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NWMO BACKGROUND PAPERS
9. ASSESSMENTS

9-2a ASSESSMENT OF BENEFITS, RISKS AND COSTS OF MANAGEMENT APPROACHES FOR USED NUCLEAR FUEL BY ILLUSTRATIVE ECONOMIC REGION

TECHNICAL REPORT

Golder Associates Ltd., Gartner Lee Limited

NWMO Background Papers

NWMO has commissioned a series of background papers which present concepts and contextual information about the state of our knowledge on important topics related to the management of radioactive waste. The intent of these background papers is to provide input to defining possible approaches for the long-term management of used nuclear fuel and to contribute to an informed dialogue with the public and other stakeholders. The papers currently available are posted on NWMO's web site. Additional papers may be commissioned.

The topics of the background papers can be classified under the following broad headings:

1. **Guiding Concepts –** describe key concepts which can help guide an informed dialogue with the public and other stakeholders on the topic of radioactive waste management. They include perspectives on risk, security, the precautionary approach, adaptive management, traditional knowledge and sustainable development.
2. **Social and Ethical Dimensions** - provide perspectives on the social and ethical dimensions of radioactive waste management. They include background papers prepared for roundtable discussions.
3. **Health and Safety –** provide information on the status of relevant research, technologies, standards and procedures to reduce radiation and security risk associated with radioactive waste management.
4. **Science and Environment –** provide information on the current status of relevant research on ecosystem processes and environmental management issues. They include descriptions of the current efforts, as well as the status of research into our understanding of the biosphere and geosphere.
5. **Economic Factors** - provide insight into the economic factors and financial requirements for the long-term management of used nuclear fuel.
6. **Technical Methods** - provide general descriptions of the three methods for the long-term management of used nuclear fuel as defined in the NFWA, as well as other possible methods and related system requirements.
7. **Institutions and Governance** - outline the current relevant legal, administrative and institutional requirements that may be applicable to the long-term management of spent nuclear fuel in Canada, including legislation, regulations, guidelines, protocols, directives, policies and procedures of various jurisdictions.

TECHNICAL REPORT ON

ASSESSMENT OF BENEFITS, RISKS AND COSTS OF MANAGEMENT APPROACHES FOR USED NUCLEAR FUEL BY ILLUSTRATIVE ECONOMIC REGION

Submitted to:

Nuclear Waste Management Organization

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1.0 INTRODUCTION

In 2002, the federal government passed the *Nuclear Fuel Waste Act* (NFWA)[1]. Among other things, the NFWA required that existing nuclear energy corporations within Canada (Hydro-Québec, Ontario Power Generation Inc. and New Brunswick Power Corporation) establish a new corporation, the Nuclear Waste Management Organization (NWMO). The purpose of the Act was to provide a framework to enable the government to make decisions on the management of used nuclear fuel that is based on a comprehensive, integrated and economically sound approach for Canada. The NWMO has been asked to propose to the Government of Canada approaches for the management of used nuclear fuel and to implement the approach that is selected.

The *Nuclear Fuel Waste Act* requires that NWMO include, as a minimum, an analysis of three specific technical methods. Each of the following methods must be the sole basis of at least one approach:

1. Deep geological disposal in the Canadian Shield;
2. Storage at nuclear reactor sites; and
3. Centralized storage, either above or below ground.

This study includes a detailed technical description of each proposed approach. Sample "illustrative" economic regions were selected as a means to demonstrate the possible range of impacts that might be expected. Each proposed approach includes a comparison of the benefits, risks and costs of that approach with those of the other approaches, taking into account the effect of location, as well as ethical, social and economic considerations.

The NWMO has undertaken considerable background research, consultation and study since its inception, and has completed a preliminary assessment of these proposed approaches within a framework based on ten key questions identified through extensive consultation with Canadians. The results of these activities, up to September 2004, are reported in two major discussion documents[2,3]. Under the requirements of the NFWA, the NWMO must complete a comprehensive comparative assessment of the benefits, risks and costs of each proposed approach. The benefit, risk and cost assessment provided in this report has been conducted to assist the NWMO in formulating and making its recommendations to the Federal Government later in 2005.

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[1] *An Act Respecting the Long-term Management of Nuclear Fuel Waste*, assented to June 13, 2002.
[2] Nuclear Waste Management Organization, *Asking the Right Questions? – The Future Management of Canada's Used Nuclear Fue*l, November 2003.
[3] Nuclear Waste Management Organization, *Understanding the Choices – The Future Management of Canada's Used Nuclear Fuel*, September 2004.

1.1 Study Goals and Objectives

The primary goal of this study was to produce a comparative assessment of the benefits, risks and costs of implementing the three proposed management approaches in a sample of illustrative economic regions[4] to provide the NWMO with clarity of choice between approaches.

More specifically, the objectives of the study were to:

1. Develop and implement a methodology for the comparative assessment of benefits, risks and costs of three management approaches, taking into account illustrative economic regions and grounded in the ten key questions identified by Canadians;
2. Address requirements of the *Nuclear Fuel Waste Act*;
3. Examine the influencing factors identified by the NWMO Assessment Team for further study and analysis;
4. Synthesize and build upon the foundation of work already available through a preliminary comparative assessment undertaken by NWMO Assessment Team (documented in "Understanding the Choices – the Future Management of Canada's Used Nuclear Fuel", as discussed below) and other studies commissioned by the NWMO; and
5. Articulate the means by which NWMO can avoid or minimize significant socio-economic effects on a community's way of life or on its social, cultural or economic aspirations.

1.2 Consideration of Preliminary Comparative Assessment

In early 2004, NWMO formed a multi-disciplinary Assessment Team to further develop an assessment framework based on the ten questions posed in NWMO's first discussion document, "Asking the Right Questions?". The Assessment Team was also asked to apply this framework to the three approaches, based on the methods outlined in the *Nuclear Fuel Waste Act*, that would allow for the systematic integration of social and ethical considerations with technical, economic, financial and environmental considerations[5].

The results of this Preliminary Comparative Assessment (PCA), summarized in NWMO's document "Understanding the Choices", identify a number of key influencing factors for each of the eight guiding objectives. The guiding objectives were developed by the NWMO Assessment Team in response to the ten key questions identified in "Asking the Right Questions?". The objectives and influencing factors from the PCA were retained in this study to ensure linkage with the PCA and to build on the foundation of the earlier assessment. This study used the same broad framework as the PCA, including many of the influencing factors and measures used to

[4] Economic regions that have physical and socio-economic characteristics that are illustrative of many other economic regions across Canada.
[5] Nuclear Waste Management Organization, *Understanding the Choices – The Future Management of Canada's Used Nuclear Fuel*, September 2004, page. 39.

compare approaches in the PCA. Accordingly, information developed in this study will support further evaluation using the multi-attribute utility analysis that was conducted and reported in "Understanding the Choices".

This study was prepared by the team of Golder Associates Ltd. (GAL) and Gartner Lee Limited (GLL), supplemented with expertise from Nuclear Safety Solutions Limited and Econometric Research Ltd.

1.3 Steps in this Assessment

This comprehensive assessment of the benefits, risks and costs of the management approaches was conducted using the following seven steps:

1. Review of the assessment framework developed and applied in the Preliminary Comparative Assessment. Retention of the objectives and influencing factors used in the Preliminary Comparative Assessment.
2. Design and development of methods and tools for assessing the benefits, risks, and costs of alternative approaches to the management of used nuclear fuel in Canada.
3. Identification and development of background information for "illustrative"[6] economic regions that allowed a comparison of the benefits, risks and costs for each approach with those of other approaches, taking into account the economic region in which the approach could be implemented:
   - Selection of "illustrative" economic regions that cover a range of physical and socio-economic conditions characteristic of the Canadian spectrum; and
   - Selection of illustrative economic regions that meet the fundamental requirements of the three approaches.
4. Examination of the numerous influencing factors for each of the eight objectives that were identified in the Preliminary Comparative Assessment for further detailed analysis.
5. Identification of measures and indicators for each of the influencing factors studied in detail for use in the comparative assessment. The measures and indicators are selected to allow the evaluation of the performance of the three approaches against each of the eight objectives:
   - Using quantitative measures for influencing factors where these are available; and
   - Providing qualitative discussion on other influencing factors, where feasible.
6. Conduct an analysis of each of the approaches across the applicable illustrative economic regions, using information from the chosen measures and indicators.

[6] The decision to choose eleven illustrative economic regions is not an attempt to pre-qualify or select a site for any of the three management approaches. Rather, it was not possible to assess and compare impacts across all 76 economic regions in Canada. Instead, eleven sample, or illustrative regions were selected solely on the basis of the fact that they represent the range of diversity of economies, environments, and population dynamics found across Canada.

7. Conduct a comparative assessment of the benefits, risks and costs using information from the above analysis:
   - Assessment and comparison of the benefits, risks and costs of each approach with those of other approaches, taking into account the economic regions in which that approach would be implemented, as well as the ethical, social and economic considerations associated with that approach[7].

1.4 Methods

The *Nuclear Fuel Waste Act* (2002) requires that three approaches be assessed, taking into account the economic regions in which they might be implemented. There is a total of 76 economic regions in Canada. As not all of the three approaches are feasible in each economic region, a methodology was developed and applied in cooperation with NWMO to select a subset of economic regions which have diverse physical and socio-economic characteristics, illustrative of many other economic regions across Canada. The assessment of the benefits, risks and costs of the three approaches was conducted within the context of the eleven illustrative economic regions (ERs) only. The illustrative ERs are identified in Section 3 and cover a range of urban and rural regions which represent unique characteristics of Canada. The selection of the illustrative ERs is not intended to indicate where a future management approach would be implemented.

The assessment of benefits, risks and costs of the management approaches across the illustrative ERs used specific measures and indicators for each of the eight objectives identified by the NWMO Assessment Team. These eight objectives include ethical, social and economic considerations. As noted, only three approaches were assessed, namely:

- Deep Geological Disposal in the Canadian Shield;
- Storage at Nuclear Reactor Sites; and
- Centralized Storage, either above or below ground.

Other approaches were not identified or considered in this assessment. However, based on the assessment, the study team reached an overall conclusion on the three approaches, and makes a conclusion with respect to an enhanced management approach which draws on the strengths of all three approaches while minimizing certain limitations. This conclusion is provided in Section 12.

The assessment relied on both quantitative and qualitative methods to enable a complete assessment of the benefits, risks, and costs of alternative management approaches for used nuclear fuel. An overview of these methods is presented in this subsection along with an explanation of how the measures were developed.

[7] *An Act Respecting the Long-Term Management of Nuclear Fuel Waste*, assented to June 13, 2002, Section 12 (4).

The starting point of the assessment was a review of the design and implementation plans for each of the management approaches. This review of the Joint Waste Owners'[8] documents [9] was conducted by experienced industry engineers from the study team, drawing mainly on their extensive experience in the planning, design and development of similar used nuclear fuel management facilities in Canada and around the world. The outcome of this review culminated in the summary of the three approaches provided in Section 2 which was used as key input to the assessment. A significant portion of this review involved a reconstruction of the Joint Waste Owners' detailed plans and cost estimates into operational phases in a way that permitted a consistent comparison of the three approaches with respect to costs and schedules. The review also took into consideration the uncertainty associated with the Joint Waste Owners' costing, including the ability to address uncertainties on long-term cost estimates. In total, this design and operational review of the management approaches took about three weeks to complete.

An array of methods and analysis tools were employed in Sections 4 through 11 to enable a thorough assessment of the benefits, risks, and costs linked to each of the measures and indicators outlined in each respective section. The assessment was carried out over approximately seven weeks.

To address the public health and safety and worker health and safety objectives, the study team conducted a comprehensive qualitative assessment of the benefits, risks and costs. Specifically, public and/or worker health and safety risks are a function of:

- ***"Consequence"*** or impact on the public or workers if exposed to radiation or other hazards; and
- The ***"likelihood"*** and ***"timing"*** when such an event might occur.

Drawing on a combination of the extensive published literature on the subject and the study team's own experience, criteria and parameters for enhanced risk mitigation of public/worker health and safety were established and assessed. The study team examined the specific measures of the Joint Waste Owners' concept designs and operations in relation to these criteria in an effort to establish a better understanding of the relative benefit, risk, and/or cost of each approach.

A similar method was used for the assessment of security, given that it is closely tied to the foregoing analysis of public and worker health and safety. Of particular focus in this section were the events that might provide a threat to people and the environment through unplanned intrusions and the possible unwanted uses of the used nuclear fuel. The assessment of security

[8] The Joint Waste Owners are the owners of existing nuclear facilities in Canada. They include: New Brunswick Power, Ontario Power Generation, and Hydro-Quebec.

[9] Refer to Table 2.1-1 (Appendix A).

was based on the study team's experience with security design features in other nuclear facilities around the world, including used nuclear fuel transportation. In essence, a "model" of an "ideal" facility was developed, including consideration of physical and geological security barriers, and the three management approaches were benchmarked against this standard.

The environmental integrity of each of the approaches was assessed within a standard environmental risk framework following a source-pathway-receptor model. In assessing effects, consideration was given to the following:

- The ***"likelihood"*** of an effect occurring;
- The ***"ability to monitor and detect"*** impacts early, before irreversible effects can occur;
- The ***"severity"*** of the effect, including its magnitude and extent; and
- The ***"permanence"*** of the effect should it occur.

The potential sources of environmental effects were developed from the study team's own experience, supported by similar assessment of other used nuclear fuel management facilities. Pathways by which the various ecological receptors in the physical and biophysical environment might be impacted were identified and specific ecological receptors at risk were also identified. This ensured that the assessment was conducted with the specific ecological conditions present in the eleven illustrative economic regions. The result of this analysis was the identification of environmental factors at risk.

A detailed financial model of each management approach was developed for the purpose of assessing their economic viability. These financial models describe the management phases and apply specific costs for labour and materials over a 10,000 year time-frame. Each spreadsheet-based financial model enabled the study team to test alternative costing assumptions. The costing data was compiled from the Joint Waste Owners' concept design documents over a three week period. Output from each financial model provided input to the assessment of impact on community well-being in Section 8.

The assessment of community well-being was divided into two parts. The first involved detailed modelling of economic relationships within each of the eleven illustrative economic regions. Specifically, a unique Input/Output model was developed for each economic region, which enabled the study team to accurately quantify the impact on employment, income and taxes from the possible introduction of any of the management approaches. In addition to this, a qualitative assessment of other community values was conducted based on a combination of published literature and the study team's own extensive experience with nuclear and mining industry developments in both urban and rural regions of Canada.

The second part of the community well-being assessment involved application of a "Sustainable Livelihoods Framework" to each of the eleven illustrative economic regions. This framework allows an objective assessment of specific "capitals" (including social, human, physical, financial, and natural) that most influence community social well-being. The intent of this quantitative analysis was to provide an indication of how each economic region ranks in its ability to adapt to the opportunities and challenges posed by the possible introduction of any of the management approaches.

Both components of the community well-being assessment required extensive research and data synthesis from multiple sources, but primarily from Statistics Canada.

In summary, the methodology and analytical tools employed in assessing the benefits, risks and costs of the three approaches across the illustrative economic regions were selected and used to ensure that the comparative assessment was carried out in a transparent and reproducible manner. Specifically, the methodology and analytical tools used ensured that:

- The assessment built on and expanded the preliminary comparative assessment conducted by the NWMO Assessment Team;
- The assessment considered commonly used and appropriate measures and indicators of the eight objectives outlined in the Preliminary Comparative Assessment;
- The analysis developed and applied appropriate and proven models capable of predicting effects within the social and environmental framework of the assessment;
- While acknowledging that not all measures can be quantified, the assessment incorporated measures for each of the eight objectives that are capable of being quantified for each approach; and
- While recognizing that there are many similarities in the benefits, risks and costs of all three approaches, the assessment incorporated measures that would highlight possible differences between approaches, including those that may occur across illustrative economic regions.

1.5 Organization of This Report

This report documents the comparative analysis of the benefits, risks and costs of the three approaches for the long-term management of used nuclear fuel currently being considered by the NWMO. The report is structured to correspond to each of the eight objectives outlined in the Preliminary Comparative Assessment across the eleven illustrative economic regions.

Section 1 of this report outlines the goals and objectives of this assessment; how they compare to the Preliminary Comparative Assessment; and the structure of this report. Section 2 provides an overview of the three approaches assessed, based on information provided by the Joint Waste Owners. The methodology for selecting the illustrative economic regions, and a description of the eleven illustrative economic regions used in the comparative assessment, can be found in Section 3.

The analysis of the three approaches with respect to each of the eight objectives is found in Sections 4 through 11, in the following order:

- Public Health and Safety (Section 4);
- Worker Health and Safety (Section 5);
- Security (Section 6);
- Economic Viability (Section 7);
- Community Well-Being (Section 8);
- Environmental Integrity (Section 9);
- Adaptability (Section 10); and
- Fairness (Section 11).

Ethical issues and considerations are explicitly considered in all eight objectives, particularly as part of community well-being, adaptability, and fairness.

All sections describe the context and methodology for the analysis of each objective, along with detailed results of the analysis and a comparison of management approaches. The assessment includes consideration of implementing the approaches in the illustrative economic regions.

Finally, Section 12 provides a summary overview and conclusion with respect to the assessment. A comparison of the benefits, risks and costs of the three approaches across the eight objectives is provided to assess the strengths and limitations of each approach. The study team's conclusion provides an enhanced management approach, which draws on the strengths of the three approaches.

2.0 USED NUCLEAR FUEL MANAGEMENT APPROACHES

2.1 Used Nuclear Fuel Management Approaches Assessed

Conceptual designs and costs for used nuclear fuel management facilities, transportation, interim storage and retrieval have been previously developed by CTECH Radioactive Materials Management (CTECH), COGEMA LOGISTICS, and the Joint Waste Owners Group. A comprehensive list of reports consulted during the current study, to identify the range of conceptual designs being considered to date by NWMO for the management of used nuclear fuel, is shown in Table 2.1-1 (see Appendix A).

As indicated in Section 1.0, three different approaches for the long-term management of used nuclear fuel have been proposed:

1. Deep Geological Disposal in the Canadian Shield (previously referred to as Deep Geologic Repository – DGR);
2. Storage at Nuclear Reactor Sites (previously referred to as Reactor-site Extended Storage – RES); and
3. Extended Storage at a Centralized Site (Centralized Storage), either above or below ground (previously referred to as Centralized Extended Storage – CES).

A number of technologies for implementing long-term storage at either the existing nuclear reactor sites or at a centralized facility have been considered. These are:

Storage at Nuclear Reactor Sites – Existing Technologies

- Casks in Storage Buildings (CSB)
- Silos
- Vaults

Storage at Nuclear Reactor Sites – (New, Above-Ground Technologies)

- Surface Modular Vaults (SMV)
- Silos in Storage Buildings (SSB)

Storage at Nuclear Reactor Sites – (New, Below-Ground Technologies)

- Casks in Shallow Trenches (CST)
- Vaults in Shallow Trenches (VST)
- Silos in Shallow Trenches (SST)

Centralized Storage – Above-Ground Technologies

- Casks and Vaults in Storage Buildings (CVSB)
- Surface Modular Vaults (SMV)

Centralized Storage – Below-Ground Technologies

- Casks and Vaults in Shallow Trenches (CVST)
- Casks in Rock Caverns (CRC)

Figure 2.1-1 shows the combinations of approaches, technologies and sites that were considered in the previous studies, resulting in a total of 26 alternative methods for the long-term management of used nuclear fuel. For the purposes of the present comparative assessment of approaches, this long list of methods was reduced to a short-list of illustrative methods which are compatible with the requirements of the NFWA.

Figure 2.1-1: Long-Term used Fuel Management Conceptual Designs

Location	**Conceptual Designs**												
	Deep Geological Disposal in the Canadian Shield	**Extended Storage**											
		Centralized Storage				**Storage at Nuclear Reactor Sites**							
						Continue Existing Technology			New Above-Ground Technology		New Below-Ground Technology		
	DGR	CVSB	SMV	CVST	CRC	CSB	Silo	Vault	SMV	SSB	CST	VST	SST
New Site	●	○	●	○	●								
Nuclear Reactor Site:													
Pickering						○			●		○		
Bruce						○			●		○		
Darlington						○			●		○		
Gentilly								○	●			○	
Point Lepreau							○		●			○	
Chalk River							○			●			○
Whiteshell							○			●			○

Notes:
- ○ Conceptual design prepared by CTECH
- ● Conceptual design prepared by CTECH, advanced for further evaluation in the current study

Acronyms and Abbreviations:

CRC	Casks in Rock Caverns
CSB	Casks in Storage Buildings
CST	Casks in Shallow Trenches
CVSB	Casks and Vaults in Storage Buildings
CVST	Casks and Vaults in Shallow Trenches
DGR	Deep Geological Repository
Silo	Silos
SMV	Surface Modular Vaults
SSB	Silos in Storage Buildings
SST	Silos in Shallow Trenches
Vault	Vaults
VST	Vaults in Shallow Trenches

Conceptual designs for used nuclear fuel management identified for further evaluation are:

1. **Disposal in a Deep Geologic Repository (DGR), hereinafter referred to as "Deep Geological Disposal in the Canadian Shield".**

   To date, a number of technologies for implementing Deep Geological Disposal in the Canadian Shield have been considered. However, these technologies are minor variations of the Canadian disposal concept developed for the Joint Waste Owners and referred to as the Deep Geologic Repository (DGR). This concept is discussed in CTECH's report entitled "Conceptual Design for a Deep Geologic Repository for Used Nuclear Fuel" (Table 2.1-1, Appendix A).

2. **Storage at Nuclear Reactor Sites in Surface Modular Vaults (SMV) or Silos in Storage Buildings (SSB), depending on current site management practices at existing nuclear reactor sites.**

   Existing Surface Modular Vaults (SMV) at Pickering, Bruce, Darlington, Gentilly and Point Lepreau, and Silos in Storage Buildings (SSB) at Chalk River and Whiteshell combine new above-ground technologies proposed by the Joint Waste Owners. These represent potentially improved above-ground concepts for storage at the existing nuclear reactor sites. New technologies offer few compelling advantages over existing practices and new below-ground technologies are vulnerable to unexpected subsurface conditions, and were not included in the current study.

3. **Above-ground Storage in Surface Modular Vaults (SMV) and Below-ground Storage in Casks in Rock Caverns (CRC) at a Centralized Storage Facility. These are new technical solutions which are considered to be compatible with the requirements of the NFWA.**

   Surface Modular Vaults are a new above-ground technology that is based on existing experience with current dry storage vaults, e.g., Atomic Energy of Canada Limited's (AECL's) CANSTOR ™ system. Casks in Rock Caverns are a new below-ground technology that is based on existing experience with dry storage casks, e.g., OPG's Dry Storage Container (DSC) system. As both Surface Modular Vaults and Casks in Rock Caverns are based on proven, existing practices, they are anticipated to represent improvements from the already excellent service record of Canadian used nuclear fuel storage.

Consideration of Deep Geological Disposal in the Canadian Shield and Centralized Storage in Casks in Rock Caverns will identify the general advantages and disadvantages of a permanent repository relative to periodically renewed storage in an underground facility. Consideration of Centralized Storage in Surface Modular Vaults versus Storage at Nuclear Reactor Sites in Surface Modular Vaults will allow the identification of the advantages/disadvantages of long-term storage at a new Centralized Storage facility relative to long-term storage at individual reactor sites.

In considering the foregoing management approaches, it is important to note that Deep Geological Disposal in the Canadian Shield relies almost totally on engineered and natural geological barriers to isolate radionuclides in the fuel from the biosphere for as long as they remain a threat to the environment (including humans)[10]. There is no intention for long-term, anthropogenic intervention to maintain containment or for retrieval of the used nuclear fuel. The long-term storage approaches, on the other hand, rely almost totally on anthropogenic intervention in the form of on-going monitoring, maintenance and periodic replacement of engineered barriers to isolate radionuclides in the fuel from the biosphere for as long as they remain a threat. This difference in long-term management philosophy is reflected in the conceptual designs of the management approaches and their associated costs and benefits.

2.2 Description of Used Nuclear Fuel Management Approaches

2.2.1 Deep Geological Disposal in the Canadian Shield

Deep Geological Disposal in the Canadian Shield would involve construction of an engineered repository within the Precambrian bedrock of the Canadian Shield. The design concept used in the assessment has been developed over more than twenty-five years. During the period 1978-1996, Atomic Energy of Canada Limited (AECL) developed a deep geologic repository for used CANDU fuel under the Canadian Nuclear Fuel Waste Management Program. Subsequently, the Seaborn Panel reviewed that concept under the Federal Environmental Assessment and Review Process. The Panel listened to a broad range of stakeholders, including the public. Its final report (1998) recommended changes to address stakeholder comments. Since then, the Joint Waste Owners have continued the development of the original AECL repository concept. The conceptual design prepared on behalf of the Joint Waste Owners and used in this assessment (i.e., the Deep Geologic Repository) was synthesized from all of this work (www.nwmo.ca/geologicaldisposal)[11].

A Deep Geologic Repository would be located in the Canadian Shield at a nominal design depth of 1,000 metres. The facility design is based on the receipt, packaging and placement of CANDU used-fuel bundles at a rate of 120,000 per year. The design assumes that these bundles have been discharged from reactors and stored for at least 30 years prior to receipt at the repository. Until the repository is operational, interim measures would be needed to manage the used nuclear fuel effectively and to ensure safety and security.

[10] The radiotoxicity of used nuclear fuel suggests that the material will remain hazardous to humans and the natural environment for time periods that exceed 100,000 years (OECD/NEA Report No. 4435, "The Handling of Timescales in Assessing Post-Closure Safety". OECD 2004.)

[11] Nuclear Waste Management Organization, *Understanding the Choices – The Future Management of Canada's Used Nuclear Fuel*, September 2004, page 49.

As illustrated on Figure 2.2-1 (see Appendix A), the Deep Geological Disposal in the Canadian Shield facility involves a series of interconnected "emplacement rooms" which are excavated on a single level at a depth of 500 m to 1,000 m below ground surface. The repository is connected to ground surface by a series of shafts for mining (excavation), waste transfer and ventilation purposes.

As previously noted (Section 2.1), Deep Geological Disposal in the Canadian Shield relies on engineered barriers as well as the natural containment of the host rock to isolate the used nuclear fuel from the biosphere. To this end, used nuclear fuel bundles, placed in unsealed baskets, are sealed inside specially designed "Used Fuel Containers" (UFC) as illustrated on Figure 2.2-1 (see Appendix A). Each UFC is jacketed with bentonite, a naturally occurring, clay-based sealing material with good buffer characteristics and low water permeability. Bentonite-jacketed UFCs are placed in the emplacement rooms as illustrated on Figure 2.2-1.

Thick blocks of pre-compacted buffer and dense backfill are placed between individual UFCs and between UFCs and the rock walls and floors of the emplacement room. Gaps are filled with pneumatically placed light backfill. After the rooms are filled, the room bulkhead is sealed and monitoring begun to verify the performance of engineered barriers. Only after extended monitoring to verify the performance of barriers is completed are the tunnels and shafts backfilled and sealed with a series of bulkheads. At the end of this process, the facility is closed.

