legacy problem – there has been no “technical fix” discovered and the need for vigilance remains; a “nuclear priesthood” is established to maintain watch.

⁶⁵ Developed from the original scenario, “Tea with the Wise” found in Looking Forward to Learn.

In the analysis, Test Scenario 1 was split into two sub-scenarios differentiated as follows:

Test Scenario 1A This Scenario assumes that adequate funds are set aside in a stable instrument during the generation of the used nuclear fuel to ensure that all costs of managing that fuel are covered in perpetuity. This ensures that the “polluter pays” principle is adhered to for all three of the alternative management approaches.

Test Scenario 1B This Scenario assumes that funds are set aside during the generation of used nuclear fuel to the extent that requirements for covering the cost of deep geological disposal to facility closure are covered (thus the polluter pays principle is respected for this alternative) but that for the storage options, funds from future generations will eventually be required to cover the cost of repackaging and maintenance (thus the polluter pays principle is not respected for the two storage alternatives).

Test Scenario 2⁶⁶

Test Scenario 2 is more “pessimistic” than Scenario 1. Key characteristics include: nuclear has been abandoned because of a major nuclear disaster and total loss of public trust; political and social instability; greater dependence on fossil fuel with attendant environmental problems including extreme climate change, more severe than earlier predicted; drought in southern prairies, decrease in water levels in Great Lakes, drastic reduction in use of St. Lawrence Seaway; huge increases in food costs; mass migrations of people, population shrinks by 50 percent, many are driven to subsistence lifestyles; Canada as a nation is reduced to a shell of what it once was.

Test Scenario 3⁶⁷

Test Scenario 3 is also “pessimistic.” Key characteristics include: economies are strong; energy demand is high – nuclear dependency high; nuclear capacity and weapons proliferate; there is no technical solution to the challenge of used nuclear fuel, and even though used nuclear fuel remains safe, security remains a major concern; the threat of nuclear war is very real but doesn’t occur; life is risky and society teeters; technology for those who have it allows the massing of wealth but the gap between rich and poor widens, social instability results, totalitarian rule is imposed while personal freedoms are reduced; technology also supports terrorism with disastrous results; climate change occurs but is not extreme.

3. Assessment by Future Scenario

Using the above three Test Scenarios, the subgroup completed assessments by each objective for each of the three alternative management approaches under consideration for each of the scenarios. The same assessment process was followed as was used by the full Assessment Team: scoring was undertaken while being guided by the influence diagrams and an integrated score for each objective was compiled. The results were then compared across objectives for each alternative management approach under the conditions provided by each of the test scenarios.

⁶⁶ Developed from the original Scenario, “Accident at Dark” found in Looking Forward to Learn.

⁶⁷ Developed from the original Scenario, “Threat before Midnight” found in Looking Forward to Learn.

4. Observations and Conclusions

From the analysis, the following observations were drawn:

1. For the two pessimistic scenarios (either scenarios 2 or 3), while there is some variation between how the same objective scores, the Deep Geological Repository (DGR) is significantly better than both storage options (the spread is clearly evident) while on-site scores the worst.
2. For the optimistic futures 1-A and 1-B, all three management approaches score similarly – so closely that minor variations in scoring, well within the bounds of uncertainty, could push any one of the three to the best performing position. When the economic viability and fairness aspects are improved to ensure the polluter-pays principle is maintained in perpetuity (Scenario 1A), there is a slight preference for the on-site storage option.
3. In assessing the significance of future conditions for each alternative management approach:
 - The scoring of the relative performance of DGR appears to be less dependent on the vision of future conditions than the two storage alternatives.
 - The scoring of the centralized storage option is heavily dependent on the future – its relative performance differs significantly between the two optimistic scenarios and the two more challenging futures.
 - The on-site storage option is the most influenced by assumptions made about future conditions.

In summary, two overall significant conclusions arise. First, it is clear from this analysis that assumptions made about future conditions heavily influence how any given alternative management approach will score as well as the relative positioning of the three alternatives assessed. However, second, DGR generally performs more strongly than the storage alternatives and its lack of dependency on future scenario implies a degree of robustness not shared by the others.

This analysis serves to re-enforce the overall conclusions arrived at by the Assessment Team. However, in addition, it has brought to light sets of conditions which would result in favourable scoring for the storage options. These conditions include:

- Strong, stable, respected, and vigilant institutions must remain in place in perpetuity.
- Climate change must be limited to the very low end of what is now projected.
- The polluter pays principle must be entrenched in a way that provides for an indefinite stream of resources to cover costs of the storage options in perpetuity such that those receiving the benefit from generation of the used nuclear fuel would truly shoulder the burden of providing the resources for its management over the long term.

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