Deep Geological Disposal in the Canadian Shield does not require rebuilding of the containment facility (i.e., the repository) or repackaging of the used nuclear fuel. Siting, design and construction are followed by a 30 year period of fuel emplacement (referred to as “initial operations”). Once fuel is emplaced, the facility enters a monitoring period of approximately 70 years (referred to as “operations”), during which fuel retrieval is reasonably straightforward. After monitoring data warrants, the facility would be decommissioned and closed over a period of approximately 25 years. Once tunnels and underground structures have been filled and sealed, fuel retrieval becomes significantly more difficult, but is still possible.

2.2.2 Storage at Nuclear Reactor Sites

Extended storage at existing nuclear reactor sites involves permanent or indefinite storage with necessary maintenance and facility refurbishment conducted on an ongoing basis (www.nwmo.ca/reactorstorage). Long-term storage at existing nuclear reactor sites involves the expansion of existing dry storage facilities or the establishment of new, long-term dry storage facilities at each of the seven existing reactor sites in Canada. In the latter case, used nuclear fuel would be transferred from the existing interim storage facilities to newly designed storage containers and storage facilities that are designed to last between 100 and 300 years. Additional replacement capacity would be provided by the construction of storage facilities on a rolling (cyclical) program.[12]

As discussed in Section 2.1, for the purposes of this comparative assessment of management approaches, the CTECH conceptual designs for Surface Modular Vaults (SMV) were selected as the representative management approach at the Pickering, Darlington, Bruce, Gentilly and Point Lepreau reactor sites. Silos in Storage Buildings (SSB) were selected as the representative management approach at Chalk River and Whiteshell. With both approaches, used nuclear fuel bundles are sealed into steel containers (module canisters or baskets, depending on the site) which are, in turn, sealed into vertical "tubes". In the case of Surface Modular Vaults, the tubes are enclosed in reinforced concrete vaults (see Figure 2.2-2 in Appendix A), which would be housed in storage buildings (i.e., after fuel receipt, all fuel movement is under cover). In the case of Silos in Storage Buildings, the tubes would be enclosed in reinforced concrete silos within a warehouse-type structure. In both cases, passive circulation would be used to cool and regulate the used nuclear fuel temperature.

Both the vaults and the Silos would have a finite lifespan and must be periodically renewed through the long-term management period. The design life of a concrete vault would be finalized during detailed design, but has been assessed to be in the order of 100 years. Sealed containers would be moved from the old vault to a new vault in a process very similar to modular facility expansion. The old vault would then be decontaminated and demolished/recycled.

After a significantly longer period, the fuel containers would themselves reach the end of their design life. This has been estimated to be in the order of 300 years. The end of container service life would require full fuel repackaging. A special repackaging facility would need to be constructed. Fuel containers would be removed from aging vaults and transported to the repackaging facility where individual fuel bundles would be placed into new containers. These, in turn, would be placed into new vaults.

Thus, each long-term storage facility would be renewed in a cyclical fashion as long as it was required. Major structures would be replaced approximately at 100 year intervals. Every 300 years, these facility replacements would be concurrent with major repackaging events. At the end of each 300 year cycle, the facility would be in the same condition as at its initial commissioning.

While the Storage at Nuclear Reactor Sites approach requires constant maintenance and periodic major overhauls, it also provides opportunity for monitoring, fuel recovery and future

[12] Nuclear Waste Management Organization, *Understanding the Choices – The Future Management of Canada's Used Nuclear Fuel*, September 2004, page 42.

incorporation of new technology. The costs to perform these latter functions are at this time not developed, and could be significant.

2.2.3 Centralized Extended Storage (Above or Below Ground)

Twelve countries currently operate centralized used nuclear fuel storage systems. These systems range from common temporary storage for used nuclear fuel from a few reactors, to fully centralized national management systems. Although some use centralized water pools, dry storage is generally the preferred option[13].

Current technologies for centralized dry storage of used nuclear fuel include metal storage casks, concrete storage casks, silos and vaults. As previously noted (Section 2.1), the Joint Waste Owners selected four alternatives as representative of a range of possible conceptual designs for the Centralized Storage facility (www.nwmo.ca/centralstorage). These alternatives are:

- Casks and Vaults in Storage Buildings;
- Surface Modular Vaults;
- Casks and Vaults in Shallow Trenches; and
- Casks in Rock Caverns.

Except for Surface Modular Vaults, these alternatives would minimize repackaging of fuel upon receipt at the Centralized Storage facility, which allows for higher fuel throughput and minimizes costs. Although Centralized Storage could be implemented at a nuclear plant site or at a fully independent site, for the purpose of this assessment it is assumed that the Centralized Storage facility would be located on an undeveloped site and would be considered as a stand-alone facility. For all of the alternatives, additional capacity would be provided by the construction of storage facilities on a rolling or cyclical program.

As discussed in Section 2.1, for the purposes of this comparative assessment of management approaches, two Centralized Storage methods were selected: Surface Modular Vaults, an above-ground storage method; and Casks in Rock Caverns, a below-ground storage method.

Above-ground Centralized Storage is conceptually similar to Storage at Nuclear Reactor Sites (see Section 2.2.2). Used fuel bundles are initially placed into steel containers (module canisters or baskets, depending on the origin of the fuel) which are, in turn, sealed into vertical "tubes" installed in reinforced concrete vaults. The vaults are enclosed in a warehouse-type structure,

[13] Nuclear Waste Management Organization, *Understanding the Choices – The Future Management of Canada's Used Nuclear Fuel*, September 2004, page 46.

which also houses the equipment for handling the containers of used fuel bundles (see Figure 2.2-3 in Appendix A). Service life and replacement frequency for Centralized Storage (above ground) is similar to that for the Storage at Nuclear Reactor Sites, discussed in Section 2.2.2.

Below-ground Centralized Storage differs from above-ground Centralized Storage in that steel containers of used fuel bundles are stored underground in self-shielded storage "casks". These storage casks are stacked in a series of storage caverns constructed by underground mining methods in competent bedrock at a nominal depth of 50 m. Storage casks are moved on a series of ramps and roads by purpose-built cask transporters, and arranged in individual caverns by overhead gantry cranes (see Figure 2.2-4 in Appendix A).

Used fuel is isolated by up to two containment barriers: the sealed basket, (where applicable) and the sealed storage cask within which fuel containers (modules or baskets) are contained. The casks are double-steel shell containers (Figure 2.2-4 in Appendix A) with the space between the inner and outer shell filled with approximately 60 cm of reinforced high-density concrete. The essential principals of cask design have been validated by OPG's safety record using similar storage casks (called DSCs). Although nominally directly connected with the biosphere through a ventilation system, the use of underground caverns creates some degree of additional buffer if contamination were ever discovered outside the storage casks.

As with Centralized Storage (above ground), the Centralized Storage (below ground) facility has a finite design lifespan. Facility repeats include the refurbishment of caverns. Old caverns, however, would not necessarily be abandoned and backfilled; they would more likely be refurbished and returned to service. Storage casks are replaced in 100 year cycles. Replacement of storage casks requires repackaging, as does the less frequent replacement (once every 300 years) of individual steel containers within the storage casks. The operating cycle, similar to Centralized Storage (above ground) is assumed to be a series of 100-year interval refurbishment and repackaging efforts, culminating in a major 300 year full repackaging event, after which the facility is essentially as it was when new.

While the Centralized Storage approach (either above or below ground) requires constant maintenance and periodic major overhauls, it also provides opportunity for monitoring, fuel recovery and future incorporation of new technology. The costs to perform these latter functions are, at this time, not developed and could be significant.

2.3 Common Features

All used nuclear fuel management approaches share certain aspects, such as interim storage, and transportation. These have been factored into the current study.

2.3.1 Interim Storage and Retrieval

Interim storage is the on-going storage of used nuclear fuel in irradiated fuel bays and/or existing dry storage facilities until such time as it is transferred to a new long-term storage/disposal facility. This activity and the related costs will remain the responsibility of the individual members of the Joint Waste Owners group and constitute the continuation of current fuel management practices until Canada's long-term used nuclear fuel management approach is in place. Retrieval refers to the removal of the used nuclear fuel from the interim storage facilities and the transfer of the fuel to transportation containers (in the case of Centralized Storage and Deep Geological Disposal in the Canadian Shield), or directly into long-term storage containers (in the case of Storage at Nuclear Reactor Sites).

The Joint Waste Owners group has estimated costs for interim storage and retrieval for the approaches under consideration and has presented these figures, in lump-sum form, to NWMO. For each long-term management approach, conceptual annual interim storage and retrieval costs were developed for the current study by dividing the Joint Waste Owners' lump-sum estimates by the estimated duration of the activity (fuel storage before facility in-service date plus the duration of transportation activities) in years (see also Section 7, Analysis of Economic Viability).

2.3.2 Transportation

Storage at Nuclear Reactor Sites does not require off-site transportation of used nuclear fuel. Transportation options for Centralized Storage and for Deep Geological Disposal in the Canadian Shield have been analysed by COGEMA (see Table 2.1-1). COGEMA considered three modes of shipment to a hypothetical facility: entirely by truck; mostly by rail; and mostly by water (ship). It was noted that reactor locations required some truck transport, even when the emphasis was on shipment by rail or water. International experience and standards for the shipment of used nuclear fuel were applied and costed (see also Section 7). Fuel will be moved in transportation packages which meet international standards and Canadian regulations.

2.4 Geo-Environmental Conditions Conducive to Constructability and Predictability

Different long-term management approaches have different geo-environmental requirements with regard to constructability and predictability of performance. However, the present study is only concerned with the general likelihood of being able to find suitable conditions within broad economic regions of Canada. At the scale of the illustrative economic regions (see Section 3), such requirements are very general.

The Centralized Storage (above or below ground) and Deep Geological Disposal in the Canadian Shield approaches have generally similar requirements and are discussed together below (Section 2.4.1). Storage at Nuclear Reactor Sites is discussed separately (see Section 2.4.2).

2.4.1 Deep Geological Disposal in the Canadian Shield and Centralized Storage

Regions likely to contain suitable geo-environmental conditions for Deep Geological Disposal in the Canadian Shield and Centralized Storage (above or below ground) may be characterized by:

- Stable soils/stable geology;
- Seismic stability;
- Relative freedom from permafrost; and
- In the specific case of Deep Geological Disposal, location in the Canadian Shield to meet the requirements of the disposal method specified in the NFWA. However, other potentially suitable geomedia exist in Canada.

Many other factors must be considered during the Environmental Assessment and detailed design, such as watershed boundaries, topography, existing land use, and avoidance of natural resources (e.g., minerals or fossil fuels). These are largely local phenomena, however, and do not characterize general regions of Canada. Moreover, many of these factors are not clear-cut advantages or disadvantages. For example, mountainous terrain places constraints on constructability and transportation, though mountain-based repositories have been considered in other countries due to off-setting advantages.

As indicated by Figures 2.4-1 though Figure 2.4-4, inclusive, extensive areas of Canada have the potential to meet these general geo-environmental requirements.

Figure 2.4-1 (see Appendix A) shows the extent of thick and continuous till as denoted in Geological Survey of Canada maps of Canadian surficial geology. Although areas of stable soil may be found in other areas, thick and continuous till generally constitutes a geomedia conducive to facility development. Glacial till, the mass of rocks and finely ground material deposited by glaciers, is an unsorted, relatively impermeable material. Construction in tills is routine in Canada. Tills are generally fairly stable, and the movement of groundwater through tills is typically very slow, potentially an advantage for a waste management facility. Construction is potentially easier, and performance more predictable in regions with widespread till deposits.

Figure 2.4-2 (see Appendix A) illustrates potentially active seismic zones of Canada (Zones 2 and greater), as presented in the National Building Code. Although it is possible to safely construct and operate facilities in more seismically active areas, the related seismic requirements increase cost and complexity.

Figure 2.4-3 (see Appendix A) shows areas of continuous and widespread discontinuous permafrost. Again, it is generally possible to safely construct and operate facilities in permafrost; however, cost and complexity increase. Also, the used nuclear fuel constitutes a potentially significant source of heat, which could affect the long-term performance of a facility.

Figure 2.4-4 (see Appendix A) shows the extent of the Canadian Shield as represented by granitic bedrock on Geological Survey of Canada maps of Canadian bedrock geology. The rock of the Canadian Shield was formed by the cooling of the earth's crust some three billion years ago and is among the oldest and most stable rock in the world. While geomechanical, hydrogeological and geochemical conditions within the rocks of the Canadian Shield are highly variable, previous studies have concluded that massive granite plutons, which are known to occur within the Shield, are technically suitable for the construction of a deep repository.

In conclusion, there is a high likelihood of finding suitable geo-environmental conditions for a centralized facility, i.e., Deep Geological Disposal in the Canadian Shield or Centralized Storage (both above and below ground), in many regions of Canada.

2.4.2 Storage at Nuclear Reactor Sites

Storage at Nuclear Reactor Sites, by definition, would be constructed at existing reactor locations. With the possible exception of Whiteshell, none of the existing nuclear reactor sites were initially chosen because of their inherent suitability for long-term storage of used nuclear fuel. Rather, these sites were chosen for power generation facilities based on assumed relatively short-term occupancy (50 years ±), proximity to load centres, and proximity to large surface water bodies. In the case of Lepreau, Gentilly and Chalk River, the sites are in seismically active zones.

It is noted that each site has existing used nuclear fuel storage facilities and that extensive studies in support of this existing fuel storage have established that it is safe and practical. However, Storage at Nuclear Reactor Sites contemplates used nuclear fuel storage for periods far exceeding the design life of any facility currently on a power reactor site.

2.5 Facility Stages

For the current study, common groupings of siting, design, construction and operating stages for each of the long-term management approaches were developed to facilitate the comparison of approaches. Stage dates were developed by reference to the narratives included in CTECH reports and by reference to cost data presented in CTECH summary spreadsheets. Professional judgement was applied to re-categorize CTECH phases into a common set of stages for all approaches. These stages are discussed in more detail below.

2.5.1 Timeframes Considered in the Assessment

As previously noted, the radiotoxicity of used nuclear fuel suggests that the material will remain hazardous to humans and the natural environment for time periods that exceed 100,000 years[14]. Thus, the used nuclear fuel must be safely isolated from the environment essentially in perpetuity.

The above not withstanding, for the purpose of the present comparative assessment of the benefits, risks and costs of the long-term management approaches for used nuclear fuel, two basic timeframes have been assumed:

- Near-term - extending from project initiation for a period of 175 years ("seven generations of knowledge"), including the initial construction, operation (i.e., used nuclear fuel emplacement) and monitoring/ maintenance of the facility; and
- Long-term – Extending for a period of approximately 10,000 years from project initiation, which is considered sufficient to allow a rational comparison of the "long-term" benefits, risks and costs of the approaches.

2.5.2 Deep Geological Disposal in the Canadian Shield

Stages for Deep Geological Disposal in the Canadian Shield as defined for this study are shown in Table 2.5-1.

Table 2.5-1: Project Stages for Deep Geological Disposal in the Canadian Shield

Stage	Duration (Years)
Siting/Approval	Y1-Y18
Design and Construct	Y19-Y29
Operations/Extended Monitoring	Y30-Y129
Decommission and Closure	Y130-Y154

The broad characteristics of these stages are as follows:

14 OECD, *The Handling of Timescales in Assessing Post-Closure Safety*, OECD/NEA Report No. 4435, 2004.

- Siting/Approval - A formal decision is made to start the process of finding a suitable site; a site is found; and regulatory approval is received to construct the facility at the preferred site. This work involves developing a siting process and site screening criteria, site screening and site evaluations, site investigations, preparation of safety assessment and environmental impact documents, participation in public consultations and hearings, and the preparation of licence applications.
- Design and Construct – The underground characterisation facility, the functional surface and underground facilities and infrastructure are created for the purpose of used nuclear fuel emplacement.
- Operations/Extended Monitoring – Used nuclear fuel is placed in the facility in a 30 year period from Year 30 to 59. A period of extended monitoring (70 years) is also included. The operation phase ends when approval is given to start decommissioning the facility.
- Decommission and Closure – During the period between year 130 and year 141, surface facilities are decontaminated, dismantled and removed. The underground facilities are decontaminated (if necessary) and dismantled, with tunnels and shafts backfilled and sealed. At the end of the monitoring stage the site will be in a state suitable to allow public use of the surface. However, access will still be denied by maintenance of fencing securing ongoing monitoring activities.

  During the period from year 142 to year 154, instruments and boreholes that could compromise the integrity of the Deep Geological Disposal facility over the long term are removed. The remaining surface facilities serving these ongoing monitoring activities are removed together with all security measures. The objective is to return the site to greenfield conditions.

It should be noted that these stages/durations were developed primarily on the basis of available costing data, and differ from the stages/phases described in the relevant CTECH report and in NWMO's Discussion Document 2: "Understanding the Choices – The Future Management of Canada’s Used Nuclear Fuel". However, the stages/durations were used in the economic viability assessment, Section 7.

2.5.3 Storage at Nuclear Reactor Sites

Storage at Nuclear Reactor Sites for this study has been defined in Table 2.5-2 out to 10,000 years in the future to facilitate the current comparative assessment.

Table 2.5-2: Project Stages for Storage at Nuclear Reactor Sites

Stage	Duration (Years)		
	Pickering	Bruce	Darlington
Siting/Approval	Y1 to Y7	Y1 to Y9	Y1 to Y11
Design and Construct	Y8 to Y10	Y10 to Y12	Y12 to Y14
Initial Operations	Y11 to Y48	Y13 to Y54	Y15 to Y49
Operations Cycle 1	Y49 to Y319	Y55 to Y322	Y50 to Y323
Operations Cycles 2 to 33	Y320 to ~Y9803	Y323 to ~Y9969	Y324 to ~Y9877

Stage	Duration (Years)			
	Gentilly	Point Lepreau	Chalk River	Whiteshell
Siting/Approval	Y1 to Y11	Y1 to Y7	Y1 to Y9	Y1 to Y11
Design and Construct	Y12 to Y14	Y8 to Y10	Y10	Y12
Initial Operations	Y15 to Y26	Y11 to Y18	n/a	n/a
Operations Cycle 1	Y27 to Y294	Y19 to Y290	Y11 to Y283	Y13 to Y281
Operations Cycles 2 to 33	Y295 to ~Y9941	Y291 to ~Y9809	Y284 to ~Y9837	Y282 to ~Y9964

The broad characteristics of these stages are as follows:

- Siting/Approval - A formal decision is made to start the process of developing facilities, and suitable extended storage alternatives are reviewed. Plans are developed for each site, and regulatory approval is received to proceed.
- Design and Construct - Initial functional facilities and infrastructure are created for the purpose of used nuclear fuel storage. Note that construction, as an activity, will continue during the subsequent operations of each facility.
- Initial Operations - Fuel is received by the facility. Additional fuel storage capacity will be constructed, expanding the storage complex capacity in a staged manner.
- Operations Cycle 1 – Used nuclear fuel and storage structures are monitored on a regular basis. This period includes periodic overhauls, i.e., facility repeats and repackaging events. During facility repeats (once every hundred years) fuel is moved from ageing storage complexes to new facilities. Once the used nuclear fuel has been transferred and the storage unit has been emptied, the redundant structure will be demolished. Fuel modules/baskets may be repackaged during these facility repeats. A special repackaging event will occur every 300 years, in which the modules/baskets themselves will be replaced.
- Operations Cycles 2 through 33 – As discussed in Section 2.5.1, while management of the used nuclear fuel will be required essentially in perpetuity, an assessment period of approximately 10,000 years was defined for this study. Thus, Operations Cycle 1 is assumed to be repeated 32 times. This is compatible with the suggested procedure in the

CTECH Conceptual Cost Estimate Reports (see Table 2.1-1-see Appendix A), although the conceptual cost estimates were not carried beyond the first Operations Cycle in the CTECH documents.

It should be noted that these stages/durations were developed primarily on the basis of available costing data, and differ from the stages/phases described in the relevant CTECH report and in NWMO's Discussion Document 2: "Understanding the Choices – The Future of Canada's Used Nuclear Fuel". However, the stages / durations were used in the economic viability assessment, Section 7.

Minor stage date variations between individual reactor sites stem from the fact that each of the sites is currently at a different operational stage. Further, individual waste owners with multiple sites, such as OPG and AECL, are expected to construct facilities on a rolling basis, rather than attempt to develop facilities at various sites simultaneously.

2.5.4 Centralized Storage (Above or Below Ground)

Stages for Centralized Storage (above or below ground) as defined for this study are shown in Table 2.5-3.

Table 2.5-3: Project Stages for Centralized Storage (Above and Below Ground)

Stage	Duration (Years)
Siting/Approval	Y1-Y13
Design and Construct	Y14 -Y17
Initial Operations	Y18 - Y47
Operations Cycle 1	Y48 - Y347
Operations Cycles 2 through 33	Y348 - ~Y9947

The broad characteristics of these stages are the same as discussed previously for Storage at Nuclear Reactor Sites, with two key differences:

- The siting and approvals process necessarily includes development and execution of a site selection and characterization program; and
- During normal operations, fuel arrives from other sites, and is not merely transferred from existing storage at the same site.

It should be noted that these stages/durations were developed primarily on the basis of available costing data, and differ from the stages/phases described in the relevant CTECH report and in NWMO's Discussion Document 2: "Understanding the Choices – The Future of Canada's Used Nuclear Fuel". However, the stages/durations were used in the economic viability assessment, Section 7.

2.5.5 Summary of Project Stages

Figure 2.5-1 illustrates the stages of Deep Geological Disposal in the Canadian Shield, Storage at Nuclear Reactor Sites, and Centralized Storage (above or below ground) and allows a comparison of the approaches. The schedules for Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites are substantially similar, apart from the small differences introduced by slight differences in implementation at each of the seven existing nuclear reactor sites.

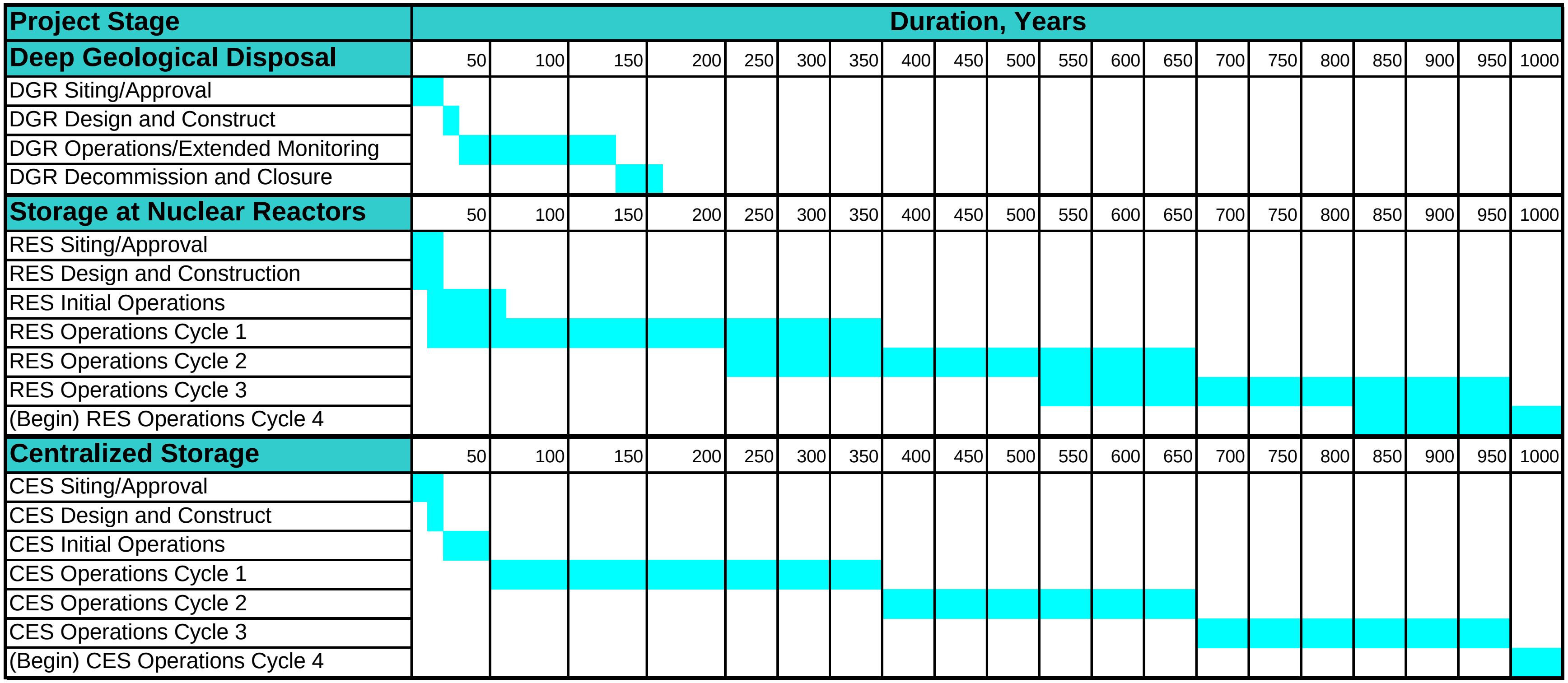

Figure 2.5-1: Summary of Project Stages – Deep Geological Disposal in the Canadian Shield (DGR), Storage at Nuclear Reactor Sites (RES) and Centralized Storage (Above or Below Ground - CES)

3.0 ILLUSTRATIVE ECONOMIC REGIONS

3.1 Methodology for Selecting Illustrative Economic Regions

The Nuclear Fuel Waste Act requires that three approaches be assessed, based on those presented in the Act, taking into account the economic regions in which they might be implemented. There are a total of 76 economic regions in Canada. As not all of the three approaches are feasible in each economic region, a methodology was developed and applied to select a subset of economic regions, which have diverse physical and socio-economic characteristics that are illustrative of many other economic regions across Canada. It is important to appreciate that the illustrative economic regions are examples, and they are not necessarily where a future management approach would be implemented. Also, it is important to note that assessing impacts at an economic region level fails to account for the diversity of population and environmental communities that make up each region. The analysis of impacts presented in this report is generalized for each economic region. A more thorough assessment within selected economic regions will be required at a latter date when specific candidate sites for the management of used nuclear fuel are more evident.

The methodology for selecting illustrative economic regions was as follows. The study team:

a) Identified those of Canada's 76 economic regions that could meet the fundamental requirements of the approaches:

- **Deep Geological Disposal in the Canadian Shield** – all economic regions within the Canadian Shield (22 economic regions);
- **Storage at Nuclear Reactor Sites** – all current nuclear reactor communities (6 economic regions); and
- **Centralized Storage**, above or below ground - all economic regions (76 economic regions).

b) Identified a small number of illustrative economic regions by considering the diverse range of physical and socio-economic characteristics across Canada.

Four characteristics of the economic regions were selected from a long list of information available from Statistics Canada and other federal agencies:

1. **Population** – This includes two measures: population density and aboriginal presence. There is a broad range of population density across Canada. Higher population densities represent urban centres and lower population densities are typical of rural areas. Aboriginal presence is an indication of the concentration of aboriginal people as a percentage of the total population, as well as consideration of potential land claims, traditional economic structures and cultural values.
2. **Environment** – This includes two measures: terrestrial ecozone and drainage region. The terrestrial ecozone represents the breadth of natural environments across the country. Some environments are more sensitive than others in relation to potential

adverse consequences. Identifying the drainage region (i.e., whether rivers drain into the Arctic Ocean, Great Lakes, Atlantic Ocean or Pacific Ocean) was deemed important so that illustrative economic regions would be selected that drain into diverse bodies of water to address the possible consequences of water movement.

3. **Transport Distance** – As the majority of used nuclear fuel is currently produced and stored in Ontario, consideration of this criterion represents a key concern for many Canadians regarding long-term management of used nuclear fuel: Canada is a large country and transportation distances from current locations to different economic regions vary dramatically.

4. **Economics** – This includes three measures. The first measure, economic base, is considered by identifying the top four economic activities in each of the illustrative economic regions. This provides an indication of the mix and range of activities across Canada. For example, in the economic region denoted "ER-1", manufacturing, retail, health care and construction are the top four economic activities. Forestry processing is classified as manufacturing; retail and construction activities serve the growing retirement and tourism industry in the Okanogan Valley area. The rapidly growing population base of seniors is one key driver for health care.

   The second economic measure is the percent of the total land base that is comprised of productive agricultural land. This measure provides an indication of the variability in agricultural production throughout the illustrative economic regions. It is important to note that in regions with a high percent of productive agricultural land, the processing of products (e.g., dairy) is classed under manufacturing.

   The third economic measure is average annual household income within each economic region. This divergent measure across regions is an indication of the level of education and workforce skill levels.

The above four characteristics were used to select illustrative economic regions because they provide reasonable indicators of differentiation between the regions for the purpose of this study. For example, population density and economic mix were used to help differentiate between urban and rural regions on the one hand, and between single versus multiple industry-based economies on the other hand. These two characteristics are important considerations for assessing the possible range of social and economic consequences of alternative management approaches. Likewise, transportation distance from the used nuclear fuel sources to a centralized facility is a major factor in the determination of security and other risks, hence it was important to select illustrative economic regions with varying lengths of transportation. It was also considered important to select illustrative economic regions that cover a range of natural environments (e.g., ecozones) so that an assessment of a wide range of environmental integrity risks could be completed.

A summary of these four selection criteria is shown in Table 3.1-1 along with their range in Canada and their range in the selected illustrative economic regions.

Table 3.1-1: Selection Criteria for Illustrative Economic Regions

Criterion	Measure	Canadian Range	Illustrative ER Range
Population	Density (Population / km^{2})	~ 0.01 – 713	0.05 – 713
	Aboriginal Presence (% of population)	~ 0 - 90	0.4 – 83.2
Environmental	Terrestrial Ecozone – (Physiographic Classification - e.g., Boreal Shield, Mixedwood Plains)	15 types (including 3 Arctic)	12 types (including 3 Arctic)
	Drainage Region	Five regions	Four regions
Transport Distance (for majority of used nuclear fuel)	Distance (km)	~ 0 – 6,000	~ 0 – 5,200
Economics	Economic Base/Major Industrial Groups (e.g., Manufacturing, Agriculture)	20	20
	% Agricultural Land	~ 0 – 48%	~ 0- 48%
	Average Household Income ($/year)	$31k - $65k	$31k - $60k

3.2 Identification of Illustrative Economic Regions

The criteria in Table 3.1-1 along with the need to meet the fundamental requirements for each approach were used to select a short list of illustrative economic regions from among all of Canada's 76 economic regions. For example, the Deep Geological Disposal in the Canadian Shield approach must have the repository located within the Canadian Shield.

The eleven identified illustrative economic regions are shown on Figure 3.2-1. Six economic regions were defined by the location of current nuclear reactor sites and the study team selected the remaining five regions. In total, the illustrative economic regions selected for Deep Geological Disposal and/or Centralized Storage are representative of the characteristics across Canada where these approaches could be implemented. The short list of illustrative economic regions and their selection criteria are shown in Table 3.2-1. This table provides the specific details of the diverse range of physical and socio-economic characteristics exhibited by each of the illustrative economic regions.

Table 3.2-1 Illustrative Economic Regions with Selection Criteria

Criteria and Measure	Economic Regions										
	British Columbia	**Saskatchewan**	**Manitoba**	**Ontario**					**Quebec**		**New Brunswick**
	ER-1	**ER-2**	**ER-3 Current Reactor Site**	**ER-4**	**ER-5 Current Reactor Site**	**ER-6 Current Reactor Site**	**ER-7**	**ER-8 Current Reactor Site**	**ER-9**	**ER-10 Current Reactor Site**	**ER-11 Current Reactor Site**
Population: Density (Persons/km^2)	4.9 Medium	0.1 Low	4.1 Medium	2 Low	20 Medium	713 High	20 Medium	20 Medium	0.05 Low	31.5 High	20 Medium
Population: Aboriginal Presence (% of Population)	5.2 Medium	83.4 High	8.6 Medium	7.7 Medium	1.2 Low	0.5 Low	1.9 Low	2.4 Low	54.9 High	0.4 Low	0.9 Low
Environmental: Terrestrial Ecozone	Montane Cordillera	• Boreal Plains • Boreal Shield • Taiga Shield	• Boreal Plains • Boreal Shield • Prairies	• Boreal Shield • Hudson Plains	Mixedwood Plains		• Mixedwood Plains • Boreal Shield		• Boreal Shield • Hudson Plains • Taiga Shield • Southern Arctic • Northern Arctic • Arctic Cordillera	• Mixedwood Plains • Atlantic Maritime	• Atlantic Maritime
Environmental: Drainage Region	Pacific Ocean	• Arctic Ocean • Hudson Bay	Hudson Bay	• Hudson Bay • Atlantic Ocean	Atlantic Ocean	Atlantic Ocean	Atlantic Ocean	Atlantic Ocean	Arctic Ocean	Atlantic Ocean	Atlantic Ocean
Transport distance (for majority of used nuclear fuel, where applicable)	~4,000 km Long	~3,500 km Long	Not applicable	~1,000 km Medium	Not applicable	~100 km Short	~200 km Short	Not applicable	~2,000 km Long	Not applicable	Not applicable
Aboriginal Presence (% of Population)	5.2 Medium	83.4 High	8.6 Medium	7.7 Medium	1.2 Low	0.5 Low	1.9 Low	2.4 Low	54.9 High	0.4 Low	0.9 Low
Economics: Top four Industries	• Manufacturing • Retail • Health Care • Construction	• Government • Educational Services • Health Care • Retail	• Manufacturing • Agriculture, Forestry & Fishing • Health Care • Construction	• Retail • Health Care • Manufacturing • Hospitality	• Manufacturing • Retail • Agriculture, Forestry & Fishing • Health Care	• Manufacturing • Retail • Professional services • Health Care	• Manufacturing • Retail • Health Care • Construction	• Retail • Manufacturing • Health Care • Government	• Health Care • Government • Educational Services • Manufacturing	• Manufacturing • Retail • Health Care • Agriculture, Forestry & Fishing	• Retail • Health Care • Manufacturing • Hospitality
Economics : % Agricultural Land	0.9	0.9	2.7	0.5	47.9	28.7	11	10.7	0	33.6	2.7
Economics: Household Income ($/yr.)	44,643	31,106	40,758	41,992	46,278	59,697	44,736	44,354	50,187	36,420	40,758

Range: Population Density (High - >20; Medium: 2 – 20; Low - <=2); Transport Distance (Long - >2000 km; Medium – 500-2,000 km; Short - <= 500 km); Aboriginal Presence (High - >20 %; Medium – 5-20 %; Low - <=5 %).

A brief description of the key features of each illustrative economic region (ER) and the key differences between regions is provided below. These illustrative economic regions cover the diverse range of economies, population dynamics and natural environments found across Canada. Most ERs are rural in nature with small population centers and some highly concentrated natural resource industries. One ER is predominantly urban with a diverse economic base.

3.2.1 Features and Differences of Illustrative Economic Regions

ER-1 (Thompson–Okanagan, 5930) was selected to be illustrative of an ER that is a long distance from the current location of the majority of the used nuclear fuel. This ER is used for the assessment of Centralized Storage (above or below ground). It has a medium population density and aboriginal presence. It is located in a sensitive pacific ecozone and does not meet the requirements for Deep Geological Disposal in the Canadian Shield. The four leading industrial activities are manufacturing, retail, health care, and construction. The first two activities are respectively consistent with a high forest product manufacturing presence and a growing retail sector to supply an increasing population and expanding tourism industry. The region is quickly becoming a preferred location for retirement communities, which helps explain the importance of health care and construction activities.

The region has a relatively low agricultural land base (about 1% of the total land area), but it is home to an important fruit and vegetable industry, including internationally recognized wine production.

As a British Columbia economic region, it is neither a reactor community nor in a province that generates electricity using nuclear power.

ER-2 (Northern, 4760) was selected to be illustrative of an ER located a long distance from the majority of the used nuclear fuel. This ER is being used for the assessment of Centralized Storage (above or below ground) and Deep Geological Disposal in the Canadian Shield. It has a relatively low population density overall, but it contains one of the highest concentrations of aboriginal people relative to the total population. It is located predominantly in the boreal plains and boreal shield ecozones and meets the requirements for Deep Geological Disposal in the Canadian Shield. The four leading industrial activities are government, educational services, health care, and retail.

There is virtually no agricultural presence in the region; however, this does not include the traditional harvesting of wild berry crops or the extensive hunting, trapping, and fishing activities that sustain both aboriginal communities and remote tourism. Given the relatively low population base in this region, it is not surprising that government, educational, and health care services are the dominant sectors as this region hosts many seasonal resource extraction activities. The middle portion of the region contains a significant presence of productive forest lands that feed lumber processing mills just to the south of the region, while the northern part of the region contains a major uranium mining industry.

As a region of Saskatchewan, it is neither a reactor community nor in a province that generates electricity using nuclear power. The region does however produce uranium.

ER-3 (Southeast, 4610) is a reactor community. This ER is being used for the assessment of Storage at Nuclear Reactor Sites. It has a medium population density (80% rural) and aboriginal presence. It is located in the boreal plains, boreal shield, and prairie ecozones. The four leading industrial activities are manufacturing, agriculture, forestry and fishing, health care and construction. This is consistent with the region's primary activities - agricultural production and food processing (manufacturing). The region also contains a significant amount of productive forest lands, which adds to the base of manufacturing and resource extraction activities.

ER-4 (Northeast, 3590) was selected to be illustrative of an economic region a medium distance from the current location of the majority of the used nuclear fuel. This region is being used for the assessment of Centralized Storage (above or below ground) and Deep Geological Disposal in the Canadian Shield. It has a low population density and medium aboriginal presence. It is located predominantly in the boreal plains ecozone and meets the requirements for Deep Geological Disposal in the Canadian Shield. The four leading industrial activities are: health care, retail, manufacturing and hospitality services. This region is home to a significant productive forest land base and associated forest product processing (manufacturing) activities. The region also hosts a wide range of tourism related activities (such as camping, cottages, resorts and the like) which drive numerous seasonal retail and hospitality service activities. The region contains more than one large urban centre which acts as service centres for the wider rural areas throughout northern Ontario, including health care and government services.

It is not a reactor community, although the province of Ontario generates electricity using nuclear power.

ER-5 (Stratford-Bruce Peninsula, 3580) is a reactor community located in the southwest portion of Ontario. This economic region is being used for the assessment of Storage at Nuclear Reactor Sites. It has a medium population density and low aboriginal presence. It is located in the mixedwood plains ecozone. The four leading industrial activities are manufacturing, retail, agriculture, forestry and fishing, and health care. The region is home to a significant productive agricultural land base (almost 48% of the total land area), with just over half the population classed as rural. The region hosts a significant seasonal cottage population and has more than one urban centre that provides regional health care. There is a very limited productive forest land base with no large-scale forest product industries.

ER-6 (Toronto, 3530) was selected to be illustrative of an economic region a short distance from the current location of the majority of the used nuclear fuel. This region is being used for the assessment of Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites. It has the highest population density in Canada with one of the lowest aboriginal presence levels. It is located in the mixedwood plains ecozone and does not meet the requirements for Deep Geological Disposal in the Canadian Shield as it is outside the shield area. The four leading industrial activities are manufacturing, retail, professional services, and health care. This region is expected to expand in population by some 4 million people over the next 25 years. The Greater Toronto Area (GTA) is considered to be the industrial and financial services capital of the country with the greatest concentration of professionals, universities and health service R&D. The region is over 90% urban but does include some concentrations of agricultural production and productive forest land outside the GTA core. In fact, this region's land base is considered to have almost 29% productive agricultural land.

It is also host to the two largest of the largest nuclear reactor facilities in Canada.

ER-7 (Muskoka-Kawarthas, 3520) was selected to be illustrative of an economic region a short distance from the current location of the majority of the used nuclear fuel. This region is being used for the assessment of Centralized Storage (above or below ground) and Deep Geological Disposal in the Canadian Shield. It has a medium population density (about 64% rural) and a low aboriginal presence. It is located in the mixedwood plains and boreal shield ecozones and meets the requirements for Deep Geological Disposal in the Canadian Shield. The four leading industrial activities are manufacturing, retail, health care, and construction. The region is home to some of the most valuable recreational lands (e.g., cottages and resorts) in Canada, as it hosts many picturesque lakes and rivers and is a short driving distance from the GTA. The region's land base contains about 11% productive agricultural land.

It is not a reactor community, although the province of Ontario generates electricity using nuclear power.

ER-8 (Kingston-Pembroke, 3515) is a small reactor community located in the southeast portion of Ontario. As a current reactor community, it is included in the assessment of Storage at Nuclear Reactor Sites. It has a medium population density (about 54% urban) with a low aboriginal presence. It is located in the mixedwood plains and boreal shield ecozones. The four leading industrial activities are retail, manufacturing, health care, and government. The region contains a relatively small portion of productive agricultural land (i.e., about 10% of land area) and low level productive forest land (i.e., 10-25% productive forest land).

ER-9 (Nord-du-Quebec, 2490) was selected to be illustrative of an economic region a long distance from the current location of the majority of the used nuclear fuel. This region is being used for the assessment of Centralized Storage (above or below ground) and Deep Geological

Disposal in the Canadian Shield. It has the lowest general population density of all the illustrative regions with the second highest aboriginal presence. It is located predominantly in the boreal shield ecozone and meets the requirements for Deep Geological Disposal in the Canadian Shield. The four leading industrial activities are health care, government, educational services, and manufacturing.

The region contains no productive agricultural land base, but like ER-2, there is traditional harvesting of wild berry crops, and extensive hunting, trapping, and fishing activities that provide an economic base for both aboriginal communities and remote tourism. The region is also rich in resource extraction activities including logging and mining operations. Given the sparseness of its population, it is not surprising that health care, government and educational services are dominant economic activities. Manufacturing is associated with the processing of both forest and mining products from the region. The southern portion of the region is home to productive forests while the northern portion, bordering James Bay, contains numerous sensitive ecological areas and hosts many remote tourism activities. The region is also home to a major hydro-electric power development.

It is not a reactor community, although the province of Quebec generates electricity using nuclear power.

ER-10 (Centre-du-Quebec, 2433) is a reactor community in the Eastern Townships of Quebec. As a reactor community, this economic region is being considered for the assessment of Storage at Nuclear Reactor Sites. It has a high population density and low aboriginal presence. It is located in the mixedwood plains and Atlantic maritime ecozones. The four leading industrial activities are manufacturing, retail, health care, and agriculture, forestry and fishing.

The region's land base contains nearly 34% productive agricultural land and is home to numerous recreational and tourism activities. This region has only limited areas of productive forest land.

ER-11 (Saint John-St. Stephen, 1330) is a reactor community located in the southwest portion of the Province of New Brunswick. This region is being used for the assessment of Storage at Nuclear Reactor Sites. It has a medium population density and low aboriginal presence. It is located in the Atlantic maritime ecozone. The four leading industrial activities are retail, health care, manufacturing, and hospitality. The region contains less than 5% productive agricultural land, but contains significant manufacturing for a highly productive forest industry. In fact, the Province of New Brunswick contains some of the most productive and intensively managed forests in Canada.

3.2.2 Illustrative Economic Regions Used in this Assessment

This assessment of the three management approaches is conducted within the context of the above eleven illustrative economic regions. Table 3.2-2 shows which of the management approaches is assessed in each of the economic regions. Not all approaches are considered in all eleven economic regions.

Table 3.2-2: Illustrative Economic Regions Used in This Assessment

Long-term Management Approach	Economic Regions Identification Code[15]										
	ER-1	ER-2	ER-3	ER-4	ER-5	ER-6	ER-7	ER-8	ER-9	ER-10	ER-11
Deep Geological Disposal in the Canadian Shield		•		•			•		•		
Storage at Nuclear Reactor Sites			•		•	•		•		•	•
Central Storage (above ground)	•	•		•		•	•		•		
Central Storage (below ground)	•	•		•		•	•		•		

These eleven economic regions can be classified into two groups (urban vs. rural/remote) with the following characteristics:

Urban (ER-6, ER-10)	Rural (ER-1, ER-3, ER-5, ER-7, ER-8, ER-11) / Remote (ER-2, ER-4, ER-9)
High population density	Low population density
Mixed economy – multiple industry and retail sectors	Resource-based economy (Agriculture, forestry, and/or mining)
Typically shorter distance from used nuclear fuel sources	Longer distance from used nuclear fuel sources

This generalization of the economic regions into Urban vs. Rural/Remote categories simplifies the discussion in the following sections relating to the benefit, risk and cost comparisons of the management approaches, taking into account the NWMO's eight objectives, time, and location factors.

[15] These identification codes – ER-1 through ER-11 – are used exclusively throughout the balance of this report.

3.2.3 Comparison of Effects Between Different Economic Regions

There are four illustrative economic regions for Deep Geological Disposal in the Canadian Shield including those:

- With long, medium, and short transportation distances;
- With medium and low population densities (i.e., rural and remote in nature) – there are no high population density economic regions within the Canadian Shield;
- With high, medium, and low aboriginal presence;
- With a range of leading industries - government, educational services, health care, retail, manufacturing, hospitality, and construction; and
- In three provinces, including those with and without nuclear power generation.

There are six illustrative economic regions for Centralized Storage (above or below ground), including those:

- With long, medium, and short transportation distance;
- With medium and low population density;
- With high, medium, and low aboriginal presence;
- With a range of industries, but primarily focused on resource extraction (i.e. forestry, mining, and/or agriculture) and some processing; and
- In four provinces, including those with and without nuclear power generation.

There are six illustrative economic regions for Storage at Nuclear Reactor Sites. These economic regions illustrate a range of conditions, including those:

- With high and medium population density (i.e., both urban and rural);
- With medium and low aboriginal presence;
- With a range of leading industries - manufacturing, agriculture, forestry & fishing, health care, construction, retail, professional services, government, hospitality; and
- In four provinces.

4.0 ANALYSIS OF PUBLIC HEALTH AND SAFETY

4.1 Context for the Analysis of Public Health and Safety

***Objective**: 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*[16].

This section provides an analysis of the risks to the public for each of the management approaches for both normal (i.e., routine) and off-normal (i.e., malfunction or accident) situations. The risks to public health and safety depend upon the source and probability of the potential hazards occurring, the pathways by which effects may reach members of the public, and the number of people who potentially may be affected. Accordingly, the risks to the public will depend upon the location where an approach is implemented, including the transportation route. It is assumed that transportation risks are a function of the total distance the used nuclear fuel will need to be transported.

The management approach, 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, the public will not be subject to risks or harmful exposures, chronic or accidental, greater than those acceptable to Canadian and international authorities. Security and terrorism as a threat to public health and safety is discussed in Section 6.0.

4.2 Influencing Factors and Measures Used in the Analysis of Public Health and Safety

Indicators and measures are required to allow a comparative assessment of the benefits, risks and costs of public health and safety of each approach. It is assumed that all approaches are capable of being implemented safely using current industrial best practices, although there may be differences between approaches. Further, an assessment based on indicators and measures developed using current public health and safety information is likely to exaggerate the actual risks of implementing an approach in the future, since the public health and safety in industrial countries, including Canada, has shown continuous improvement over the past decades as is evidenced by increasing life expectancy and lower highway accident rates.

The measures used in the assessment are provided in Table 4.2-1 and include:

[16] Nuclear Waste Management Organization, *Understanding the Choices – The Future Management of Canada's Used Nuclear Fuel*, September 2004, page 58.

- commonly used measures of public health and safety, such as maximum radiation doses and traffic casualty rates;
- consideration and development of the influencing factors used by the Assessment Team, including the size of the population at risk and the seriousness of potential health consequences;
- measures that are capable of being quantified for each approach, including size of potentially affected population, radiation exposures, and risk of transportation accidents;
- measures that include both probability and consequence, including the probability of a particular radiation exposure occurring; and
- measures that allow possible differences between approaches to be highlighted, including those that may occur across illustrative economic regions.

The measures are based on quantitative information available in the literature or capable of being estimated within the timeframe available for the assessment. Their selection and evaluation builds on the approach used by GAL/GLL in similar studies and includes six principal assumptions:

- The overall risk to members of the public is a function of the **size of the population** potentially involved in implementing the approach, including the population along the transportation route: the greater the number of people the greater the corresponding risk;
- The **population density** of an **economic region** and the number and size of population centres along the **transportation route** provide a useful and appropriate indication of the number of people potentially at risk, both now and in the future;
- Risks to members of the public result both from potential **radiation exposures** and conventional **safety**, including both normal and accidental exposures;
- The radiation dose to the **maximally exposed member of the public** (identified as the bounding case) and the **time of peak impact** provide an indication of the average radiation dose to members of the public as a whole: approaches where the maximum dose is lower will have lower typical or average doses;
- The current Canadian **public dose limit of 1 mSv/y** provides a benchmark for assessing the severity of the risk to members of the public; and

- **Current experience** with respect to radiation exposures and safety, including traffic safety, provides a useful and appropriate basis for predicting and comparing the benefits and risks of implementing each of the approaches.

Table 4.2-1: Influencing Factors Used in the Analysis of Public Health and Safety

Influencing Factors used in Preliminary Comparative Assessment	Influencing Factors used in this Analysis	Measures Used in this Analysis
Size of population potentially at risk	Size of public population at risk - Public adjacent to facility - Public adjacent to transportation route	- Number of public at risk
Seriousness of potential consequences to impacted individual - Normal operations (radiological, vehicle accident) - Off-normal scenarios (unintended intruder, facility accident, unanticipated vehicle accident, unanticipated deterioration of barriers) - Effectiveness of safety barriers and institutions	Seriousness of potential consequences to the public - Normal operations (radiological, transportation) - Off-normal conditions (human intrusion, climate change, facility failure, accident in transport) - Loss of institutional control	Radiological risks - Dose to the public Transportation Accidents (Conventional) - Fatalities - Injuries
Duration of potential health consequences (short, temporary or long-term)	• Duration of health impact	- Time of peak impact
Ability to respond to, correct, remove, mitigate		
Likelihood of impacted individuals experiencing consequences - Likelihood to typical, average individual - Likelihood of impact to most sensitive individual - Likelihood of impact to the individual at maximum risk	Likelihood of member of public experiencing consequences - Maximum exposure - Maximum impact	- Probability of maximum impact to receptor

4.3 Methods and Details of Public Health and Safety Analysis

The risks to the public associated with the management approaches are considered over the near term during which the facility is constructed and the used nuclear fuel emplaced (1 to 175 years) and during the long term, beyond 175 years until the time of maximum health impacts

(~10^6 years)[17] . Public health and safety was analyzed for normal conditions and off-normal (accident) scenarios.

The analysis of the effects of the management approaches on public health and safety was conducted using the following three measures:

- Number of public at risk;
- Risks due to exposure to radiation, which includes the radiological dose, probability of maximum impact and time of peak impact; and
- Risks during transportation.

This assessment of risks to public health and safety is based on a number of existing peer-reviewed studies available for dry used nuclear fuel storage (similar in concept to Storage at Nuclear Reactor Sites), and for deep geological repositories (Deep Geological Disposal in the Canadian Shield). There is limited data available for Centralized Storage (above or below ground); therefore, bounding scenarios have been applied to Centralized Storage where they are functionally similar to either Storage at Nuclear Reactor Sites or Deep Geological Disposal in the Canadian Shield.

4.3.1 Number of Public at Risk

The number people at risk was determined from the population density of each illustrative ER and is the main point of comparison between the ERs. To determine the magnitude of public at risk due to transportation activities, the average length of the transportation routes to ERs were compared and the number of people along the transportation route established.

4.3.2 Risks Due to Exposure to Radiation

The public may be exposed to radiation as a result of any of the management approaches. The analysis of radiation dose to the public identified the potential exposure pathways by which people could be affected by radiation. The pathways and resulting radiation exposures were determined from the study team's experience based on a review of available information from other studies. This included:

- For each management approach, work activities associated with potential radiological risks were categorized into different phases and major activities for each phase were summarized;

[17] Russell, S., Nuclear Waste Management Organization, Personal communication, December 2004.

- For each management approach, a variety of scenarios with potential for radiation exposure to members of the public under normal and off-normal conditions were analyzed; and
- The radiological risks of each approach are presented and compared against the Canadian dose limits to the public.

Whenever possible, bounding cases which have the potential to result in the largest radiological risk were identified. Where the bounding cases resulted in negligible consequences, it can be reasonably assumed that cases involving lesser risks cannot result in significant negative impacts. Events with extremely low probabilities (of below 1×10^{-7}) were not considered.

For members of the public, a dose limit of 1 mSv/y was used to evaluate the performance of the management approaches. This limit is defined in Canada by the CNSC and is consistent with international guidelines[18]. For waste management facilities, a dose constraint of 0.3 mSv/y is recommended by the International Commission on Radiological Protection (ICRP) for the design of a single new facility.

Currently, in Canada there is no separate dose criteria defined for human intrusion and the same dose limit of 1 mSv/y is applied. This limit was used for human intrusion in the current study. It should be noted that for human intrusion, ICRP 81[19] recommends a criterion of between 10 mSv/y and 100 mSv/y.

Under off-normal conditions, the consequences to members of the public were compared to the regulatory compliance limits used for licensing nuclear generating stations[20]. Table 4.3-1 summarizes the radiological dose limits for members of the public used in this study.

Table 4.3-1: Radiological Criteria for Members of the Public Used in this Study

Conditions	Frequency	Dose Limit
Normal Conditions	1	1 mSv/y
Off-normal Conditions	Frequency > 0.01	0.5 mSv
	0.01 > Frequency > 0.001	5 mSv
	0.001 > Frequency > 1×10^{-4}	30 mSv
	1×10^{-4} > Frequency > 1×10^{-5}	100 mSv
	Frequency < 1×10^{-5}	250 mSv

[18] Canada Gazette, *Nuclear Safety and Control Act and Regulations*, Part II, Vol. 134, June 13, 2000; and International Commission on Radiological Protection (ICRP), *Recommendations of International Commission on Radiological Protection*. ICRP Publication 60, Ann. ICRP, 1991, Vol. 21, pp. 1-3.

[19] International Commission on Radiological Protection (ICRP) 1998. *Radiation Protection Recommendations as Applied to the Disposal of Long-Lived Solid Radioactive Waste*. ICRP Publication 81, Ann. ICRP, Vol. 28.

[20] Canadian Nuclear Safety Commission (CNSC), S*afety Analysis of CANDU Nuclear Power Plants*. C-006 Rev. 1., 1999.

4.3.3 Risks During Transportation

Radiological risks associated with transportation of used nuclear fuel are predicted for road, rail and water transportation for the Deep Geological Disposal in the Canadian Shield and Centralized Storage (above or below ground) management approaches. The off-normal radiological scenario for transportation assumes an impact and fire of the used nuclear fuel shipment.

Conventional (i.e., non-radiological) risks during transportation were assessed using the casualty rates reported by Statistics Canada[21]. The traffic casualty rates used are:

- 8.9 fatalities per billion vehicle-kilometres; and
- 711.0 injuries per billion vehicle-kilometres.

The number of predicted accidents was compared by destination economic region based on the estimated transportation distance. An analysis of conventional risks during transportation was completed for road transport only. As storage at nuclear sites does not involve off-site transportation, transportation analysis is not required for this approach.

It is acknowledged that there will be transportation of people and construction materials for all approaches in addition to the transportation of used nuclear fuel; however, these were not considered in this assessment. It is likely that the travel distances transporting people and construction materials will likely be very small as compared to the travel distances transporting the used nuclear fuel.

4.4 Results of Public Health and Safety Analysis

The results of the analysis are presented in this section for each of the measures. In each case, the information is presented and evaluated to allow differences between the management approaches to be identified and assessed. Where there are differences in implementing management approaches in different economic regions these are identified. Also, if applicable, any differences between implementing different management approaches within the same economic region were considered.

4.4.1 Number of Public at Risk

The number of people potentially at risk relates to the size of the population potentially at risk, including the public adjacent to the facility and adjacent to the transportation routes. For the purposes of this analysis it has been assumed that the number of public adjacent to the facility is

[21] Transport Canada. 2004. Canadian Motor Vehicle Traffic Collision Statistics 2003. http://www.tc.gc.ca/roadsafety/tp/tp3322/2003/page5.htm. Site last updated November 9, 2004. Site accessed November 30, 2004.

proportional to the population density of the ER the facility is located in. Table 4.4-1 summarizes the population densities of the ERs considered in this analysis. Those ERs with a higher population density will likely have more members of the public at the facility fence line than those with a low population density.

Table 4.4-1: Illustrative Economic Regions with Population and Transportation Criteria

Illustrative Economic Region	Population Density (person/km^2)	Approximate Transport Distance (km)
ER-1	4.9 (Medium)	~4,000 (Long)
ER-2	0.1 (Low)	~3,500 (Long)
ER-3 (current reactor site)	4.1 (Medium)	Not Applicable
ER-4	2 (Low)	~1,000 (Medium)
ER-5 (current reactor site)	20 (Medium)	Not Applicable
ER-6 (current reactor site)	713 (High)	~100 (Short)
ER-7	20 (Medium)	~200 (Short)
ER-8 (current reactor site)	20 (Medium)	Not Applicable
ER-9	0.05 (Low)	~2,000 (Long)
ER-10 (current reactor site)	31.5 (High)	Not Applicable
ER-11 (current reactor site)	20 (Medium)	Not Applicable

More members of the public will be exposed with Storage at Nuclear Reactor Sites than the other approaches because the used nuclear fuel will be managed in seven separate locations and several of the ERs have relatively high population densities.

Members of the public along the transportation route may also be exposed during transportation activities. Table 4.4-1 also shows the approximate transport distance to the destination ER. Those ERs with a longer transportation route will potentially expose more members of the public than those with shorter transportation routes, depending upon the number and size of population centres along the routes.

For each of the bounding exposure scenarios considered for the radiological assessment (see Section 4.4.2) a hypothetical public receptor was identified. Table 4.4-2 summarizes the characteristics and estimated number of public affected in each scenario. Information in this table shows that only a small number of people are at risk and those affected are likely in close proximity to the facility.

Table 4.4-2: Summary of Number of Members of the Public at Risk by Management Approach[22]

Management Approach	Bounding Exposure Scenario	Estimated Number of People Affected
Normal Conditions		
Deep Geological Disposal in the Cdn. Shield, operations	Routine airborne and water emissions	Small number of people at facility fence (smaller number than storage at nuclear sites due to low population density)
Deep Geological Disposal in the Cdn. Shield, post-closure	Groundwater pathway	Self sufficient local farmers
Storage at Nuclear Reactor Sites	External exposure at fence boundary	Small number of people at facility fence
Centralized Storage (Above Ground)	External exposure at fence boundary	Small number of people at facility fence (smaller number than storage at nuclear sites due to low population density)
Centralized Storage (Below Ground)	External exposure at fence	Small number of people at facility fence (smaller number than storage at nuclear sites due to low population density)
Off-Normal Conditions		
Deep Geological Disposal in the Cdn. Shield, operations	Failure in the shaft and hoisting facilities, along with ventilation failure	Small number of people at facility fence (smaller number than storage at nuclear sites due to low population density)
Deep Geological Disposal in the Cdn. Shield, post-closure	Human Intrusion	Unknown. Depends on the intrusion scenario; likely very few.
Storage at Nuclear Reactor Sites	Dropping of a loaded DSC in the process building	Small number of people at facility fence
Storage at Nuclear Reactor Sites	Human Intrusion	Unknown. Depends on the intrusion scenario.
Centralized Storage (Above or Below Ground)	Human Intrusion	Unknown. Depends on the intrusion scenario.
Centralized Storage (Above Ground)	Dropping of a loaded DSC in the process building	Small number of people at facility fence (smaller number than storage at nuclear sites due to low population density)
Centralized Storage (Below Ground)	Dropping of fuel assembly and fuel cask	Small number of people at facility fence (smaller number than storage at nuclear sites due to low population density)

4.4.2 Risks Due to Radiation Exposure

For each approach, the radiological impact to members of the public under normal conditions and off-normal conditions was determined and compared against the Canadian limits. Bounding case

[22] NSS Limited, *Used Nuclear Fuel Management Options, Radiological Safety Review*. GA001. Internal Draft. November 17, 2004.

impacts were calculated for each of the management approaches; these are summarized in Table 4.4-3. These bounding cases and data sources are discussed below.

The normal conditions bounding cases are:

- Routine Airborne and Waterborne Emissions – Radiation doses will be kept low by the optimization of system design; however, potential airborne and waterborne emissions could lead to radiation doses to the public (applicable to Deep Geological Disposal in the Canadian Shield during operations)[23];
- Groundwater Pathway – Assumes the transport of radionuclides (^{129}I) from the geological repository post-closure until the time of maximum exposure (this scenario assumes two containers with undetected manufacturing defects and is applicable to Deep Geological Disposal in the Canadian Shield, post-closure)[24]; and
- Operation of the Storage Building – Assumes the storage buildings containing a full inventory of loaded DSCs resulting in increased gamma radiation (applicable to Storage at Nuclear Reactor Sites and Centralized Storage, above or below ground)[25].

[23] Grondin, L., K. Johansen, N.C. Cheng, M. Fearn-Duffy, G.R. Frost, T.F. Kempe, J. Lockhart-Grace, M. Paex-Victor, H.E. Reid, S.B. Russell, C.H. Ulster, J.E. Villagran and M. Zeya, *The disposal of Canada's Nuclear Fuel Waste: Preclosure Assessment of a Conceptual System*, prepared for Ontario Hydro Nuclear for AECL Research, N-03784-90010 (UFMED), COG-93-6, June 1994.
[24] Garisto, F., J. Avis, N. Calder, A. D'Andrea, P. Gierszewski, C. Kitson, T. Melnyk, K.Wei and L. Wojciechowski, *Third Case Study – Defective Container Scenario*, OPG Report 06819-REP-01200-10126-R00, March 2004.
[25] Ontario Power Generation, *Darlington Used Fuel Dry Storage Project Environmental Assessment Study Report*, 2003.

Table 4.4-3: Summary of Bounding Cases for Each Approach

Management Approach	Bounding Case	Max Impact (mSv/y)	Probability	Estimated number of People Affected	Time of Peak Impact	Limit (mSv/y)	Impact % of the Limit
Normal Conditions							
Deep Geological Disposal in the Cdn. Shield, operations	Routine airborne and waterborne emissions	Adult: 0.00034 Infant: 0.00052	1	Persons living at the facility boundary	During placement of used nuclear fuel in geological repository	1	0.034 0.052
Deep Geological Disposal in the Cdn. Shield, post-closure	Groundwater pathway	10^{-4}	1	Self-sufficient farmers in local area	500,000 years post-closure	1	0.01
Storage at Nuclear Reactor Sites	External exposure at fence boundary	0.0003	1	Small number of people at facility fence	During storage of used nuclear fuel at reactor sites	1	0.03
Centralized Storage (above ground)	External exposure at fence boundary	0.0003	1	Smaller number of people than for Storage at Nuclear Reactor Sites assuming no other activity takes place on site and smaller population density	After placement of used nuclear fuel in storage	1	0.03
Centralized Storage (below ground)	External exposure at fence boundary	0.0003	1	Smaller number of people than for Storage at Nuclear Reactor Sites assuming no other activity takes place on site and smaller population density	After placement of used nuclear fuel in storage	1	0.03
Off-normal Conditions							
Deep Geological Disposal in the Cdn. Shield, operations	Failure in the shaft and hoisting facilities along with ventilation failure	Adult: 0.16 Infant: 0.25	$3x10^{-4}$	Persons living at the facility boundary	Placement of fuel into geological repository	100	<0.16 <0.25
Storage at Nuclear Reactor Sites	Dropping of a loaded DSC in the process building	0.005	$<10^{-7}$	Small number of people at facility fence	Placement of used nuclear fuel in storage	250	0.002
Centralized Storage (above ground)	Dropping of a loaded DSC in the process building	0.005	$<10^{-7}$	Smaller number of people at facility fence than for Storage at Nuclear Reactor Sites due to lower population density	Placement of used nuclear fuel in storage	250	0.002
Centralized Storage (below ground)	Dropping of fuel assembly and fuel cask	0.00002	Not known	Smaller number of people at facility fence than for Storage at Nuclear Reactor Sites due to low population density	Placement of fuel into storage	1	0.002

The off-normal bounding cases are:

- Failure in the Shaft and Hoisting Facilities, along with Ventilation Failure – Assumes that equipment or human failure in the shaft results in a fuel container being dropped down the shaft, and ventilation failure causes airborne effluent to bypass the HEPA filters (applicable to Deep Geological Disposal in the Canadian Shield) [26].
- Dropping of a Loaded DSC in Process Building – Assumes one hundred percent failure of used nuclear fuel in the dropped DSC with the immediate release of the free inventory of both tritium and krypton-85 gasses to the environment (applicable to Storage at Nuclear Reactor Sites and Centralized Storage – above ground) [27]; and
- Dropping of a Fuel Assembly and Fuel Cask – scenario assumes a dropped fuel assembly during handling (applicable to Centralized Storage – below ground)[28].

In addition to the near-term risks during construction and development, risks from off-normal conditions in the long term were also assessed. This includes assessing the effects of loss of institutional control and human intrusion.

Extended storage will involve continuous operation and surveillance, provision of security, repackaging, rebuilding of the facilities and transfer of fuel. Technically, long-term storage beyond 300 years seems feasible if maintenance is exercised. The approach to determining the period of time over which this can be assured differs in different countries.

In Canada, a period of time after 175 years from now is considered separately for long-term analyses. This is based on the seven generation teachings of the Aboriginal people and is defined as a period of time over which information can be passed onto future generations. This period is roughly consistent with the maximum time defined elsewhere[29] as the period over which institutional controls can be assured. Beyond that period there is an increased likelihood that security and maintenance of the facilities will collapse at some point.

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[26] Grondin, L., K. Johansen, N.C. Cheng, M. Fearn-Duffy, G.R. Frost, T.F. Kempe, J. Lockhart-Grace, M. Paex-Victor, H.E. Reid, S.B. Russell, C.H. Ulster, J.E. Villagran and M. Zeya, *The disposal of Canada's Nuclear Fuel Waste: Preclosure Assessment of a Conceptual System*, prepared for Ontario Hydro Nuclear for AECL Research, N-03784-90010 (UFMED), COG-93-6, June 1994.
[27] Ontario Power Generation, *Darlington Used Fuel Dry Storage Project Environmental Assessment Study Report*, 2003.
[28] Zellbi, I. 2004. SKB Sweden. *Personal Communication*. November 5, 2004.
[29] Wickham, Steven M, *Literature Review of Approaches to Long-Term Storage of Radioactive Waste and Materials*, Nirex Report N/107 (Draft), July 2004; Codée, H., *Controlled Containment: Radioactive Waste Management in the Netherlands*, Proceedings of Waste Management 2002, February 24-28, 2002, Tucson, Arizona; and Kema Nucleair, *Optimizing Aspects of Surface Storage: Optimisation Study of KSA, Nuclear Fuel and HAVA Storage at COVRA*, NRG, Kema Nucleair Report 41441-NUC 98-5209, 2000.

Of the three approaches, the Deep Geological Disposal in the Canadian Shield is the only one that provides a planned containment of the radioactivity at times in the future if institutional control cannot be assured. The potential hazard from Deep Geological Disposal in the Canadian Shield has been assessed over time periods of millions of years after fuel emplacement and has been shown to be small compared to Canadian regulatory requirements[30]. The only exception to this case is human intrusion (discussed below).

For the near term (<175 years) with the appropriate institutional control in place, the likelihood of inadvertent human intrusion into the storage facilities is very low, since the facility will be a secure facility located entirely within the fenced and access-controlled site. Correspondingly, resulting radiation exposure to members of the public is negligible; however, for a long-term period with a loss of institutional control, the situation for the three approaches would be different. Table 4.4-4 summarizes the effect on public health and safety due to human intrusion into each management facility.

[30] Garisto, F., J. Avis, N. Calder, A. D'Andrea, P. Gierszewski, C. Kitson, T. Melnyk, K.Wei and L. Wojciechowski, *Third Case Study – Defective Container Scenario*, Ontario Power Generation Report 06819-REP-01200-10126-R00, March 2004.

Table 4.4-4: Summary of Effects on Public Health Due to Human Intrusion

Management Approach	Bounding Case	Max Impact (mSv)	Probability	Estimated number of People Affected	Time of Peak Impact	Impact
Deep Geological Disposal in the Cdn. Shield	Loss of institutional control resulting in intrusion by drilling and retrieval of the core	300	5×10^{-10}	Depends on the intrusion scenario.	At the time of intrusion	Site selection and design of Deep Geological Disposal can ensure that the probability of human intrusion is minimized
Storage at Nuclear Reactor Sites	Loss of institutional control resulting in inadvertent intrusion into facility	>1,000	Probable at some point after 175 years	Depends on the intrusion scenario.	At the time of intrusion	Storage at Nuclear Reactor Sites cannot minimize human intrusion if institutional control is lost
Centralized Storage (above ground)	Loss of institutional control resulting in inadvertent intrusion into facility	>1,000	Probable at some point after 175 years	Depends on the intrusion scenario.	At the time of intrusion	Centralized Storage (above ground) cannot minimize human intrusion if institutional control is lost
Centralized Storage (below ground)	Loss of institutional control resulting in inadvertent intrusion into facility	>1,000	Probable at some point after 175 years	Depends on the intrusion scenario.	At the time of intrusion	Centralized Storage (below ground) cannot minimize human intrusion if institutional control is lost

For the Deep Geological Disposal in the Canadian Shield approach, the bounding case off-normal scenario considers a borehole drilled through the container with used nuclear fuel debris brought to the surface in the form of drilling slurry and a piece of the core. The critical groups considered are the drill crew, a lab technician, a construction worker and a resident at the site.

Doses in excess of 100 mSv/y, which justify intervention in accordance with ICRP-81[31], were estimated using a simplistic conservative analysis. They occur for a period of up to several thousand years with the probability of such exposure never exceeding one in a million chance per year. In all cases, the number of people who could receive these doses is likely to be small and restricted to those who are intimately in contact with the used nuclear fuel debris.

Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground) cannot prevent human intrusion if institutional controls are not maintained. Due to dose rates greater than 1 Sv/h at fuel surface[32], the fuel will remain potentially lethal over several hundred thousand years. The number of people who could receive the dose is likely to be restricted to those in intimate contact with the fuel debris.

Human intrusion into Centralized Storage (below ground) is less likely than into Centralized Storage (above ground) as the used nuclear fuel is less accessible. Human intrusion into Storage at Nuclear Reactor Sites is more likely than into Centralized Storage (above ground) as the used nuclear fuel is stored in more locations.

4.4.3 Risks from Transportation

An analysis of the radiological risks of transportation was carried out under normal and off-normal conditions for transportation by road, rail and water. Table 4.4-5 summarizes the results of this analysis. This analysis is applicable for the Deep Geological Disposal in the Canadian Shield and Centralized Storage (above or below ground) options.

[31] International Commission on Radiological Protection (ICRP), *Radiation Protection Recommendations as Applied to the Disposal of Long-Lived Solid Radioactive Waste*, ICRP Publication 81, Ann. ICRP, Vol. 28., 1998.
[32] McMurray, M. *et. al.* 2004.

Table 4.4-5: Summary of Radiological Risks to Members of the Public from Transportation Activities[33]

Mode of Transportation	Maximum Impact (mSv/y)	Probability (per year)	Number of People Affected
Normal Conditions			
Road transportation	0.09	1	Persons present at truck stop used by the shipments
Rail transportation	0.0004	1	Persons living beside the rail link
Water transportation	0.05	1	Persons following a shipment through a canal
Off-normal Conditions			
Road transportation – fire and impact	Adult: 9 Infant: 13	$3x10^{-6}$	Persons in the vicinity of the transport accident
Rail transportation – fire and impact	Adult: 28 Infant: 40	$4x10^{-7}$	Persons in the vicinity of the transport accident
Water transportation – fire and impact	Adult: 28 Infant: 40	$8x10^{-7}$	Persons in the vicinity of the transport accident

For normal conditions all transportation scenarios are well below the Canadian dose limit of 1 mSv/y[34]. For off-normal scenarios, if the radiation dose limit applied to the nuclear generating station licensing is applied to transportation accidents, the worst case transportation accident with an annual frequency of less than 10^{-5} is bounded by a constraint of 250 mSv/y[35]. Table 4.4-5 shows that the maximum dose ranges from 9 to 40 mSv/y, which is well within the limit.

Conventional risks of transportation were estimated using casualty rates and the total truck kilometres (rounded up to the nearest significant digit) anticipated for each of the illustrative, destination economic regions considered for the Deep Geological Disposal in the Canadian Shield and Centralized Storage (above or below ground) management approaches. The number of truck kilometres includes both the trip to the management facility and the return trip. There is no off-site transportation involved in Storage at Nuclear Reactor Sites. Table 4.4-6 summarizes the potential injury and fatality rates for each of the economic regions.

[33] Grondin, L., K. Johansen, N.C. Cheng, M. Fearn-Duffy, C..R. Frost, T.F. Kempe, J. Lockhart-Grace, M. Paex-Victor, H.E. Reid, S.B. Russell, C.H. Ulster, J.E. Villagran and M. Zeya, *The disposal of Canada's Nuclear Fuel Waste: Preclosure Assessment of a Conceptual System*, prepared for Ontario Hydro Nuclear for AECL Research, N-03784-90010 (UFMED), COG-93-6, June 1994.
[34] Canada Gazette, *Nuclear Safety and Control Act and Regulations*, Part II, Vol. 134, No. June 13, 2000; and International Commission on Radiological Protection (ICRP), *1990 Recommendations of International Commission on Radiological Protection,* ICRP Publication 60, Ann. ICRP, Vol. 21, 1991, pp. 1-3.
[35] Canadian Nuclear Safety Commission, *Safety Analysis of CANDU Nuclear Power Plants*, C-006 Rev. 1, 1999.

Table 4.4-6: Summary of Estimated Casualty Rates Due to Transportation for Deep Geological Disposal in the Canadian Shield and Centralized Storage (above or below ground) by Destination Economic Regions

Destination Illustrative Economic Region	Total Truck Travel (billion km)	Total Estimated Fatalities[a]	Total Estimated Injuries[b]
ER-1	0.16	1.4	114
ER-2	0.14	1.2	100
ER-4	0.04	0.4	28
ER-6	0.008	0.08	5.6
ER-7	0.01	0.08	7.2
ER-9	0.08	0.8	56

[a] Based on Canadian average rate of 8.9 fatalities per billion vehicle-kilometres
[b] Based on Canadian average rate of 711 injuries per billion vehicle-kilometres

Based on this analysis, all economic region destinations have a predicted a very low number of fatalities due to transportation, only the two longest routes predicted greater than one fatality. With respect to injuries, those routes with a shorter total travel distances (i.e., to ER-6 and ER-7) have fewer predicted injuries than those with longer total travel distances (i.e., ER-1 and ER-2).

Storage at Nuclear Reactor Sites does not require the used nuclear fuel to be transported off-site to a central location and therefore avoids the potential conventional risks associated with transportation activities.

4.5 Summary of Public Health and Safety Analysis – A Comparison of Management Approaches

Public health and safety relates to the likelihood that members of the public proximate to the facility or along the transportation route might be exposed to unacceptable radiological and conventional risks as a result of implementing an approach. The management approach, 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, the public will not be subject to risks or harmful exposures, chronic or accidental, greater than those acceptable to Canadian and international authorities. Security and terrorism as a threat to public health and safety is discussed in Section 6.0.

The assessment used quantitative information available in the literature or capable of being estimated within the timeframe available for the assessment, and builds on the approach used by the Assessment Team and GAL/GLL in similar studies. Information was developed for each of the approaches within each of the illustrative economic regions. This included the identification of the radiological and physical risks associated with each approach, including transportation of the used nuclear fuel.

The primary considerations for the analysis included:

1. **Number of people potentially exposed:** The overall risk to members of the public is a function of the size of the population potentially located proximate to the facility, including the population along the transportation route: the greater the number of people, the greater the corresponding risk. The population density and size and number of population centres in each illustrative ER provide a good indication of the number of people potentially affected in both the near and far-term.

2. **Seriousness of potential risks:** Risks to members of the public result both from potential radiation exposures and conventional safety, including both normal and off-normal exposures The maximum radiation dose to the public (identified as the bounding case) at the facility or during transportation, and the time of peak impact, was assumed to provide an indication of the average radiation dose to the public as a whole. It was assumed that approaches where the maximum doses are lower will have lower typical or average doses. Conventional health and safety risks relate primarily to transportation: it was assumed that injuries and fatalities as a result of transportation accidents depend on distance travelled.

3. **Likelihood of a potential risk occurring:** The probability of a serious effect to members of the public was determined by estimating the radiation exposures for a variety of credible normal and off-normal scenarios. Whenever possible, bounding cases which have the potential to result in the largest radiological risk were identified and events with extremely low probabilities were not considered. Where the bounding cases result in negligible consequences, it was assumed that cases involving lesser risks would not result in significant negative impacts. The likelihood of conventional accidents occurring during transportation is based on current transportation accident statistics.

A summary of public health and safety analysis for the three management approaches in terms of their benefits, risks and costs is presented below and is detailed in Table 4.5-1.

Benefits

All three approaches can be built and operated to meet applicable safety criteria with a considerable margin of safety under normal conditions. Under off-normal conditions, radiation exposure is well below the applicable criteria for near and long term for all approaches, with the exception of the human intrusion scenario. As long as institutional control is in place, the risk to the public from off-normal conditions is very low for all approaches.

Differences between approaches relate to the number of people that may be exposed to unacceptable risks as a result of implementing an approach and the total transportation distance involved in transporting used nuclear fuel. The nature of the risks associated with all three approaches are similar, namely radiation exposures, and injuries and fatalities as a result of traffic accidents in the case of Deep Geological Repository and Centralized Storage (above or below ground).

Risks

All three approaches involve real and perceived risks, including risks associated with transporting used nuclear fuel for the Deep Geological Repository and Centralized Storage (above or below ground) approaches.

During normal and off-normal conditions in the near term, all potential radiation exposures are expected during or just after placement of the fuel in the management facility. The repackaging cycles associated with Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground) may result in potential radiation exposures of members of the public through the time of maximum exposure (greater than 10,000 years into the future). Human intrusion into these two management approaches may result in an unacceptable radiation risk to the public in the long term if institutional control is not maintained.

The probability of the bounding off-normal scenarios during the near term for all approaches is very low for as long as institutional control features are in place. For Deep Geological Disposal, the probability of human intrusion in the long term is extremely low compared with the probability of intrusion for Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground).

If there is a loss of institutional control before closure (Year 154 for Deep Geological Disposal), none of the three approaches can prevent an unacceptable radiation risk to public health caused by an inadvertent human intrusion. However, the risk from Deep Geological Disposal is far lower because the used nuclear fuel is managed at well below ground surface. In the long term, the risk to the public is lowest for Deep Geological Disposal because the used nuclear fuel is contained below ground in a secure facility with engineered and geological barriers. However, for some off-normal scenarios for Deep Geological Disposal, there is a perceived risk that some radioactivity may escape from the facility via the groundwater pathway at some unspecified point in the future. The predicted impact of any groundwater release from Deep Geological Disposal is well below applicable standards.

Transportation activities associated with Deep Geological Disposal and Centralized Storage (above or below ground), can be designed and carried out safely and meet all applicable criteria. Risks from off-normal transportation conditions primarily relate to transportation distance.

Costs

Costs of radiation protection and public safety are accounted for in the economic costs of all approaches through facility designs and monitoring programs using today's technology and standards.

Table 4.5-1: Summary of Public Health and Safety Analysis – A Comparison of Management Approaches: Benefits, Risks and Costs

Measure or Indicator	Benefits	Risks	Costs
Number of People at Risk	• There are no benefits associated with this measure.	• There are more members of the public exposed in ERs with higher population densities than in those with low population densities. • Storage at Nuclear Reactor Sites will have a larger number of public at risk than the other facilities because the used nuclear fuel will be stored in seven separate locations. • Deep Geological Disposal in the Canadian Shield and Centralized Storage (above or below ground) have more people at risk along the transportation route. • Economic regions farther away from the source of the used nuclear fuel will expose more members of the public to risk.	• There are no costs associated with this measure.
Radiological Dose to the Public	• Under normal operations all approaches are capable of meeting applicable criteria in the near and long term. • Radiation exposures for normal and off-normal transportation activities are insignificant. • Only Deep Geological Disposal in the Canadian Shield offers protection from unacceptable risks through unauthorized or inadvertent intrusion into the used nuclear fuel in the long term.	• Following a loss of institutional control in the long term, Storage at Nuclear Sites and Centralized Storage (above or below ground) do not prevent an unacceptable radiation exposure risk to public health and safety caused by an intrusion. The resulting fatal exposure will persist for hundreds of thousands of years. • There are no differences between ERs.	• Costs of radiation protection are accounted for in the economic costs of all approaches through facility designs and monitoring programs using today's technology and standards. • There are no differences between ERs.
Estimated Fatalities and Injuries Due to Transportation	• There is no conventional transportation risk associated with Storage at Nuclear Reactor Sites as there is no off-site transportation associated with this approach.	• Deep Geological Disposal in the Canadian Shield and Centralized Storage (above or below ground) have off-site transportation and associated transportation risks. • Greater than 1 fatality is predicted only for the two longest transportation routes. • The estimated number of injuries is small for all economic regions and is proportional to transport distance.	• The costs associated with transportation are included in the economic costs of the approaches.

Measure or Indicator	Benefits	Risks	Costs
Time of Peak Impact	• There are no benefits associated with this measure.	• During normal and off-normal conditions in the near-term, all potential exposures are expected during or just after placement of the fuel in the facility. • For Deep Geological Disposal in the Canadian Shield, radiation can continue to be exposed through the groundwater pathway for hundreds of thousands of years into the future (although predicted impact is well below applicable standards) • Repackaging cycles associated with Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground) cause an associated radiation exposure well into the future (greater than 10,000 years) • Human intrusion into Centralized Storage (above or below ground) and Storage and Nuclear Reactor Sites may result in an unacceptable risk to the public in the long term if institutional control cannot be maintained • Time of peak impact is independent of economic region.	• Costs of radiation protection are accounted for in the economic costs of the management approaches
Probability of Maximum Impact to Receptor	• There are no benefits associated with this measure.	• The probability of the bounding off-normal scenarios during the near term for all approaches is very low (less than 10^{-4}). • The probability of human intrusion into the Deep Geological Disposal in the Canadian Shield facility in the long term is very low (less than 10^{-7}). • If institutional control is not maintained, human intrusion into the management facility for Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground) is likely.	• There are no costs associated with this measure.

5.0 ANALYSIS OF WORKER HEALTH AND SAFETY

5.1 Context for the Analysis of Worker Health and Safety

Objective: *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*[36]*.*

This section provides an analysis of the risks to workers for each of the management approaches. With the exception of the transportation risks, the risks associated with the management approaches are independent of the economic region in which they would be implemented. Transportation risks are dependent on the total distance the used nuclear fuel will need to be transported.

The management approach, 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 and international authorities at the time of construction. In addition, workers engaged in future monitoring and maintenance activities will not be subject to risks greater than those acceptable today.

Risks to workers may occur as a result of radiation exposures as a result of handling or being near to used nuclear fuel. Workers likely to be exposed to a measurable radiation dose would be designated as Nuclear Energy Workers subject to specific radiation monitoring and control procedures, including recording all exposures received. Non-radiation occupational risks could occur at any stage of the design, construction and operation of the facility. Transportation of used nuclear fuel may also result in a risk to workers.

5.2 Influencing Factors and Measures Used in the Analysis of Worker Health and Safety

Indicators and measures are required to allow a comparative assessment of the benefits, risks and costs with respect to the health and safety of workers engaged in implementing each approach. It was assumed that all approaches are capable of being implemented safely using current industrial best practices, although there may be differences between approaches. Further, an assessment based on indicators and measures developed using current worker health and safety information is likely to exaggerate the actual risks of implementing an approach in the future, since the safety of

[36] Nuclear Waste Management Organization, *Understanding the Choices – The Future Management of Canada's Used Nuclear Fuel*, September 2004, page 60.

workers in industrial countries, including Canada, has shown continuous improvement over the past decades.

The indicators and measures used in the assessment are provided in Table 5.2-1 and include:

- commonly used measures of worker health and safety, such as accident frequency and severity;
- consideration and development of the influencing factors used by the Assessment Team, including the size of the workforce at risk and the seriousness of potential health consequences;
- measures that are capable of being quantified for each approach, including size of workforce, number of accidents and maximum radiation exposures; and
- measures that allow possible differences between approaches to be highlighted, including those that may occur across illustrative economic regions.

The measures are based on quantitative information available in the literature or capable of being estimated within the timeframe available for the assessment. Their selection and evaluation builds on the approach used by GAL/GLL in similar studies and includes four principal assumptions:

- The overall risk to workers is a function of the **number of workers** involved in implementing the approach: the greater the number of workers, the greater the corresponding risk;
- Risks to workers result both from potential **radiation exposures** and conventional **occupational health and safety**, including both normal and accidental exposures;
- The radiation dose to the **maximally exposed worker** (identified as the bounding case) provides an indication of the average radiation dose to the workforce as a whole: approaches where the maximum dose is lower will have lower typical or average doses; and
- **Current experience** with respect to radiation exposures and occupational health and safety provides a useful and appropriate basis for predicting and comparing the benefits and risks of implementing each of the approaches.

Table 5.2-1: Influencing Factors Used in the Analysis of Worker Health and Safety

Influencing Factors used in Preliminary Comparative Assessment	Influencing Factors used in this Analysis	Measures Used in this Analysis
Size of population potentially at risk	Size of workforce at risk	Number of workers during each stage
Seriousness of potential consequences to impacted individual • Normal operations (radiological, conventional and industrial hazards) • Off-normal scenarios (radiological, construction accidents, extreme handling accidents) Duration of potential health consequences (short, temporary or long-term) Ability to respond to, correct, remove, mitigate	Seriousness of potential consequences to workers • Normal operations (radiological, conventional and industrial hazards) • Off-normal scenarios (radiological, construction accidents, extreme handling accidents) Duration of health consequences	Radiological risks • Dose to workers (normal and off-normal) Conventional occupational risks • Lost Time Accident Frequency Rate (LTAFR) • Total Recordable Accident Frequency Rate (TRAFR)
Likelihood of impacted individuals experiencing consequences	Accident statistics in representative industrial sectors	• Lost Time Accident Frequency Rate (LTAFR) • Total Recordable Accident Frequency Rate (TRAFR)

The following influencing factors were assessed qualitatively and are discussed in Section 5.4.5:

- Effectiveness of safety barriers (related to *Risk Scenarios*);
- Effectiveness of safety institutions (related to *Risk Scenarios*); and
- Exposures during monitoring (related to *Radiological Exposures*).

5.3 Methods and Details of Worker Health and Safety Analysis

The risks to workers associated with the management approach are assessed over the near term during which the facility is constructed and the used nuclear fuel emplaced (1 to 175 years). Risks to workers in the long term (>175 years), including workers involved in the repackaging and rebuilding of the Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites approaches, are anticipated to be similar to those incurred in the near term.

The analysis of the effects of the management measures on workers was conducted using four measures:

- Number of workers potentially at risk;
- Risks due to exposure to radiation;

- Risks due to conventional occupational hazards; and
- Risks during transportation.

The assessment of risks to worker health and safety is based on a number of existing peer-reviewed studies available for dry used nuclear fuel storage facilities (similar in concept to Storage at Nuclear Reactor Sites) and for Deep Geological Repositories. There is limited data available for Centralized Storage (above or below ground); therefore, bounding scenarios have been applied to Centralized Storage where they are functionally similar to either Storage at Nuclear Reactor Sites or Deep Geological Disposal in the Canadian Shield.

5.3.1 Number of Workers Potentially at Risk

The cost estimates for each of the management approaches in Section 7.0 (Economic Viability) include the labour cost for each stage, namely interim storage and retrieval, representative transportation, etc. These labour costs are used to determine the approximate number of workers during each of the stages. The estimates include workers directly associated with the construction and operation of the facility and do not include indirect or induced employment. Employment is provided as the number of full-time equivalents (person-years) and should be useful in determining relative differences in the number of employees for each of the management approaches.

5.3.2 Risks Due to Exposure to Radiation

Workers may be exposed to radiation-based hazards related to all project stages. The analysis of the radiation dose to workers is based on a review of the available information from other studies. The approach for the determination of risks from radiation exposure is as follows:

- For each management approach, work activities associated with potential radiological risk are categorized into different phases and the major activities for each phase are summarized;
- For each management approach, a variety of scenarios with potential for radiation exposure to workers under normal and off-normal conditions are analyzed; and
- The radiological risks of each approach are presented and compared against the Canadian dose limits to workers.

Whenever possible, bounding cases which have the potential to result in a largest radiological risk are identified. Events with extremely low probabilities (i.e., less probable than $1x10^{-7}$ per year) are not considered. Where the bounding cases result in negligible consequences, it can be reasonably assumed that cases involving lesser risks can not result in significant negative impacts.

The criteria used in the analysis are developed from the CNSC dose limits for workers[37]. These limits establish the maximum exposure for a nuclear energy worker as 50 mSv in any single one-year dosimetry period. Based on these dose limits, an annual average of 20 mSv is used in this analysis for the limit on workers (i.e., one fifth of the five-year limit of 100 mSv). This analysis also uses a dose of 30 mSv as an accident criteria for workers consistent with that used by OPG for potential accidents at a nuclear station[38].

5.3.3 Risks Due to Conventional Occupational Injury

Construction and operation of the management approaches involve many aspects and tasks typically associated with a conventional construction or mining project. There are no other immediately comparable facilities from which to extrapolate probable performance or to compare performance. Consequently, it is necessary to identify other industry sectors with equivalent site activities to predict occupational health and safety incident rates and performance. For the purposes of this analysis, it is assumed the conventional occupational health and safety risks are similar to those that may be associated with resource-based industries such as mining, quarrying and aggregate production.

The risk of occupational injury or illness is generally expressed as a frequency rate based on the numbers of injuries and illnesses of a particular severity over the course of a calendar year. The following two reactive or trailing performance measures are commonly used as occupational health and safety performance measures used by industry and workers' compensation boards:

- Lost Time Accident Frequency Rate (LTAFR), involving work-related injury or illness resulting in days away from work or days of restricted work activity, or both, whether consecutive or not; and
- Total Recordable Accident Frequency Rate (TRAFR), involving work-related illness resulting in fatality, lost time, restricted work or medical treatment greater than routine first aid.

The LTAFR and TRAFR are the numbers of injuries and illnesses of the particular type being measured per 200,000 person-hours worked. The 200,000 person-hours worked is the factor used to bring the frequency rate to a common exposure base of 100 full-time equivalents. The frequency rates are calculated according to the general formula:

[37] Canadian Nuclear Safety Commission, *Safety Analysis of CANDU Nuclear Power Plants*. C-006 Rev. 1, 1999.
[38] Grondin, L., K. Johansen, N.C. Cheng, M. Fearn-Duffy, C..R. Frost, T.F. Kempe, J. Lockhart-Grace, M. Paex-Victor, H.E. Reid, S.B. Russell, C.H. Ulster, J.E. Villagran and M. Zeya, *The disposal of Canada's Nuclear Fuel Waste: Preclosure Assessment of a Conceptual System*, prepared for Ontario Hydro Nuclear for AECL Research. N-03784-90010 (UFMED), COG-93-6, June 1994.

$$\text{Rate} = \frac{\#\ \text{Incidents} \times 200{,}000}{\text{Exposure Hours Worked During Reporting Period}}$$

The Lost Time and Total Recordable Accident Frequencies for workers in similar industries were available from:

- The Mining and Aggregate Safety and Health Associations (MASHA)[39] – lost time and total medical injury frequencies for workers at quarries, as well as sand and gravel pit operations;
- Saskatchewan Workers' Compensation Board[40] – the time loss claim injury rate and the medical (no time loss) injury rate for the uranium mining industry;
- The Construction Safety Association of Ontario[41]– the lost time injury incident rates for the general construction industry; and
- Ontario Power Generation and Bruce Power[42] – lost time injury incident rates for nuclear power stations in Ontario.

5.3.4 Risks During Transportation

Radiological risks to workers were assessed using the same methodology described in Section 5.3.3. Radiological risks of transportation were predicted for road, rail and water transportation for the Deep Geological Disposal in the Canadian Shield and Centralized Storage (above or below ground) management approaches. The off-normal radiological scenario for transportation involved an impact and fire of the used nuclear fuel shipment.

Conventional risks to workers during transportation occur as a result of traffic accidents. Injury and fatality rates for traffic accidents are included in the analysis of public safety and include the vehicle driver.

5.4 Results of Worker Health and Safety Analysis

The results of the analysis are presented for each of the measures in this section. In each case, the information is presented and evaluated to allow differences between the three management approaches to be identified and assessed. Where there are differences in implementing management approaches in different economic regions these are identified. Finally, if applicable,

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[39] Nighbor, D. 2003, email correspondence from Ms. Dawna Nighbor, Information Coordinator for the Saskatchewan Workers' Compensation Board, to Tammy Bowen of Golder Associates Ltd., subject: Quarries and Sand and Gravel Pits Lost Time and Total Medical Injury Frequencies, November 25, 2003.
[40] Marshall, G.J. 2003. email correspondence from Mr. George J. Marshall, Research Officer and Revenue Analyst for the Saskatchewan Workers' Compensation Board, to Tammy Bowen of Golder Associates Ltd., subject: Statistical Request. November 23-24, 2003.
[41] Construction Safety Association of Ontario, *Injury Atlas – Ontario Construction*, Toronto, 2000.
[42] Bruce Power, *Environmental Assessment Study Report Bruce A Units 3 & 4*, August 2002.

any differences between implementing different management approaches within the same ER are considered.

5.4.1 Number of Workers Potentially at Risk

Table 5.4-1 provides an estimate of the total direct employment, expressed as full time equivalents (person-years), for each of the management approaches. With the exception of transportation, the estimated employment is independent of the economic region. The representative transportation employment included in Table 5.4-1 assumes a transportation of approximately 1,000 km and does not depend upon the economic region. Estimates of total direct employment are based on an approximate average annual labour cost of $120,000 per person-year. This value has been derived in reference to CTECH cost studies and current wage levels in Ontario.

Table 5.4-1: Estimated Workforce During Project

Management Approach	Emplacement of Used Nuclear Fuel		Ongoing Management of Facility	
	Total Full Time Equivalents (person-years)	Period (year)	Total Full Time Equivalents (person-years)	Period (year)
Deep Geological Disposal in the Cdn. Shield	33,000	1 - 59	11,000	60 - 154
Storage at Nuclear Reactor Sites (all sites)	11,000	Varies	1,300,000	to 10,000
Centralized Storage (above ground)	11,000	1 - 47	800,000	48 - 10,000
Centralized Storage (below ground)	13,000	1 - 47	900,000	48 - 10,000

5.4.2 Risks Due to Exposure to Radiation

The radiological impact for each approach to workers under normal conditions and off-normal conditions were investigated and compared against the Canadian limits. Bounding case impacts were calculated for each of the management approaches. These are summarized in Table 5.4-2.

The normal conditions bounding scenarios are:

- Operation of the Deep Geological Disposal in the Canadian Shield[43] – Assumed workers within the facility boundary during operations. Under normal conditions, the radiological dose will be kept low by the optimization of system design and the implementation of an occupational radiation management system;
- Operation of the below-ground Centralized Storage[44] – Assumed workers within the facility boundary during operations. Under normal conditions, the radiological dose will be kept low by the optimization of system design and the implementation of an occupational radiation management system; and
- Operation of the Surface Storage Facility[45]– Assumes the storage buildings containing a full inventory of loaded DSCs resulting in increased gamma radiation (applicable to Storage at Nuclear Reactor Sites and Centralized Storage – above ground).

The off-normal bounding scenarios are:

- Failure in the Shaft and Hoisting Facilities, along with Ventilation Failure[46]– Assumes that equipment or human failure in the shaft results in a fuel container being dropped down the shaft, and ventilation failure causes airborne effluent to bypass the HEPA filters (applicable to Deep Geological Disposal in the Canadian Shield); and
- Drop of Loaded DSC in Process Building[47]– Assumes one hundred percent failure of the 384 fuel bundles in the dropped DSC with the immediate release of the free inventory of both tritium and krypton-85 gasses to the environment (applicable to Storage at Nuclear Reactor Sites and above or below ground Centralized Storage).

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[43] Grondin, L., K. Johansen, N.C. Cheng, M. Fearn-Duffy, C..R. Frost, T.F. Kempe, J. Lockhart-Grace, M. Paex-Victor, H.E. Reid, S.B. Russell, C.H. Ulster, J.E. Villagran and M. Zeya, *The disposal of Canada's Nuclear Fuel Waste: Preclosure Assessment of a Conceptual System,* prepared for Ontario Hydro Nuclear for AECL Research, N-03784-90010 (UFMED), COG-93-6, June 1994.
[44] *ibid*
[45] Ontario Power Generation, *Darlington Used Fuel Dry Storage Project Environmental Assessment Study Report*, 2003.
[46] Grondin, L., K. Johansen, N.C. Cheng, M. Fearn-Duffy, C..R. Frost, T.F. Kempe, J. Lockhart-Grace, M. Paex-Victor, H.E. Reid, S.B. Russell, C.H. Ulster, J.E. Villagran and M. Zeya, *The disposal of Canada's Nuclear Fuel Waste: Preclosure Assessment of a Conceptual System*, prepared for Ontario Hydro Nuclear for AECL Research, N-03784-90010 (UFMED), COG-93-6, June 1994.
[47] Ontario Power Generation, *Darlington Used Fuel Dry Storage Project Environmental Assessment Study Report*, 2003.

Table 5.4-2: Summary of Bounding Worker Exposure Cases for Each Approach

Management Approach	Bounding Case	Max Impact mSv/y	Probability	Estimated number of Workers Affected	Stage When Peak Impact Anticipated	Limit mSv/y	Impact % of the Limit
Normal Conditions							
Deep Geological Disposal in the Cdn. Shield	Operation of the Deep Geological Disposal facility	17	1	Operators and mechanics	Placement of used nuclear fuel into deep geological repository	20	85
Storage at Nuclear Reactor Sites	Operation of the surface management facility	0.5	1	Site operators	After placement of used nuclear fuel in storage	20	2.5
Centralized Storage (above ground)	Operation of the surface management facility	0.5	1	Site operators	After placement of used nuclear fuel in Centralized Storage	20	2.5
Centralized Storage (below ground)	Operation of the below-ground centralized management facility	17	1	Operators and mechanics	After placement of used nuclear fuel in Centralized Storage	20	85
Off-Normal Conditions							
Deep Geological Disposal in the Cdn. Shield	Failure in the shaft and hoisting facilities, along with ventilation failure	20	$4x10^{-3}$	Nuclear energy worker	Deep geological repository operations	30 [a]	67
Storage at Nuclear Reactor Sites	Failure of all 384 fuel bundles due to DSC drop	15	$<10^{-7}$	Nuclear energy worker	Placement of used nuclear fuel in storage	30 [a]	50
Centralized Storage (above ground)	Failure of all 384 fuel bundles due to DSC drop	15	$<10^{-7}$	Nuclear energy worker	Placement of used nuclear fuel in storage	30 [a]	50
Centralized Storage (below ground)	Failure of all 384 fuel bundles due to DSC drop	15	$<10^{-7}$	Nuclear energy worker	Placement of used nuclear fuel in storage	30 [a]	50

[a] The CNSC has not specified a nuclear energy worker dose limit for accidental conditions. 30 mSv is used by OPG for potential accidents at a nuclear station.

5.4.3 Risks Due to Conventional Occupational Injury

Table 5.4-3 shows the annual average Lost Time Accident Frequency Rate (LTAFR) and Total Recordable Accident Frequency Rate (TRAFR) for each of four representative industrial sectors over the period 1997 through 2002.

Table 5.4-3: Industrial Injury and Fatality Rates

Industry	General Construction		Mining and Quarrying		Uranium Mining		Nuclear Power	
	LTAFR	**TRAFR**	**LTAFR**	**TRAFR**	**LTAFR**	**TRAFR**	**LTAFR**	**TRAFR**
Average Rate	1.9	N/A	2.7	9.2	1.1	2.2	0.9	3.7
Years	1997 to 2000		1998 to 2002		1998 to 2002		1995 to 1998	
Data source	Construction Safety Association of Ontario[48]		Aggregate Safety and Health Associations[49]		Saskatchewan Workers' Compensation Board[50]		OPG and Bruce Power[51]	

The industrial injury and fatality rates in Table 5.4-3 provide a benchmark of what is currently acceptable and identifies differences between the non-nuclear (general construction and mining and quarrying) and nuclear (uranium mining and nuclear power). Inspection of the information in the table shows that the comparable injury and fatality rates for the nuclear industry are lower than the non-nuclear sector reflecting the high level of effort and focus on safety in the nuclear industry. The rates in Table 5.4-3 can be multiplied by the estimated workforce in Table 5.4-1 to provide an estimate of the industrial injury and fatality rates for each of the approaches.

Using the nuclear power industry injury and fatality rates, Table 5.4-4 presents the estimated number of injuries and fatalities for each of the management approaches.

48 Construction Safety Association of Ontario, *Injury Atlas – Ontario Construction*, Toronto, 2000.
49 Nighbor, D. ,email correspondence from Ms. Dawna Nighbor, Information Coordinator for the Saskatchewan Workers' Compensation Board, to Tammy Bowen of Golder Associates Ltd., subject: Quarries and Sand and Gravel Pits Lost Time and Total Medical Injury Frequencies, November 25, 2003.
50 Marshall, G.J., email correspondence from Mr. George J. Marshall, Research Officer and Revenue Analyst for the Saskatchewan Workers' Compensation Board, to Tammy Bowen of Golder Associates Ltd., subject: Statistical Request, 23-24 November 2003.
51 Bruce Power, *Environmental Assessment Study Report Bruce A Units 3 & 4*, August 2002.

Table 5.4-4: Estimated Work-Related Injuries and Fatalities for Each Management Approach

Management Approach	Emplacement of Used Nuclear Fuel			Ongoing Management of Facility		
	Estimated Lost time Accidents	Estimated Recordable Accidents	Period (year)	Estimated LTAFR	Estimated TRAFR	Period (year)
Deep Geological Disposal in the Cdn. Shield	297	1,221	1 - 59	99	407	60 – 154
Storage at Nuclear Reactor Sites	99	407	Varies	11,700	48,100	to 10,000
Centralized Storage (above ground)	99	407	1 – 47	7,200	29,600	48 – 10,000
Centralized Storage (below ground)	117	481	1 – 47	8,100	33,300	48 – 10,000

The total number of lost time and total recordable injuries as a result of the management approach is directly related to the total person-years worked. Therefore, Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites predict significantly more injuries over the lifetime of the project than Deep Geological Disposal in the Canadian Shield. Health and safety programs will be implemented as part of the management approaches which will aim to minimize the actual number of injuries.

5.4.4 Risks During Transportation

An analysis of the radiological risks of transportation was carried out under normal and off-normal conditions for transportation by road, rail and water. Table 5.4-5 summarizes the results of this analysis. This analysis is applicable for the Deep Geological Disposal in the Canadian Shield and Centralized Storage (above or below ground) approaches.

Table 5.4-5: Summary of Radiological Risks to Workers from Transportation Activities

Mode of Transportation	Maximum Dose (mSv/y)	Probability (per year)	Number of Workers Potentially Affected
Normal Conditions			
Road transportation	2.4	1	Members of the transport crew
Rail transportation	1.2	1	Members of the transport crew
Water transportation	10	1	Members of the transport crew
Off-normal Conditions			
Fire and Impact - Duration of fire >0.5 hrs - Speed of impact > 50km/h	190	1×10^{-5}	Members of the transport crew

For normal conditions, all transportation scenarios are below the CNSC dose limit of 20 mSv/y. For off-normal scenarios, the worst credible accident was estimated to result in a dose of 190 mSv/y. This is higher than the 30 mSv/y dose constraint used for nuclear accidents in Canada; however the probability is low (10^{-5} per year) and the estimate is made using a conservative release scenario.

Although it has not been quantified, transportation by mostly rail and mostly water will involve more handling events (loading and unloading) and potentially more opportunities for radiation exposures.

5.5 Summary of Worker Health and Safety Analysis – A Comparison of Management Approaches

Worker health and safety relates to the conventional and radiological risks that workers may be exposed to as a result of implementing the used nuclear fuel management approaches. This includes risks associated with the transportation of used nuclear fuel and other operations associated with its long-term management. The construction, 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 greater than those acceptable to Canadian and international authorities at the time of construction.

The assessment used quantitative information available in the literature or capable of being estimated within the timeframe available for the assessment, and builds on the approach used by the Assessment Team and GAL/GLL in similar studies. Information was developed for each of the approaches within each of the relevant illustrative economic regions. This included the identification of the radiological and physical risks associated with each approach, including transportation. Current experience with respect to radiation exposures and occupational health and safety in similar industrial sectors provides a useful and appropriate basis for predicting and comparing the benefits and risks of implementing each of the approaches.

The primary considerations for the analysis included:

1. **Number of workers potentially exposed:** The overall risk to workers is a function of the number of workers involved in implementing the approach, including transporting the used nuclear fuel. The estimated number of workers includes workers directly associated with the construction and operations of the facility and do not include indirect or induced employment. The size of the workforce for each management approach is generally independent of ER. It is assumed that the greater the number of workers, the greater the corresponding risk.

2. **Seriousness of potential risks:** The radiation dose to the maximally exposed workers (identified as the bounding case) at the facility or during transportation provides an indication of the average radiation dose to the workforce as a whole. It is assumed that approaches where the maximum doses are lower will have lower typical or average doses. It is assumed the conventional occupational health and safety risks are similar to those that may be associated with resource-based industries such as mining, quarrying and aggregate production, as expressed by accident frequency and severity rates.

3. **Likelihood of a potential risk occurring:** The probability of a serious effect to workers was determined by estimating the radiation exposures for a variety of credible normal and off-normal scenarios. Whenever possible, bounding cases which have the potential to result in the largest radiological risk were identified and events with extremely low probabilities (i.e., less probable than $1x10^{-7}$ per year) were not considered. Where the bounding cases result in negligible consequences, it was assumed that cases involving lesser risks would not result in significant negative impacts. The likelihood of conventional accidents occurring is included in the predicted accident frequency and severity rates.

A summary of worker health and safety analysis for the three management approaches in terms of their benefits, risks and costs is presented below and is detailed in Table 5.5-1.

Benefits

All three approaches can be built and operated to meet applicable worker health and safety standards under normal and off-normal conditions. Most importantly, all of the activities required to implement the approaches involve current and proven procedures and practices, which have been demonstrated to be capable of being carried out safely without undue risk to workers.

Differences between approaches relate to the number of workers required for construction and operation, the nature of the activities and the total transportation distance involved in transporting used nuclear fuel.

The size of the workforce anticipated for Deep Geological Disposal is less than that required for Storage at Nuclear Reactor Sites and Centralized Storage. However, the workforce required for Deep Geological Disposal is only required until Year 154, whereas the other methods require a workforce beyond Year 10,000.

In the near term, radiation doses to workers are lower for Storage at Nuclear Reactor Sites and Centralized Storage (above ground), because most of the work is conducted aboveground where work tends to be less confined and ventilation is easier and generally more effective, during normal and off-normal conditions.

The industrial accident rate (injuries and fatalities) predicted for all approaches is typically less than in non-nuclear mining and construction projects for all management approaches. This assumption is based on the current safety record of the nuclear industry, including uranium mining.

Risks

Radiation exposures to workers during operations and transportation are within acceptable Canadian standards for all management approaches under normal and off-normal conditions. Radiation exposures will be incurred throughout the entire management period for Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground). In contrast, all radiation exposures to workers will be incurred through Year 154 for Deep Geological Disposal, at which time the facility is closed (i.e., all risks to workers are incurred during the near term only). The highest radiation exposure to the greatest number of workers occurs for Deep Geological Disposal; however, risks are within acceptable standards and occur before the closure of the underground facility.

The anticipated number of industrial accidents depends on the total person-years anticipated for each management approach; therefore, over the entire analyzed time span (until year 10,000) there are more injuries predicted for Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites, which require ongoing repackaging cycles. In the near term, and particularly during placement of the used nuclear fuel, there are more injuries anticipated for Deep Geological Disposal.

Transportation activities associated with the two approaches that have off-site movement of used nuclear fuel, namely, Deep Geological Disposal and Centralized Storage (above or below ground), can be designed and carried out safely and meet all applicable criteria. Risks from off-normal transportation conditions primarily relate to transportation distance. Accordingly, risks associated with transportation would be lowest for illustrative economic regions that are located closest to the current reactor sites or regions.

Costs

The cost of the approaches includes the total workforce costs which incorporate reasonable and predictable costs for worker safety. These include the costs for worker radiation protection and conventional occupational health and safety programs and procedures for all management approaches through facility designs and monitoring programs.

Table 5.5-1: Summary of Worker Health and Safety Analysis - A Comparison of Management Approaches: Benefits, Risks and Costs

Measure or Indicator	Benefits	Risks	Costs
Number of Workers During Each Stage	• There are no benefits associated with this measure.	• The size of the workforce for 'fuel in place' is approximately three times higher for Deep Geological Disposal in the Canadian Shield than for the other management approaches • Closure of the Deep Geological Disposal in the Canadian Shield facility is complete by year 154; therefore the workforce during ongoing management of the facility is 70 to 120 times smaller than that required for Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites. • There are no differences between ERs.	• Costs of employing the workforce are included in the economic costs of the management approaches as the labour cost for each stage.
Radiological Dose to Workers	• Radiation exposures to workers during operations and transportation are within acceptable Canadian standards for all management approaches for normal and off-normal conditions. • In the near term, radiation exposures to workers are lower for Storage at Nuclear Reactor Sites and Centralized Storage (above ground). • All radiation exposures to workers will be incurred in the first 154 years (i.e., in the near term only) for Deep Geological Disposal in the Canadian Shield.	• The highest radiation exposure to the greatest number of workers occurs for Deep Geological Disposal in the Canadian Shield; however risks are within acceptable standards and are in the near term only. • Risks are incurred over the long term for both Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground), and are committing future generations of workers to repeated exposure conditions due to repackaging events. • There are no differences between ERs.	• Some costs for worker safety, including radiation protection, are accounted for in the economic costs of all management approaches through facility designs and monitoring programs. • There are no differences between ERs.
Conventional Risks to Workers	• The anticipated industrial accident rate is expected to be less than in non-nuclear mining and construction projects due to a higher standard of care in the nuclear industry. • Storage at Nuclear Reactor Sites does not require transportation, and therefore has none of the associated transportation risks.	• A significantly greater number of injuries are anticipated over the life of the project for Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites due to the ongoing repackaging events. • During the placement of used nuclear fuel more injuries are anticipated for Deep Geological Disposal in the Canadian Shield than for the other management approaches. • Injuries and fatalities as a result of transportation depend on distance traveled; therefore, there is a greater risk of injury for longer transportation routes than for shorter routes.	• Some costs for worker safety, including conventional occupational health and safety protection, are accounted for in the economic costs of all management approaches through facility designs and monitoring programs. • There are no differences between ERs.

6.0 ANALYSIS OF SECURITY

6.1 Context for the Analysis of Security

Objective: *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*[52].

Security, in the context of this report, relates to the capacity of a used nuclear fuel management approach to provide long-term security of nuclear material, facilities and infrastructure. The security analysis focuses on differences in the vulnerability of the management approaches. For the purpose of this analysis, vulnerability is defined as a weakness that may be exploited by terrorists by causing a radiological release near a population centre or by obtaining material to construct a nuclear device.

Used nuclear fuel is a heavy, ceramic material that is neither explosive nor volatile and resists easy dispersal. Therefore, the dispersion of large amounts of radioactive material would require either a sustained, high temperature fire or an external force such as a high speed impact or violent explosion in which it would be pulverized into small particles. There are two basic types of bombs that could be constructed: a nuclear device or a so-called “dirty” bomb. The use of used nuclear fuel for manufacturing a dirty bomb would result in the release of radioactivity into the atmosphere and potential exposure of people. In order to develop a nuclear device, several inherent safeguards would have to be overcome, including the intense radiation level of used nuclear fuel and the difficulty in separating the plutonium from the used nuclear fuel matrix.

The analysis considered a variety of tactics that could potentially result in the forced dispersal of radioactivity during the storage and/or transportation and/or management of used nuclear fuel:

- Capture and breach – e.g., by application of explosives and/or via an engineered breach;
- Transportation infrastructure attack – e.g., attack a tunnel during transportation to attempt an impact or crush breach and/or a fire related incident sufficient to cause a failure of the shipment container; and
- A remote attack with current weapons – e.g., anti-tank missiles and military piercing weapons.

[52] Nuclear Waste Management Organization, *Understanding the Choices – The Future Management of Canada’s Used Nuclear Fuel*, September 2004, page 65.

6.2 Influencing Factors and Measures Used in the Analysis of Security

Indicators and measures are required to allow a comparative assessment of the benefits, risks and costs with respect to the security of each approach. It is assumed that all approaches would incorporate features to minimize or avoid entirely the threat of theft despite possibilities of terrorism or war, although there may be differences between approaches. Further, an assessment based on indicators and measures developed using current security information and understanding is likely to exaggerate the risks of implementing an approach in the future, since the security of potentially vulnerable facilities has been significantly enhanced over the past few years and continuing improvements are likely to continue.

The indicators and measures used in the assessment are provided in Table 6.2-1 and include:

- commonly used measures of security, such as used nuclear fuel accessibility and transportation distance;

- consideration of the potential vulnerability of used nuclear fuel and the consequences of the release and dispersal of radioactive material;

- consideration and development of the influencing factors used by the Assessment Team, including the security of facilities, nuclear materials and transportation systems;

- measures that are capable of being quantified for each approach, including the number and robustness of physical barriers, and the size of population potentially affected at the facility and along the transportation route; and

- measures that allow possible differences between approaches to be highlighted, including those that may occur across illustrative economic regions.

The measures are based on quantitative information available in the literature or capable of being estimated within the timeframe available for the assessment. Their selection and evaluation builds on the approach used by GAL/GLL in similar studies and includes five principal assumptions:

- The risk of security threats or breaches is proportional to the time period while the **used nuclear fuel is accessible**, either in the facility or during transportation; greater risks exist while the used nuclear fuel is accessible;

- The overall risk to members of the public is a function of the population density or **number of population centres** proximate to the facility and along the transportation route; the greater the number and size of population centres workers, the greater the corresponding risk;

- The number and size of population centres within an **economic region** and along the **transportation route** provide an indication of the number of people potentially at risk, both now and in the future;

- **Physical barriers** provide the greatest deterrent to security threats and breaches, including threats as a result of societal breakdown; and

- **Current experience and understanding** with respect to security can provide only a general indication of potential threats. It is not possible or prudent to speculate on specific new types of terrorist threats that could exist in future.

Table 6.2-1: Influencing Factors Used in the Analysis of Security

Influencing Factors used in Preliminary Comparative Assessment	*Influencing Factors used in this Analysis*	*Measures used in this Analysis*
Impacts on non-proliferation	Impacts on non-proliferation	• Used nuclear fuel accessibility
Security of facilities	Security of facilities	• Number of used nuclear fuel-bundle repackaging cycles • Robustness of physical barriers • Number of population centres in the region
Security of nuclear materials	Factor addressed in security of facilities and security of transportation systems factors	
Security of transportation and other support systems	Security of transportation systems	• Transportation distance and number of shipments • Number of population centres along transportation corridor

The following influencing factors were assessed qualitatively and are discussed in Section 6.4.7:

- Related to *Adequacy of Contingency Plans*
- Related to *Risk Scenarios*:

- Societal breakdown
- Civil disobedience
- Potential for insider threats

6.3 Methods and Details of Security Analysis

The security of the management approaches in the illustrative economic regions was assessed in the near term (up to 175 years) and in the long term (>175 years). The analysis was conducted for on-site considerations and transportation.

Six specific measures were developed to represent "target richness", i.e., instances or conditions that may increase the vulnerability of the transportation and/or management systems. Collectively, the measures represent the relative opportunity for terrorists to strike when the nuclear materials are likely to be the most vulnerable and placing the maximum number of people at risk if a strike is successful. The first three measures differentiate between the management approaches and are independent of the economic region involved. The last three measures allow differences, if any, between the approaches and the specific economic regions to be identified.

6.3.1 Used Nuclear Fuel Accessibility

The accessibility of used nuclear fuel measure relates to non-proliferation. The threat of obtaining bomb-making material is minimized by the security measures that are or would be in place; the difficulty in moving the massive storage/transport casks; the inherent radiation barrier to handling the material once removed from a cask; and the difficulty in separating the plutonium from the used nuclear fuel matrix. Any attempt to gain access to the used nuclear fuel, whether at a reactor site or Centralized Storage site, would be met by armed guards and physical protection measures. If terrorists were able to gain access to the used nuclear fuel, the massive size and weight of the containers would be a formidable barrier to removal. Furthermore, the intense radiation would make it difficult to handle and extract plutonium from it. However, the radiation barrier decreases with time, with around a 95% reduction in the radiation level within 10 years following removal from a reactor - making the used nuclear fuel an increasingly attractive target for diversion[53]. While the residual radiation levels are still a significant deterrent and the used nuclear fuel still very dangerous, additional safeguards may be required as the used nuclear fuel ages.

[53] Nuclear Waste Management Organization, *Guiding Concepts – Nonproliferation Aspects of Spent Fuel Storage and Disposition*", December 2003, page 42.

6.3.2 Number of Used Nuclear Fuel-Bundle Repackaging Cycles

The need to periodically repackage the used nuclear fuel increases the vulnerability of the facility to attack during each cycle when the material is removed, albeit temporarily, from the engineered barriers (e.g., storage vault, dry storage containers).

Storage at Nuclear Reactor Sites and the two Centralized Storage (above or below ground) management approaches include an ongoing, cyclical program of regular replacement and refurbishment activities. The containers and facilities will be designed to last between 100 and 300 years.

6.3.3 Robustness of Physical Barriers

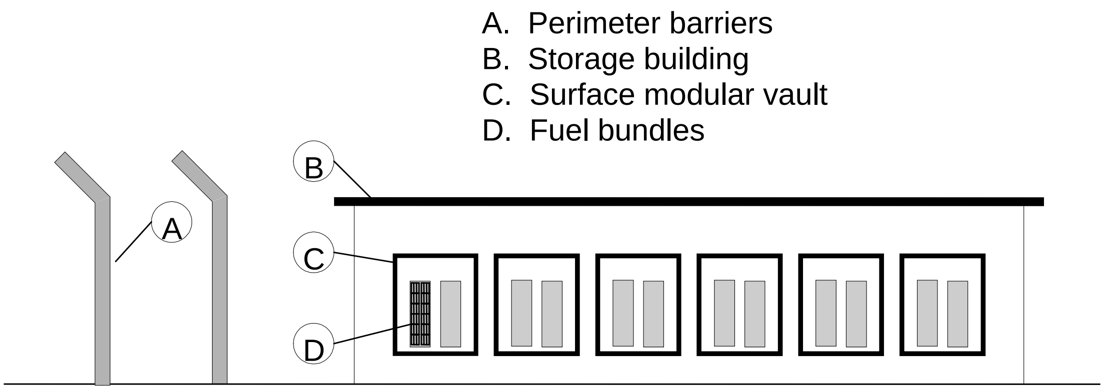
All management approaches provide a basic set of physical barriers to protect the used nuclear fuel. These include two or more outer barriers such as perimeter fences with an isolation zone on each side of the outer zone to allow for observation, continuous monitoring and threat analysis. Additional physical barriers depend on the management approach.

For Storage at Nuclear Reactor Sites and Centralize Storage (above ground), the used nuclear fuel will be sealed in either baskets or module canisters and then stacked and sealed inside steel tubes set inside a concrete vault. The concrete vaults are reinforced concrete structures with wall thicknesses in the order of 1 m. The vaults will be contained inside surface storage buildings (Figure 6.3-1 and 6.3-2).

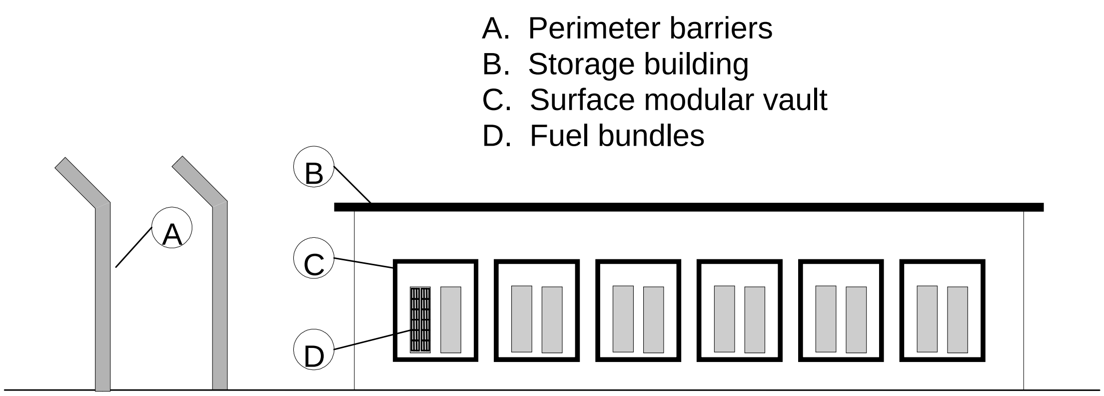
For Centralized Storage (below ground), the used nuclear fuel is stored in casks. The casks are double-steel-shell containers with the space between the inner and outer shell filled with approximately 60 cm of reinforced high-density concrete. The casks are stacked in a series of storage caverns constructed in competent bedrock at a nominal depth of 50 m below surface (Figure 6.3-3).

For Deep Geological Disposal in the Canadian Shield, the used nuclear fuel is placed in unsealed baskets that are sealed inside a specially designed used nuclear fuel container. The used nuclear fuel container is composed of a 96 mm thick carbon steel shell with a 25 mm thick copper jacket. This container is jacketed with bentonite and placed in emplacement rooms excavated at a nominal depth of 1000 m within the Canadian Shield (Figure 6.3-4). Approximately 100 years after all used nuclear fuel is in place at the facility, all access to the emplacement rooms (e.g., access shafts) is permanently closed.

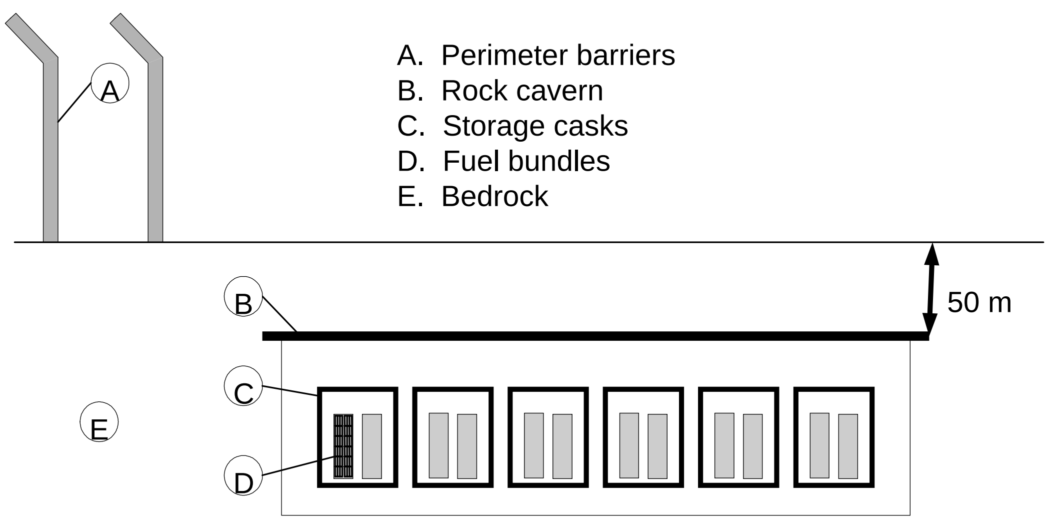
PHYSICAL BARRIERS – STORAGE AT NUCLEAR REACTOR SITES	FIGURE 6.3-1



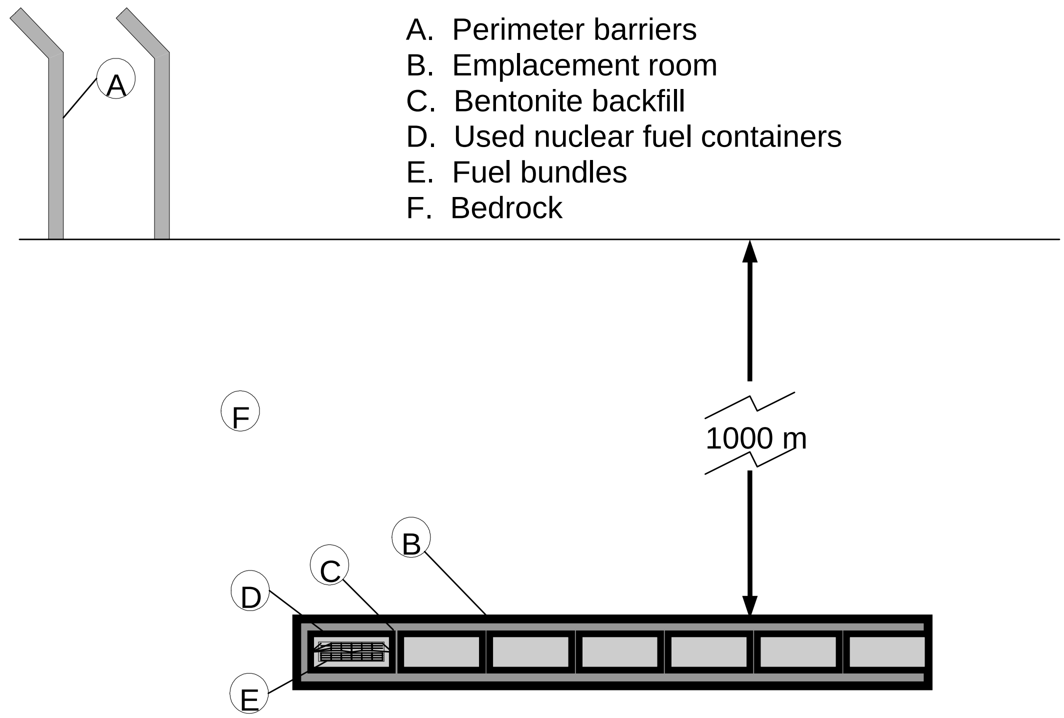
PHYSICAL BARRIERS – CENTRALIZED STORAGE (ABOVE GROUND)	FIGURE 6.3-2



PHYSICAL BARRIERS – CENTRALIZED STORAGE (BELOW GROUND)	FIGURE 6.3-3



PHYSICAL BARRIERS – DEEP GEOLOGICAL DISPOSAL IN THE CANADIAN SHIELD	FIGURE 6.3-4



6.3.4 Number of Large Population Centres in the Region

Storage/disposal sites that are located in economic regions with high population centres may be at greater risk in the event of a terrorist attack, as such centres present a more attractive target. The risk would depend on the nature of the attack and the extent of dispersion of any radioactive materials: economic regions with higher populations represent the largest risk[54,55].

6.3.5 Transportation Distance and Number of Shipments

Transportation is a key distinguishing factor between the different approaches and is a critical factor to be addressed in assessing further risks that might be posed to society or the environment through the movement of used nuclear fuel between locations.

Used nuclear fuel could be transported by road, rail or ship. In all cases, the used nuclear fuel transported will be contained in steel transportation casks or containers. The shipping containers do not represent a particularly attractive target for theft due to their weight (the DSC in particular), strength and the need for specialized handling equipment. However, they could be targeted with the objective of breaching the containment and creating radiological release and dispersion.

The Storage at Nuclear Reactor Sites management approach does not require off-site transportation of used nuclear fuel, as the used nuclear fuel would remain next to where it is generated. The Centralized Storage (above or below ground) and Deep Geological Disposal in the Canadian Shield management approaches would require additional safety requirements for the movement of the used nuclear fuel from the reactor sites to the long-term management facilities. The vulnerability is assumed to increase as a function of the transportation distance and the number of shipments along the route and is also assumed a function of transportation mode and route taken.

For this analysis, distances along major highways between each reactor site and the central point (geographic centroid) of each illustrative ER for Deep Geological Disposal in the Canadian Shield or either Centralized Storage (above or below ground) approach were added together to estimate the transportation distance by road between reactor sites and each illustrative ER. The distances are shown on Figures 6.3-5 through 6.3-11 (see Appendix A).

[54] Wiles, R. and J.R. Cox, *Nuclear Waste Accident Scenarios in the United States*, June 27, 2002.
[55] Radioactive Waste Management Associates, *Radiological Consequences of Severe Rail Accidents Involving Spent Nuclear Fuel Shipments to Yucca Mountain: Hypothetical Baltimore Rail Tunnel Fire Involving SNF*, September 2001.

6.3.6 Number of Large Population Centres along Transportation Routes

This measure considers the potential consequences of an attack during transportation of the used nuclear fuel. If released during transit, used nuclear fuel being transported to a Centralized Storage (above or below ground) or Deep Geological Disposal in the Canadian Shield facility could create public health impacts and disruption of the social and economic vitality in the region. The impact will depend, in part, on the proximity of the release to population centres and the size of the population that is exposed. Transportation routes with a higher number of large population centres represent the largest risk.

For this analysis, the number of different population centre sizes in each economic region along the transportation route was tallied based on the road transportation routes shown on Figures 6.3-5 through 6.3-11. The number of unique population centres for the complete transport route from all seven reactor sites to each of the illustrative ERs was summarized from this data set.

6.4 Results of the Security Analysis

The results of the analysis are presented for each of the six measures in this section. In each case, the information is presented and evaluated to allow differences between the management approaches to be identified and assessed. Where there are differences in implementing management approaches in different economic regions, these are also identified.

Table 6.4-1 provides the results of the security analysis for the three target richness measures that are independent of the ER where an approach would be implemented: used nuclear fuel accessibility, number of repackaging cycles and robustness of physical barriers.

Table 6.4-1: Site Independent - Target Richness Measures for Management Approaches

Management *Approach*	Used *Nuclear Fuel Accessibility*		Number of Used Nuclear Fuel Repackaging Cycles over 10,000 yrs.	Robustness of Physical Barriers (Number and Type)
	<175 yr	*>175 yr*		
Deep Geological Disposal in the Cdn. Shield	Very low	Not readily accessible	1	• Five engineered barriers • One (deep) geologic barrier and permanent closure
Storage at Nuclear Reactor Sites	Low	Low	100	• Four engineered barriers
Centralized Storage (above ground)	Low	Low	100	• Four engineered barriers
Centralized Storage (below ground)	Very low	Very low	100	• Four engineered barriers • One (shallow) geologic barrier

6.4.1 Used Nuclear Fuel Accessibility

It is assumed that all management approaches provide a high level of security, including armed guards and physical protection measures such as perimeter fencing and multiple engineered barriers. To some degree, used nuclear fuel accessibility is determined by the number and robustness of physical barriers. Nonetheless, a terrorist attack could successfully overcome the physical security measures and remove used nuclear fuel from a storage facility. The accessibility of the used nuclear fuel is generally low or very low in the near and long term. Deep Geological Disposal in the Canadian Shield results in the used nuclear fuel being relatively inaccessible in the long term because of backfilling of the rooms and sealing the access shafts after placement of the used nuclear fuel and closure of the facility in year 154.

6.4.2 Number of Repackaging Cycles

Table 6.4-1 shows the number of repackaging and rebuilding cycles over the 10,000 year assessment period. The greater the number of repackaging events, the greater the overall vulnerability of the facility to attack. Since the used nuclear fuel is most accessible and vulnerable to dispersion during repackaging, used nuclear fuel bundles are assumed to be repackaged in their storage containers every 100 years at the Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground) facilities. This corresponds to 100 repackaging events for Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground) over the 10,000 year assessment period. The used nuclear fuel bundles are assumed to be repackaged only once at a Deep Geological Disposal in the Canadian Shield site when the used nuclear fuel is transferred from interim storage into the Used Fuel Containers for emplacement in the repository.

6.4.3 Robustness of Physical Barriers

The number and types of physical barriers for the three management approaches are summarized in Table 6.4-1. As shown on Figures 6.3-1 through 6.3-4, each approach involves a variety of protective physical barriers, including engineered barriers such as fences, sealed steel containers, reinforced concrete vaults and outer storage buildings. As noted above, there is some overlap between the robustness of physical barriers and used nuclear fuel accessibility (Section 6.4-1). The geosphere that is integral to Centralized Storage (below ground) and Deep Geological Disposal in the Canadian Shield ensures an additional barrier beyond that provided for Centralized Storage (above ground) and Storage at Nuclear Reactor Sites. The geologic barrier provides additional protection from attacks involving high-energy sources such as an aircraft, anti-tank missiles and military piercing weapons.

6.4.4 Number of Large Population Centres in the Region

The consequence of a terrorist attack that results in a radiological release will depend in part on the proximity of the release to population centres. The number of population centres of different sizes is listed for each of the illustrative ERs in Table 6.4-2. Illustrative ERs with a number of large population centres (e.g., greater than 50,000 people) would present the greatest risk because of the greater number of people that would potentially be impacted from a terrorist attack. In the absence of other information, it is assumed that the current number and size of population centres is a reasonable indication of the population density in future. As noted above, the risk would depend on the nature of the attack and the extent of dispersion of any radioactive materials; economic regions with higher populations represent the largest risk.

Table 6.4-2: Population Centres by Size within Illustrative ERs

Management *Approach*	Economic Region	Number of Population Centres *>50,000 within Illustrative ER*
Deep Geological Disposal in the Canadian Shield	ER-2	0
	ER-4	2
	ER-7	0
	ER-9	0
Storage at Nuclear Reactor Sites	ER-3	0
	ER-5	0
	ER-6	8
	ER-8	1
	ER-10	0
	ER-11	0
Centralized Storage (above ground or below ground)	ER-1	0
	ER-2	0
	ER-4	2
	ER-6	8
	ER-7	0
	ER-9	0

The results provided in Table 6.4-2 show that ER-6, which is illustrative of a high population density, has the largest number of population centres greater than 50,000 and, thus, the greatest risk for this measure.

6.4.5 Transportation Distance and Number of Shipments

The vulnerability of the used nuclear fuel is assumed to increase with increases in the transportation distance and the number of shipments along the route. Illustrative ERs with the higher number of trip-kilometres required to transport all used nuclear fuel from the reactor sites would present the greatest risk. It is assumed that the current number and size of population centres is a reasonable indication of the population density in future. The total number of trip-kilometres required to transport all the used nuclear fuel by road to a facility is shown in Table 6.4-3. Similar results would be observed for transportation by rail or ship.

Table 6.4-3: Travel Distance and Number of Shipments by Road

Current Reactor Site		Whiteshell	Bruce	Pickering	Darlington	Chalk River	Gentilly	Point Lepreau	
Management Approach	**Illustrative Economic Region**	**Number of Shipments**							**No. Shipments x Distance**
		3	*7812*	*4848*	*4852*	*30*	*767*	*665*	
Deep Geological Disposal in the Cdn. Shield	ER-2	1586 km	3575 km	3527 km	3556 km	3429 km	3947 km	4728 km	69 million
	ER-4	1409 km	874 km	825 km	853 km	728 km	1245 km	2026 km	17 million
	ER-7	1986 km	298 km	154 km	125 km	308 km	647 km	1428 km	5 million
	ER-9	2850 km	2035 km	1856 km	1829 km	1628 km	1786 km	2567 km	37 million
Centralized Storage (above or below ground)	ER-1	2018 km	4002 km	3953 km	4023 km	3854 km	4372 km	5153 km	77 million
	ER-2	1586 km	3575 km	3527 km	3556 km	3429 km	3947 km	4728 km	69 million
	ER-4	1409 km	874 km	825 km	853 km	728 km	1245 km	2026 km	17 million
	ER-6	1993 km	241 km	45 km	74 km	479 km	713 km	1494 km	4 million
	ER-7	1986 km	298 km	154 km	125 km	308 km	647 km	1428 km	5 million
	ER-9	2850 km	2035 km	1856 km	1829 km	1628 km	1786 km	2567 km	37 million

The results in Table 6.4-3 show that the illustrative ERs representative of a long transportation distance, namely, ER-1, ER-2, ER-9, have the highest number of trip-kilometers and thus would be more vulnerable to a terrorist attack than illustrative ERs representative of a short transportation distance such as ER-6 and ER-7.

6.4.6 Number of Large Population Centres along Transportation Route

The vulnerability of used nuclear fuel shipments to a terrorist attack with the objective of radiological release and dispersion also may be influenced by population density along the transportation route[56]. Illustrative ERs with the higher number of large population centres along the transportation routes would present the greatest risk because of the number of people that would be potentially impacted from a terrorist event, since they represent a target with a more severe impact. Table 6.5-4 identifies the number of population centres with greater than 50,000 people located within economic regions that are crossed by road transportation routes between the reactor sites and the illustrative ERs.

Table 6.4-4: Number of Population Centres along Transportation Route with Population >50,000

Management Approach	Illustrative Economic Region	No. of Population Centres >50,000 along Transportation Route
Deep Geological Disposal in the Canadian Shield	ER-2	22
	ER-4	19
	ER-7	19
	ER-9	20
Centralized Storage (above or below ground)	ER-1	22
	ER-2	22
	ER-4	19
	ER-6	19
	ER-7	19
	ER-9	20

The results in Table 6.4-4 show that the total number of population centres greater than 50,000 people along the transportation route for the different illustrative ERs ranges from 19 to 22. This suggests that there is little difference in the risk between illustrative ERs due to this measure.

6.4.7 Qualitative Description of Other Factors

The following measures or indicators are discussed qualitatively below.

Related to *Adequacy of Contingency Plans*

Contingency Plans in the event of a terrorist attack or other security breach at a used nuclear fuel centre are typically not disclosed in the public domain. Therefore, it is not appropriate to comment on or consider how contingency plans may affect the different management approaches.

[56] Wiles, R. and J.R. Cox, *Nuclear Waste Accident Scenarios in the United States*, June 27, 2002.

Related to *Risk Scenarios*

Three of the influencing factors related to risk scenarios presented in the Preliminary Comparative Assessment are discussed below:

- **Societal breakdown** - There is a risk that security could be compromised as a result of societal breakdown and, for example, abandonment of the facility by security personnel. In the long term, it is likely that society and institutional stability will change. However, for Deep Geological Disposal in the Canadian Shield, once the facility is closed (year 154), there would be no direct risk from such events.
- **Civil disobedience** - This factor is most pertinent during transportation of used nuclear fuel to a facility, such as efforts to attempt to physically block the transportation route with a human shield. For example, there have been a number of instances in the past five years in the United Kingdom, France and Germany where shipments of used nuclear fuel have been interrupted by protestors opposed to nuclear energy and/or the disposal of used nuclear fuel[57,58,59,60]. While these incidents are a security issue, their impact has been to delay the shipment for several hours until the local law enforcement agency removed the protestors.
- **Potential for insider threats** - Insider threats have similar influences as terrorist threats, i.e., diversion, sabotage, etc. Similar to terrorism threats, insider threats could occur during transportation or repackaging. Therefore, the existing measures of vulnerability to terrorism threats are considered to be comprehensive.

6.5 Summary of Security Analysis: A Comparison of Management Approaches

This objective relates to the capacity of a used nuclear fuel management approach to provide long-term security of nuclear material, facilities and infrastructure. The security analysis focuses on differences in the vulnerability of the three management approaches. For the purpose of this analysis, vulnerability is defined as a weakness that may be exploited by terrorists by causing a radiological release near a population centre or by obtaining material to construct an illicit nuclear device.

Measures were developed to allow an assessment of the benefits, risks and costs of each of the three approaches. The specific measures used in the assessment of security are based on quantitative information available in the literature or capable of being estimated within the timeframe available for the assessment. Their selection and evaluation builds on the approach used by the Assessment Team and by GAL/GLL in similar studies. The current experience and understanding with respect to security can provide only a general indication of potential threats.

[57] http://www.cnduk.org/press2/press13.htm
[58] *Confrontation Builds in Germany as Nuclear Waste Convoy Rolls*, Agence France Presse, Marsh 26, 2001.
[59] http://www.dw-world.de/dw/article/0,1564,1387614,00.html
[60] O'Neill, Kate, *International Nuclear Waste Transportation: Flashpoints, Controversies, and Lessons*, Environment 41, no. 4, May 1999, pp 12-15, 34-39.

It is not possible or prudent to speculate on specific new types of terrorist threats that could exist in the future.

Information was developed for each of the approaches within each of the relevant illustrative economic regions. This included the identification and categorization of physical and geological barriers and the number of times used nuclear fuel needs to be repackaged for each approach. The analysis draws on the published literature and the study team's own experience in this area. Transportation requirements were determined and compared by estimating the total number of trip-kilometers required for each approach.

The primary considerations for the analysis included:

1. **Fuel Accessibility:** The risk of security threats or breaches is proportional to the duration of the time period while the used nuclear fuel is accessible, either in the facility or during transportation. It is assumed that greater security risks exist while the used nuclear fuel is accessible and capable of being dispersed into the natural and human environment.

2. **Number of repackaging recycles and transportation requirements:** Each of the approaches has different requirements with respect to transportation and/or repackaging the used nuclear fuel. Some approaches require that the used nuclear fuel be repackaged numerous times and some require the used nuclear fuel to be transported to a new location. It is assumed that transportation and repackaging provide opportunities for a security breach: the more times the used nuclear fuel is repackaged or the greater the distance it is transported the greater the risk.

3. **Robustness of physical barriers:** physical barriers, including both engineered and geological features, provide the greatest deterrent to security threats and breaches, including threats as a result of societal breakdown, regardless of the time or duration when the used nuclear fuel may be accessible. It is assumed that the greater the number of barriers, the more secure the approach.

4. **Number of large population centres in economic region and along transportation route:** It is assumed that the current number and size of population centres within an economic region and along the transportation route provide an indication of the number of people potentially at risk, both now and in the future.

A summary of security analysis for the three management approaches in terms of their benefits, risks and costs is presented below and is detailed in Table 6.5-1.

Benefits

All three approaches are capable of providing a high degree of security from threats of theft despite possibilities of terrorism or war. This high level of security is achieved by restricting the accessibility of used nuclear fuel in the near and long term through the construction of engineered and geologic barriers. These barriers prevent terrorists from gaining access to the used nuclear fuel and/or causing radioactivity to be dispersed into the environment. The barriers generally are independent of illustrative economic region, although the specific nature of a particular barrier may vary from location to location.

Differences between approaches relate to the potential accessibility of used nuclear fuel and the number of people potentially at risk at the location and along the transportation route. The accessibility of used nuclear fuel is assessed by comparing the number of used nuclear fuel repackaging events required throughout the lifetime of each approach, the number and robustness of physical and geological barriers, and the total transportation distance.

In the near term, all three approaches incorporate at least four independent engineered barriers, which prevent accessibility of used nuclear fuel. Centralized Storage (above or below ground) and Deep Geological Disposal offer more barriers than does Storage at Nuclear Reactor Sites. In the long term, Deep Geologic Disposal offers additional security compared with the other approaches because of the geologic barriers and permanent closure. In the longer term, Deep Geological Disposal also offers the greatest security in the event of societal breakdown, since it does not rely on a continuing human presence.

Risks

Transportation is a key distinguishing factor between the different approaches and is a critical factor to be addressed in assessing further risks that might be posed to society or the environment through the movement of used nuclear fuel between locations in the near term. All approaches other than Storage at Nuclear Reactor Sites require off-site transportation, with the associated risks. However, engineered and security barriers are available to ensure these risks are low. In addition, risks associated with transportation would be lowest for illustrative economic regions that are located closest to the current reactor sites or in regions with fewer large population centres.

Deep Geological Disposal offers advantages compared with the other two approaches, since the number of times the used nuclear fuel needs to be repackaged is limited to one or two compared with up to 100 repackaging events for the others. Storage at Nuclear Reactor Sites offers an advantage compared with the other two approaches since it does not require any transportation of used nuclear fuel.

Storage at Nuclear Reactor Sites includes long-term storage of used nuclear fuel at seven reactor sites across six ERs. The greater number of storage facilities for Storage at Nuclear Reactor Sites combined with the fact that these ERs have large population centres present a greater security risk than the other two approaches.

Storage/disposal sites that are located in economic regions with many large population centres may be at greater risk in the event of a terrorist attack, as such centres present a more attractive target. As illustrative economic regions in the Canadian Shield generally have lower population densities and fewer large population centres (>50,000 inhabitants), Deep Geological Disposal could have a lower risk because a lower number of people would be potentially impacted from a terrorist breach. This benefit may be off-set somewhat by a requirement to transport used nuclear fuel a long distance.

Costs

Some of the costs for security are accounted for in the economic costs of all three approaches through facility designs and monitoring programs. However, recent international events indicate that security standards can be breached and additional costs may be required to address as yet unspecified risks. With the passage of time, it may be necessary to change current security standards and activities to account for changing world events. This may dramatically change future security requirements and its attendant costs. Cost uncertainty is greatest for the Storage at Existing Reactor Sites and Centralized Extended Storage since both these approaches provide opportunities for the accessibility of used nuclear fuel throughout the entire lifetime.

Table 6.5-1: Summary of Security Analysis – A Comparison of Management Approaches: Benefits, Risks and Costs

Measure or Indicator	Benefits	Risks	Costs
Fuel Accessibility (relates to nuclear non-proliferation)	• Accessibility of used nuclear fuel is low in the near and long term for all three approaches. • Deep Geological Disposal in the Canadian Shield is inherently more secure than Storage at Nuclear Reactor Sites or Centralized Storage (above or below ground) - used nuclear fuel is relatively inaccessible in the long term because of backfilling and closure of facility in year 154. • These benefits are independent of ER.	• Risk that security could be compromised and used nuclear fuel could become accessible as a result of societal breakdown in the future. In the long term, it is likely that society and institutional stability will change. Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites could be at risk in such an event(s); for Deep Geological Disposal in the Canadian Shield only – no direct risk from such an event(s), post closure (year 154) over the long term. • These risks are independent of ER.	**For all six measures:** • Some costs for security are accounted for in the economic costs of all three approaches through facility designs and monitoring programs. However, recent international events indicate that security standards can be breached. With the passage of time, it may be necessary to change current security standards and activities to account for changing world events. This may dramatically change future security requirements and its attendant costs.
Number of Repackaging Cycles (periodic over time)	• Deep Geological Disposal in the Canadian Shield does not require repackaging of used nuclear fuel once all used nuclear fuel is placed in the repository (year 59) – significantly more secure in long term, compared with Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground), which require 100 repackaging cycles over the 10,000 year assessment period. • These benefits are independent of ER.	• Repackaging of used nuclear fuel presents some risk of hostile attack for all three approaches. Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground) have 100 repackaging cycles over the 10,000 year assessment period - represents a significantly greater security risk than for Deep Geological Disposal in the Canadian Shield over the long term. • These risks are independent of ER.	
Robustness of Physical Barriers (to protect the used nuclear fuel)	• Centralized Storage (below-ground) and Deep Geological Disposal in the Canadian Shield offer some security advantages over Centralized Storage (above-ground) and Storage at Nuclear Reactor Sites in the near and long term because they have more physical barriers (including geological barriers) and management below ground. • The greater depth of the Deep Geological Disposal in the Canadian Shield and its permanent closure after year 154 provide even further security in the long term. • These benefits are independent of ER.	• Engineered and geological barriers provide security against hostile interventions and dispersion of nuclear material in the near and long term. All approaches include at least four engineered barriers, but security risk as a result of societal breakdown in the future (e.g., abandonment of the facility by security personnel) - in the long term, it is likely that society and institutional stability will change. Both Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites could be at risk in such an event(s). Deep Geological Disposal in the Canadian Shield - no direct risk from such an event(s), post closure (year 154) over the long term. • These risks are independent of ER.	
Number of Large Population Centres (within illustrative ER)	• Deep Geological Disposal in the Canadian Shield has the lowest number of large population centres (defined as greater than 50,000 inhabitants and based on available information) with a range between 0 and 2 across the four illustrative ERs), and has a lower relative risk related to this measure compared with the other two approaches. Centralized Storage (above or below ground) - range between 0 and 8 across the six illustrative ERs; Storage at Nuclear Reactor Sites - range between 1 and 8 across the six illustrative ERs. • As ERs in the Canadian Shield tend to have lower population densities and smaller population centres, it follows that Deep Geological Disposal in the Canadian Shield has a lower number of large population centres across the illustrative ERs.	• Storage at Nuclear Reactor Sites includes long-term storage of used nuclear fuel at seven reactor sites across six ERs, compared with only one ER for each of the other two approaches. The greater number of storage facilities for Storage at Nuclear Reactor Sites combined with the fact that these ERs have large population centres (between 1 and 8 each) present a greater security risk than the other two approaches. • Although Deep Geological Disposal in the Canadian Shield has a lower number of large population centres across the illustrative ERs at present, population growth and settlement patterns could change in the future and result in different population distribution across ERs, with changes in the number of large population centres over the long term.	

Measure or Indicator	Benefits	Risks	Costs
Transportation Distance and Number of Shipments (between locations in the near term)	• Storage at Nuclear Reactor Sites does not require off-site transportation of used nuclear fuel - there are no opportunities for attempted dispersion during transportation; a significant benefit of Storage at Nuclear Reactor Sites compared with the other two approaches in the near term. • Centralized Storage (above or below ground) and Deep Geological Disposal in the Canadian Shield management approaches would require additional safety requirements for the movement of the used nuclear fuel from the nuclear reactor sites to the storage facilities.	• For Centralized Storage (above or below ground) and Deep Geological Disposal in the Canadian Shield - total number of trip-kilometres required to transport all used nuclear fuel by road to a facility vary considerably (by up to 15 times the number of trip-kilometres), depending on the illustrative ER; vulnerability of the used nuclear fuel assumed to increase with increases in number of trip-kilometers - thus a greater security risk during transportation for illustrative ERs located longer distances from majority of used nuclear fuel (i.e., longer distances from southern Ontario).	
Number of Large Population Centres along Transportation Route (across ERs on transportation route)	• Storage at Nuclear Reactor Sites does not require off-site transportation of used nuclear fuel; there are no opportunities for attempted dispersion during transportation, a significant benefit of Storage at Nuclear Reactor Sites compared with the other two approaches in the near term. • The Centralized Storage (above or below ground) and Deep Geological Disposal in the Canadian Shield management approaches would require additional safety requirements for the movement of the used nuclear fuel from the nuclear reactor sites to the storage facilities.	• Both Centralized Storage (above or below ground) and Deep Geological Disposal in the Canadian Shield have a similar number of large population centres (defined as greater than 50,000 inhabitants and based on available information) along transportation routes for all of the illustrative ERs (i.e., between 19 and 22) and thus have a similar degree of security risk for this measure in the near term.	

7.0 ANALYSIS OF ECONOMIC VIABILITY

7.1 Context for the Analysis of Economic Viability

Objective: *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*[61].

This section provides an analysis of the economic viability of the management approaches: Deep Geological Disposal in the Canadian Shield; Centralized Storage; and Storage at Nuclear Reactor Sites. With the exception of transportation costs, economic viability is independent of the economic regions (ERs) in which an approach would be implemented.

The Joint Waste Owners have estimated total costs for the three management approaches. These cost estimates are the basis of the analysis in this section. The *Nuclear Fuel Waste Act* (2002) requires the producers of used nuclear fuel to establish a trust fund to finance its long-term management. The trust fund will provide the financial resources for the implementation of the selected management approach.

The cost estimates are based on conceptual design information, as detailed design information is not yet available, since a specific management approach and a specific site for the implementation of the management approach have not been selected. Based on a validation of the Joint Waste Owners' cost estimates by others, they are "suitable for their purpose of assessing the magnitude of the costs of alternative management methods, and to assist in directional decision-making and the selection of preferred alternatives. The cost estimates have been prepared with an appropriate estimating methodology." [62]

The three management approaches assessed have different magnitudes and timing of costs for the various stages, from siting and design to on-going operation and/or decommissioning, and have different present values (i.e., the value in today's dollars of all future cash flow/costs). The magnitude and timing of these costs across project stages in the near term (1-175 years) and long term (after 175 years), as well as the present value of future costs, are important considerations in the analysis of economic viability.

Information related to the project stages used in this section is provided in Section 2.5.

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[61] Nuclear Waste Management Organization, *Understanding the Choices – The Future Management of Canada's Used Nuclear Fue*l, September 2004, page 69.
[62] ADH Technologies Inc. & Charles River Associates Inc., *Validation of Cost Estimating Process for Long-Term Management of Used Nuclear Fuel*, prepared for NWMO, April 2004.

7.2 Influencing Factors and Measures Used in the Analysis of Economic Viability

Measures are required to allow a comparative assessment of the benefits, risks and costs with respect to the economic viability of implementing each approach. It is assumed that all the necessary financial resources would be available to allow implementation of all approaches, although there may be differences between approaches in both the cost and funding required. The indicators and measures used in the assessment are presented in Table 7.2-1, and include:

- Commonly used measures of economic viability, such as life cycle cash flows (costs), timing of costs (including present value costs), and cost uncertainty;
- Consideration and development of the influencing factors used by the Assessment Team;
- Measures that are capable of being quantified for each approach, including the total costs for each of the project stages, transportation costs, cumulative costs over time, present value of costs, and contingency across project stages; and
- Measures that allow possible differences between approaches to be highlighted, including those that may occur across illustrative economic regions.

Cost estimates were developed for four common project stages for each approach as described in Section 2.5

The measures were based on quantitative costing information provided by NWMO that was developed by the Joint Waste Owners and based on quantitative information in the literature, or capable of being estimated within the timeframe available for the assessment. The specific measures selected in the comparative assessment builds on the approach used by the Assessment Team and by GAL/GLL in similar studies, and includes five principal assumptions:

- Differences in expected costs between approaches can be highlighted by comparing **total costs for each project stage** and by estimating **incremental transportation costs** for the different illustrative ERs;
- Differences in financial resources (costs) required between approaches can be highlighted by comparing **costs over time** including annual costs over time and **cumulative costs (including present value costs)**;
- Differences in the degree to which cost uncertainty has been accounted for between approaches can be highlighted by comparing the relative amount of **contingency costs included in cost estimates across project stages**;
- Both **discounted (i.e., present value) and non-discounted costs are appropriate** and provide different perspectives for highlighting differences between approaches; and
- **The current level of detail** with respect to cost estimates, which was developed at the conceptual design level, provides a useful and appropriate basis for comparing the benefits, risks and costs of implementing each of the approaches.

Table 7.2-1: Influencing Factors Used in the Assessment of Economic Viability

Influencing Factors used in Preliminary Comparative Assessment	Influencing Factors used in this Analysis	Measures used in this Analysis
Expected Costs	Total Life Cycle Costs	Total Costs for each of the project stages: • Interim Storage and Retrieval • Representative Transportation • Siting/Approval, Design & Construction, Initial Operations • Monitor, Operate and Rebuild Transportation cost: • Average by Road • Incremental by Road
Financial Resources	Time period where expenditures are required	Costs over time: • Annual costs for 1,000 years • Cumulative total costs to 60, 175, 1000, and 10,000 years • Total Costs across time periods ▪ 1 - 30 years ▪ 31-175 years ▪ 176 - 1,000 years ▪ 1,001 – 10,000 years • Present value of annual costs
Cost Uncertainty	Cost Uncertainty	Contingency Costs across project stages: • Interim Storage and Retrieval [63] • Representative Transportation • Siting/Approval, Design & Construction, Initial Operations • Monitor, Operate and Rebuild Consideration of issues related to the Certainty of Cost Estimates

The following measures or indicators related to the factors noted were assessed qualitatively and are discussed in Section 7.4.6:

- Related to *Expected Cost*
  - Civil Penalties

[63] Financial liabilities to be funded through the Nuclear Fuel Waste Act Trusts do not include Interim Storage and Retrieval Costs. While these costs add to the total liability of the Joint Waste Owners, and possibly impact their future capacity to borrow money, they are not an element of the cost estimate database or the responsibility of the NWMO.

- Related to *Financial Resources*
  - Potential for major financial recession
  - Financial Surety – ROI; Stability/competence of institutions; Guaranteed funding percent; Continued utility revenue generation
- Related to *Cost Uncertainty*
  - Sensitivity/potential for extreme events
  - Unanticipated Delays

7.3 Methods and Details of Economic Viability Analysis

The economic viability of the management approaches was assessed over several time periods, within the overall 10,000 year assessment period (see Section 2.5.1). Costs for both Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites would continue after 10,000 years. For the Centralized Storage management approach, the analysis includes both an above-ground option (Surface Modular Vault – SMV) and a below-ground option (Casks in Rock Caverns – CRC).

The economic viability of the management approaches was assessed using the five measures identified in the preceding table. With the exception of transportation cost, these measures are generally independent of the ER.

7.3.1 Total Costs for each of the Project Stages

The implementation of each management approach is considered over four common project stages, with different expenditures and timing associated with each. The four common stages are defined as:

1. Interim Storage and Retrieval;
2. Representative Transportation;
3. Siting/Approval, Design & Construction, Initial Operations (i.e., all used nuclear fuel in place inside the facility(ies)); and
4. Monitor, Operate, and Rebuild (i.e., One Cycle).

Transportation costs are described in the next sub-section.

The Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites management approaches differ from Deep Geological Disposal in the Canadian Shield because they include repackaging and rebuilding cycles and associated costs beyond the initial cycle.

The Joint Waste Owners cost estimates, upon which the current study is based (refer to Table 2.1-1 – see Appendix A), present costs for the first operational cycles of Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground), extending approximately 300 years from facility in-service dates. These cost estimates, as described in technical reports (refer to Table 2.1-1- see Appendix A), state that costs beyond a given first operational cycle can be estimated by assuming cycles equivalent to the first, extending forward in time. This methodology was used in the current study to project costs into the long term.

Adding the cost estimates for each stage gives the cost of each management approach to the completion of the initial cycle.

7.3.2 Transportation Cost

The cost for three variations of transportation mode were estimated by the Joint Waste Owners for transportation of all used nuclear fuel from the reactor sites to a hypothetical facility in Central Ontario: by road, mostly rail, or mostly water. These estimates considered an average transportation distance of approximately 1,000 km.

For this analysis, an average of these three transportation costs was used as a representative transportation cost for Deep Geological Disposal in the Canadian Shield and for Centralized Storage (above or below ground). The actual transportation costs will vary depending on the facility location and may be less or greater than the representative transportation cost.

For this analysis, distances along major highways between each reactor site and the central point (geographic centroid) of each illustrative ER for Deep Geological Disposal and for the Centralized Storage approaches were added together to estimate the average road distance between reactor sites and each illustrative ER. The distances are shown on Figures 6.3-5 through 6.3-11 (see Appendix A). This allows the incremental transportation distance and cost over and above the representative cost to be estimated.

No transportation costs have been estimated for the Storage at Nuclear Reactor Sites management approach. Transportation cost estimates[64] completed to date have assessed transport from points of transfer to the transportation system over 1,000 km or more through the public domain to new locations. In the case of Storage at Nuclear Reactor Sites, transport entails only shifts of transfer flasks or loaded storage containers hundreds of metres at slow speeds with highly specialized equipment under controlled conditions within a secured perimeter. This operation is qualitatively

[64] COGEMA Logistics, *Cost Estimate for Transportation of Used Fuel to a Centralised Facility*, Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro Quebec and Atomic Energy of Canada Limited, Ref. 500276-B-010 Rev. 00, September 2003.

and quantitatively different than transportation as considered for Deep Geological Disposal in the Canadian Shield and Centralized Storage (above or below ground). The relevant costs are borne by the waste owners as a part of interim storage, or are included in fuel receipt activities allowed for in facility cost estimates. For the purposes of the present analysis, no transportation costs, comparable to those of Deep Geological Disposal or Centralized Storage (above or below ground), are considered for Storage at Nuclear Reactor Sites.

7.3.3 Costs Over Time

Costs over time for each of the approaches were developed from the Joint Waste Owners' information.

The magnitude and timing of costs vary significantly between management approaches. For example, the Deep Geological Disposal management approach has the majority of costs in the early years (i.e., up to year 59), whereas Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites management approaches include costs far into the future.

The cost estimate for Deep Geological Disposal prepared by the Joint Waste Owners has no future costs beyond facility closure in year 154. However, some form of institutional effort could be required over the long term, as a minimum, to maintain records related to the facility layout, design and physical location. A conservative cost of $100,000 per year (2002 dollars) from year 155 and onwards has been added to the Joint Waste Owners estimates to allow for institutional control (i.e., record keeping) for this approach.

7.3.4 Present Value of Annual Costs

The costs described above allow an analysis of the differences between approaches by identifying the costs required in the near and long term and over different project stages. Another way often used to compare the total costs of different approaches is the present value (PV) cost and is often utilized for financial planning purposes. These two techniques are described below.

The analysis of alternative approaches to managing used nuclear fuel involves a comparison of costs over very long time periods. To fully appreciate how these costs "flow" over time, it is necessary to analyze the costs in real dollar terms[65]. By presenting real dollar costs over time, one is able to visualize how the size and timing of cash requirements differ between management approaches, without concern for unpredictable inflationary effects.

[65] Real dollars refer to the practice of costing activities in the future in a common year. Specifically, if one states that it will cost $1 million to build a facility in 10 years expressed in 2005 dollars, this means that one has not accounted for the effect of inflation. It simply states that if one were to build the facility today in 2005, it would cost $1 million, even though the plan is to do so in 10 years.

This practice of comparing real costs over time helps one understand "real" cost differences. It is not intended to address the strategic question: *Given the differences in cost streams for each of the management approaches, which approach requires the least amount of investment dollars today to implement?* It must be recognized that if two management approaches involve the same real dollar cash expenditures, but one is spent earlier than the other, then the latter approach is less costly to finance. The reason is that for the latter approach, one can invest a smaller amount of cash in an interest-earning bond, which the principal and interest together can be used to pay for the future costs. Specifically, the financial markets are used to help create a portion of the cash required to meet the future cost obligations. Any management approach that requires expenditures earlier have less time to generate interest income and therefore require greater up-front investment by the owner.

The tool that is used to account for the ***"time value of money***" (as exemplified above) is referred to as a Present Value (PV) Analysis. The mathematics of this calculation requires the user to stipulate an interest rate or discount factor that is applied to future cost requirements. The higher the discount factor, the more reliant the analysis depends on interest earning income to pay for future expenditures.

7.3.5 Contingency Costs Across Project Stages

The cost estimates completed by the Joint Waste Owners for the three management approaches are based on conceptual designs and have a certain degree of uncertainty related to actual costs across the project stages. These cost estimates also include contingency (refer to Table 2.1-1 for references – see Appendix A). In cost estimates at this level of conceptual design, it is standard procedure to add contingency costs to project stage cost estimates to account for cost uncertainty.

7.3.6 Certainty of Cost Estimates

The implementation of a management approach is a significant undertaking. Certain assumptions were made in the cost estimates prepared by the Joint Waste Owners for specific and detailed work structures and schedules based on the conceptual designs for the three management approaches. Issues related to the certainty of the cost estimates include the accuracy of the cost estimates; the degree of similarity between the conceptual design and what may eventually be implemented; and the ability to estimate costs far into the future.

7.4 Results of the Economic Viability Analysis

The results of the economic viability analysis are presented for each of the five measures in this section. In each case, information is presented and evaluated to allow differences between the management approaches to be identified and assessed. Where there are differences in implementing management approaches in different economic regions, these are also identified.

7.4.1 Total Costs for Each of the Project Stages

Table 7.4-1 provides the total costs for each of the four common project stages for Deep Geological Disposal in the Canadian Shield, Centralized Storage (both above or below ground), and Storage at Nuclear Reactor Sites. These project stage costs, except for 'Interim Storage and Retrieval', are used to estimate the economic benefits of the implementation of the management approaches in the illustrative economic regions (ERs) (refer to Section 8). The time periods during which the costs are incurred are provided in Table 7.4-2.

Table 7.4-1 shows there are significant differences in costs for three of the four common project stages between management approaches:

- Interim Storage and Retrieval (ranges from $1.3 – $2.4 billion);
- Siting/Approval, Design & Construction, Initial Operations (ranges from $2.6 to $10.1 billion); and
- Monitor, Operate, and Rebuild (i.e., One Cycle) (ranges from $2.6 to $17.6 billion).

As noted previously in Section 7.3.2, the transportation costs are equivalent for both Deep Geological Disposal and Centralized Storage. This is an average of transportation cost estimates provided by the Joint Waste Owners for three modes of transport.

Table 7.4-2 shows that only for the Monitor, Operate and Rebuild Stage (ranges from 60-154 years to 48-347 years) is there significant difference between management approaches in the time period during which the costs are incurred. The results highlight broad differences in costs and timing between the approaches and show that Deep Geological Disposal has higher upfront costs, but lower subsequent costs.

Table 7.4-1: Total Cost for Common Project Stages

Project Stage	MANAGEMENT APPROACH Deep Geological Deposal in the Cdn. Shield	Centralized Storage (above ground)	Centralized Storage (below ground)	Storage at Nuclear Reactor Sites (All Sites)
COSTS (2002) $1,000				
Interim Storage and Retrieval	$2,380,000	$1,964,000	$1,633,000	$1,304,000
Representative Transportation	$1,151,493	$1,151,493	$1,151,493	not applicable
Siting/Approval, Design & Construction, Initial Operations[1]	$10,084,435	$3,334,997	$2,583,305	$5,292,828
Monitor, Operate and Rebuild (One Cycle)	$2,590,452	$13,242,881	$11,494,420	$17,624,660
TOTAL - End of One Cycle (approximate)	$16.2 Billion	$19.7 Billion	$16.9 Billion	$24.2 Billion

[1] End of this project stage referred to in Section 8 and below as "used nuclear fuel in place"

Table 7.4-2: Time Periods for Common Project Stages

Project Stage	MANAGEMENT APPROACH Deep Geological Deposal in the Cdn. Shield	Centralized Storage (above ground)	Centralized Storage (below ground)	Storage at Nuclear Reactor Sites (All Sites)
TIME PERIOD (Year No.)				
Interim Storage and Retrieval	1-59	1-47	1-47	varies
Representative Transportation	30-59	18-47	18-47	not applicable
Siting/Approval, Design & Construction, Initial Operations[1]	1-59	1-47	1-47	10-54 (varies)
Monitor, Operate and Rebuild (One Cycle)	60-154	48-347	48-347	55-320 (varies)

[1] End of this project stage referred to in Section 8 and below as "used nuclear fuel in place"

7.4.2 Transportation Cost

The estimated incremental transportation costs for the illustrative ERs are shown in Table 7.4-3 for Deep Geological Disposal and for Centralized Storage. However, the transportation costs are independent of the long-term management approach selected.

The average road transport distance in the transportation cost estimate prepared by the Joint Waste Owners was 1,074 km.

The results in Table 7.4-3 show that the incremental road transportation distances to the illustrative ERs for Deep Geological Disposal, range from an increase by approximately 2,500 km (to ER-2) to a decrease by approximately 800 km (to ER-7), with incremental transportation costs ranging from an increase of approximately $750 million to a decrease of approximately $250 million, respectively.

The results in Table 7.4-4 show that the incremental road transportation distances to the illustrative ERs for Centralized Storage, range from an increase by approximately 3,000 km (to ER-1) to a decrease by approximately 900 km (to ER-6), with incremental transportation costs ranging from an increase of approximately $900 million to a decrease of approximately $250 million, respectively.

For either Deep Geological Disposal or Centralized Storage management approaches across the illustrative ERs, the incremental transportation costs are potentially significant compared with the cost of the management approaches in the near term (i.e., 175 years - refer to next sub-section, Table 7.4-5). Specifically, for Deep Geological Disposal, the incremental transportation cost for all illustrative ERs would range from a marginal decrease to an increase of up to 6% of the total cost in the near term, and for Centralized Storage, the incremental transportation cost for all illustrative ERs would range from a marginal decrease to an increase of up to 14% of the total cost in the near term.

Table 7.4-3: Deep Geological Disposal in the Canadian Shield - Incremental Transportation Costs for Specific ERs – Road

		A	B	C = B-A	D = C/A x E
Destination Economic Region (Deep Geological Disposal in the Cdn. Shield)	Representative Cost by Road (Cdn. 2002 $1,000)	Average Distance Assumed Rep. Cost by Road (km/trip)	Actual Road Distance Estimated (km/trip)	Total Incremental Road Distance (km/trip)	Incremental Cost (Cdn. 2002 $1,000)
ER-2	$1,151,000	1,074	3,613	2,539	$757,000
ER-4	$1,151,000	1,074	911	-163	-$48,000*
ER-7	$1,151,000	1,074	271	-803	-$239,000*
ER-9	$1,151,000	1,074	1,945	871	$259,000

E = Transport System Operation Cost Estimate ($320 million) - reference: COGEMA LOGISTICS. September 22, 2003. Cost Estimate for Transportation of Used Fuel to a Centralized Facility. Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro Quebec and Atomic Energy of Canada Limited. Ref. 500276-B-010 Rev. 00.

* = A negative number indicates a decrease in the transportation cost relative to the representative cost.

Table 7.4-4: Centralized Storage (above or below ground) - Incremental Transportation Costs for Specific ERs – Road

		A	B	C = B-A	D = C/A x E
Destination Economic Region (Centralized Storage (above or below ground))	Representative Cost by Road (Cdn. 2002 $1,000)	Average Distance Assumed Rep. Cost by Road (km/trip)	Actual Road Distance Estimated (km/trip)	Total Incremental Road Distance (km/trip)	Incremental Cost (Cdn. 2002 $1,000)
ER-1	$1,151,000	1,074	4,050	2,976	$887,000
ER-2	$1,151,000	1,074	3,613	2,539	$757,000
ER-4	$1,151,000	1,074	911	-163	-$48,000*
ER-6	$1,151,000	1,074	212	-862	-$257,000*
ER-7	$1,151,000	1,074	271	-803	-$239,000*
ER-9	$1,151,000	1,074	1,945	871	$259,000

E = Transport System Operation Cost Estimate ($320 million) - reference: COGEMA LOGISTICS. September 22, 2003. Cost Estimate for Transportation of Used Fuel to a Centralized Facility. Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro Quebec and Atomic Energy of Canada Limited. Ref. 500276-B-010 Rev. 00.

* = A negative number indicates a decrease in the transportation cost relative to the representative cost.

7.4.3 Costs Over Time

Annual and cumulative cost estimates over 1,000 years for Deep Geological Disposal in the Canadian Shield, the Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites are illustrated on Figures 7.4-1 through 7.4-4 (see Appendix A). These figures show dramatic differences in the magnitude and timing of cost over time across the three approaches.

Based on Figures 7.4-1 through 7.4-4, the cumulative total costs are summarized in Table 7.4-5 for four time periods, and clearly show significant differences in costs over these periods:

- Up to 59 years, corresponding to the time when all facilities (for all three approaches) are filled with used nuclear fuel [66] (ranges from $2.8 to $10.1 billion);
- Up to 175 years, corresponding to seven generations (ranges from $6.6 to $12.7 billion);
- Up to 1,000 years, including the repackaging of the used nuclear fuel and rebuilding of the Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites facilities over three cycles (ranges from $13 to $67 billion); and
- Up to 10,000 years, maximum time period for this comparative assessment of the management approaches (ranges from $14 to $673 billion).

Table 7.4-5: Cumulative Total Cost of Management Approaches Over Time

	MANAGEMENT APPROACH			
Time Period	**Deep Geological Disposal in the Cdn. Shield[1]**	**Centralized Storage (above ground)**	**Centralized Storage (below ground)**	**Storage at Nuclear Reactor Sites (All Sites)**
COSTS[2] (2002) $1,000				
Up to 59 years	$10,084,435	$3,519,021	$2,754,033	$5,455,126 [3]
Up to 175 years	$12,676,987	$7,868,188	$6,632,907	$11,600,314
Up to 1,000 years	$12,759,487	$43,877,955	$37,821,464	$67,068,440
Up to 10,000 years	$13,659,487	$440,350,070	$381,899,165	$672,916,301

[1] Deep Geological Disposal in the Canadian Shield, post-closure – $100,000 per year allowed for institutional effort
[2] Not including Interim Storage and Retrieval or Representative Transportation
[3] For the three approaches, all used nuclear fuel is 'in place' by year 59; the cost presented here is the sum of all expenditures up to and including year 59. The actual time period required until all used nuclear fuel is 'in place' varies across facilities for the Storage at Nuclear Reactor Sites approach and ranges from year 18 to year 54 across the seven nuclear reactor site facilities. In Section 8 for Storage at Nuclear Reactor Sites, the cumulative costs for used nuclear fuel 'in place' specific to each of the seven facilities was summed and used as input to the Economic Impact Model ($4.9 billion, 2002 dollars, not discounted).

[66] For the three approaches, all used nuclear fuel is 'in place' by year 59. The actual time period required until all used nuclear fuel is 'in place' varies between approaches (up to year 59) and within the Storage at Nuclear Reactor Sites approach (from year 18 to year 54 across the seven nuclear reactor site facilities).

The results show significant differences in total cost between the three approaches, and show that Deep Geological Disposal in the Canadian Shield has higher upfront costs but significantly lower subsequent costs over the remainder of the 10,000 year period of analysis.

Table 7.4-6 provides an additional breakdown of the costs, including the costs for the project stages. The estimated value of the Trust Funds at the end of 2005 is also provided. The table shows significant differences in costs over these stages across time periods:

- <u>1 to 30 years</u>, corresponding to the approximate time when current nuclear power stations in Canada will reach the end of their approximate 40 year design life;
- <u>31 to 175 years,</u> up to seven generations;
- <u>176 to 1,000 years,</u> up to the time including the repackaging of the used nuclear fuel and rebuilding of the Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites facilities over three cycles; and
- <u>1,001 to 10,000 years,</u> up to the maximum time period for this comparative assessment of the management approaches.

Table 7.4-6: Total Costs of Management Approaches Across Specific Time Periods, by Common Project Stage

	MANAGEMENT APPROACH			
Time Period	Deep Geological Disposal in the Cdn. Shield [1]	Centralized Storage (above ground)	Centralized Storage (below ground))	Storage at Nuclear Reactor Sites (All Sites)
COSTS (2002) $1,000				
1 to 30 years				
Interim Storage & Retrieval	$932,212	$1,154,619	$1,011,186	$839,212
Representative Transportation	$670,275	$670,275	$670,275	$0
Siting/Approval, Design and Construction, Initial Operations	$4,100,616	$2,079,513	$1,757,015	$3,584,800
31 to 175 years				
Interim Storage & Retrieval	$1,447,788	$809,381	$621,814	$464,793
Representative Transportation	$481,217	$481,217	$481,217	$0
Siting/Approval, Design and Construction, Initial Operations	$8,576,371	$5,788,675	$4,875,892	$8,015,514
176 to 1,000 years	$82,500	$36,009,767	$31,188,557	$55,468,125
1,001 to 10,000 years	$900,000	$396,472,115	$344,077,701	$605,847,862
Total Projected in Trust at end of 2005 ($1,000)	$899,000	$899,000	$899,000	$899,000

[1] Deep Geological Disposal in the Canadian Shield, post-closure – $100,000 per year allowed for institutional effort (i.e., record keeping only)

The results highlight differences over the longer term between Deep Geological Disposal in the Canadian Shield and the other storage management approaches, in that:

- Deep Geological Disposal requires about $100 million between year 176 and year 1,000 compared with $32 to $36 billion for Centralized Storage (below and above ground, respectively) and $55 billion for Storage at Nuclear Reactor Sites; and
- Deep Geological Disposal requires about $1 Billion between year 1,001 and year 10,000 compared with $344-$396 billion for Centralized Storage (below and above ground, respectively) and over $600 billion for Storage at Nuclear Reactor Sites.

7.4.4 Present Value of Annual Costs

The costs provided in Tables 7.4-1 through 7.4-6 are based on annual cash flow (cost) estimates in constant (2002) dollars over time. These costs are provided for comparative purposes and allow an analysis of the differences between approaches by identifying the costs required in the near and long term and over different project stages.

Present value cost is another method often used to compare the total costs of different approaches and is utilized for financial planning purposes.

The Joint Waste Owners estimated the present value cost of the three approaches for one operational cycle (refer to Table 7.4-2, ranges from 55 to 347 years), whereas the cost estimates (non discounted) shown above are over the four common project stages and over several time periods. The present value and non-discounted methods of assessing costs are different, but both useful and commonly used.

The Joint Waste Owners present value cost estimates[67] for Deep Geological Disposal, Centralized Storage (above / below ground), and Storage at Nuclear Reactor Sites (new above ground technology), including interim storage and retrieval costs[68] and transportation costs, are $6.2 billion, $3.4 to 3.8 Billion, and $4.4 billion, respectively (January 2004 dollars) - for the 3.7 million fuel bundle scenario. These present value estimates show that, even though Storage at Nuclear Reactor Sites has the greatest costs into the future, the majority of these costs are in the long term, such that the present value of these future costs is relatively small. This is in contrast to Deep Geological Disposal, which has the largest near-term costs and thus the highest present value cost estimate.

7.4.5 Contingency Costs

As shown in Table 7.4-7, a contingency amount was added to the cost for every project stage, with the exception of interim storage and retrieval, for which no information on contingency was available. The contingency amounts are significant and are in the order of 20% for cost per project stage, with the exception of the transportation stage that includes approximately 13% contingency.

As noted by others[69], even though the level of project detail is conceptual for the management approaches, with the added contingencies, the cost estimate accuracy is plus or minus 33 %, which is typical of cost estimates prepared using conceptual design information. It was also noted that the estimates are Class 3 or 4 with respect to American Association of Civil Engineers Recommended Practice No. 1712-97, “Cost Estimate Classification System”, implying that the range of costs could, in fact, be as large as -30% to +40% relative to estimated values.

The contingency costs that have been added to each project stage are related to possible changes in work scope for the conceptual designs that have been prepared. They are not related to other potential changes in the project scope such as changes in the final design of the management approaches or due to delays in project schedule, etc. As the implementation of a long-term

[67] Refer to Overview Reports in Table 2.1-1 (see Appendix A)
[68] Financial liabilities to be funded through the Nuclear Fuel Waste Act Trusts do not include Interim Storage and Retrieval Costs. While these costs add to the total liability of the Joint Waste Owners, and possibly impact their future capacity to borrow money, they are not an element of the cost estimate database or the responsibility of the NWMO.
[69] ADH Technologies Inc. & Charles River Associates Inc., V*alidation of Cost Estimating Process for Long-Term Management of Used Nuclear Fuel*, prepared for the Nuclear Waste Management Organization, April 2004.

management approach for used nuclear fuel in Canada is still in a planning phase, it is likely that in the future, the project scope will change and with it the estimated costs and related contingency cost requirements.

Table 7.4-7: Contingency Costs Across Project Stages for Each Management Approach

Time Period	MANAGEMENT APPROACH							
	Deep Geological Disposal in the Cdn. Shield [1]		Centralized Storage (above ground)		Centralized Storage (below ground)		Reactor Extended Storage (All Sites)	
	Amount	% of Cost	Amount	% of Cost	Amount	% of Cost	Amount	% of Cost
COSTS (2002) $1,000								
Interim Storage and Retrieval	not available		not available		not available		not available	
Representative Transportation	$153,839	13%	$153,839	13%	$153,839	13%	$0	
Siting/Approval, Design & Construction, Initial Operations	$1,953,481	19%	$697,990	21%	$472,036	18%	$1,118,486	21%
Monitor, Operate and Rebuild (one cycle)	$560,434	22%	$2,485,547	29%	$1,804,520	16%	$3,547,511	20%

[1] Deep Geological Disposal in the Canadian Shield, post-closure – $100,000 per year allowed for institutional effort

7.4.6 Consideration of Issues Related to the Certainty of Cost Estimates

An approach with a more certain cost estimate should provide higher confidence that a funding shortfall would not occur. It stands to reason that cost estimates are more uncertain the farther into the future they are projected.

The conceptual designs and related cost estimates have been reviewed by independent third parties[70] and found to be sufficient for NWMO's objectives. Specifically, the review of cost estimates included a professional opinion that "the accuracy of these estimates is assessed as within the range of plus and minus 33% including all the contingency allowances…[T]hese estimates are considered suitable for their purpose in assessing the magnitude of the cost of the scenarios and their alternatives…". It was also noted that the estimates are Class 3 or 4 with respect to American Association of Civil Engineers Recommended Practice No. 1712-97, "Cost Estimate Classification System", implying that the range of costs could, in fact, be as large as -30% to +40%, relative to estimated values.

[70] ADH Technologies Inc., *Review of Conceptual Engineering Designs for Used Nuclear Fuel Management in Canada*. Prepared for the Nuclear Waste Management Organization, June 2004; ADH Technologies Inc. and Charles River Associates, *Validation of Cost Estimating Process for Long-Term Management of Used Nuclear Fuel*, prepared for the Nuclear Waste Management Organization, April 2004.

The current study's review of the cost estimates and the details of estimated costs for siting/licensing, construction and initial operation of the facilities confirm the conclusion that the estimates are well thought-out and provided to an appropriate level of detail for the purpose of a comparison of alternatives.

However, during final design, siting, environmental assessment and licensing, modifications to the design or schedule could result in significant cost increases. For example, the licensing and approval process, add-ons, more restrictive standards and other possibilities unforeseeable to the designers can easily lead to costs in excess of original estimates and the allowable contingencies.

Long-term management costs for the approaches (i.e., costs out to hundreds and thousands of years) are also based on current technology costs and assumptions as to frequency of events (e.g., repackaging). Such costs should be considered order-of-magnitude only - even assuming future generations choose to continue long-term storage using essentially 20th century technology.

It is not reasonable to assume that the financial markets of today will continue unchanged for the lifetime of the management approaches. Thus, elements related to interest rates, bond markets, financial institutions, and the ability to borrow are likely to change in the long term. However, it is reasonable to expect that the financial markets will likely remain intact in the near term, including the time period to put the used nuclear fuel in place in a facility for each of the three management approaches (i.e., up to 59 years).

Although existing cost estimates appear appropriate and reasonable, they should be taken as general indications of possible costs, and not as highly accurate forecasts, at least not beyond the near term.

With respect to the time-dependence of cost estimate certainty, Deep Geological Disposal has the most certain estimates as the vast majority of costs would be incurred in the near term. Thus, Deep Geological Disposal should provide a higher confidence that funding shortfalls will not occur that would threaten the assured continuation of necessary operations compared with the other approaches.

7.4.7 Qualitative Considerations

The following measures are discussed qualitatively below:

Related to *Expected Cost* (see NWMO, *Understanding the Choices*, pg. 69)

- Civil Penalties

There is a risk of financial penalties being imposed as a result of off-normal or accident event(s) during operation and maintenance of a used nuclear fuel management facility. For all three management approaches across all illustrative ERs, best management practices will be implemented to limit the potential for effect on the environment and worker and public health and safety. There is no factual way to predict the likelihood of such events or to predict the value of related civil penalties. No specific cost allowance for civil penalties has been included in the cost estimates for any of the three management approaches. Such costs could be substantial.

Related to *Financial Resources* (see NWMO, *Understanding the Choices*, pg. 69)

- Potential for major financial recession
- Financial Surety – ROI, Stability/competence of institutions, Guaranteed funding percent, Continued utility revenue generation

In the future, there is risk of major economic recessions and/or that the stability and competence of societal institutions may change. Such events would have minimal effect on Deep Geological Disposal in the Canadian Shield post closure (i.e., post year 154), as minimal financial resources and institutional involvement will be required in the long term. On the other hand, such events could have a significant effect on the long-term viability of Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites, due to the requirement for significant financial resources and related institutional support for continued operation and rebuilding of infrastructure with these approaches. There is no clear difference in likelihood or severity anticipated across the different illustrative ERs.

Regarding Financial Surety, the factors noted above have application to all three management approaches across all ERs and only Deep Geological Disposal in the Canadian Shield requires most of its financial resources up front, relative to the other two approaches. These long time frames raise a series of issues that place the financial surety at some risk. These risks include the following:

1. The Joint Waste Owners may not be generating any revenues from nuclear power after the next 30 or so years. This means that the financial obligation to pay for the long-term management of used nuclear fuel may place financial burden on these utilities or future government institutions. The consequences of this may, in turn, lead to:
    - Losses in bond ratings that increase borrowing costs and hence lower profitability.
    - Ultimate financial collapse of the utility(ies) leading to insolvency. In this case, one can not be certain if the new owner(s) will assume the financial obligation for the management of used nuclear fuel.
2. Over the long term, one can expect that many of the social and economic forces of today will change, including but not necessarily limited to the following:
    - ***The governance of the Joint Waste Owners utilities and/or their associated governments:***

i. What will the future of government(s) be in 100 years let alone 1,000 years?

ii. How will the controls in the form of laws and social order that are in place today look in the future?

iii. Will the jurisdictions of municipalities, regions, provinces and Canada remain the same over such long time periods?

- ***Technology is in a continual state of evolution***. The current cost estimates are based on known or proven technologies of today, which may become unfounded with the passage of time. One can be sure that this will result in a dramatic cost change. For example:

  i. Our ability to monitor environmental risks may become so advanced that we will discover the need to address environmental risks currently not considered, thus adding new costs to the management of used nuclear fuel.

  ii. On the other hand, we may develop the ability to utilize used nuclear fuel as an input to other processes, thus making the used nuclear fuel an asset, not a liability.

- ***Social values will change over time***. Just consider the rapid and dramatic changes in social values over past 100 years to put this into perspective. How we value the "natural environment", for example, will likely change. This means the safety, environmental and security risks that we consider today as "acceptable" may become unacceptable in the future. In this scenario, used nuclear fuel may need to be retrieved and management differently. If so, additional financial resources may be needed for this "change in management" that are not currently accounted for in the cost estimates.

In all these cases, financial surety considerations of today become meaningless in the future. If one is only concerned about the ability to marshal the necessary financial resources to complete the management of used nuclear fuel, then this suggests a focus on Deep Geological Disposal in the Canadian Shield. This management approach places used nuclear fuel in a "final" state with relatively little financial requirements over the very long –term, compared with Centralized Storage (above or below ground) or Storage at Nuclear Reactor Sites. This means that the burden of financial surety is placed mostly in the hands of the current generation.

However, should some of the other social and/or technology issues arise, then future generations may be burdened with the used nuclear fuel legacy to an even greater extent.

Related to *Cost Uncertainty* (see NWMO, *Understanding the Choices*, pg. 69)

- Sensitivity/potential for extreme events
- Unanticipated Delays

There is a risk of changes in cost due to extreme events that may occur as a result of climate change or due to unanticipated delays caused by social, political or technical changes during the implementation of a management approach. For example, if there is social protest against the transportation of used nuclear fuel to a management facility, this could delay the implementation of the selected approach and impact costs in a material way.

There is no factual way to predict the likelihood of such events or to predict the cost impact of such events. No specific cost allowance for extreme events or for such things as unanticipated delays has been included in the cost estimates for any of the three management approaches. It may be prudent to add an allowance(s) to account for costs related to such unforeseen events. It is not possible at this point in time to reasonably estimate the cost.

7.5 Summary of Economic Viability Analysis – A Comparison of Management Approaches

This objective relates to the need to ensure that adequate economic resources are available, now and in the future, to pay all the costs of the selected approach. The selected approach should provide high confidence that funding shortfalls will not occur that would threaten the assured continuation of necessary operations.

Measures were developed to allow an assessment of the benefits, risks and costs of each of the three approaches. The specific measures used in the assessment of economic viability are based on quantitative costing information developed by the Joint Waste Owners, and based on quantitative information in the literature or capable of being estimated within the timeframe available for the assessment. Their selection and evaluation builds on the approach used by the Assessment Team and by GAL/GLL in similar studies. Economic benefits related to the implementation of the three approaches (i.e., employment, income, and taxes) are described under *Community Well Being,* Community Economic Health (Section 8.0). It is assumed that all the necessary financial resources would be available to allow implementation of any of the three approaches, although there may be differences between approaches in both the cost and funding required.

For economic viability, the primary considerations for the analysis included:

- **Costs over time (present value and non-discounted)**: It is assumed that an approach with a smaller present value cost is preferred from a financial planning perspective. It is also assumed that an approach with a greater portion of its costs in the near term would have a more certain cost estimate than for an approach with a greater portion of costs in the long term. The Joint Waste Owners’ cost estimates, by nature and necessity, are based on current technology costs and are order-of-magnitude only for costs to be incurred beyond the near term.

- **Incremental Transportation Cost:** It is assumed that transportation of used nuclear fuel to a facility farther from the current location of the majority of the used nuclear fuel (i.e., southern Ontario) would have higher costs.

- **Certainty of Cost Estimates:** An approach with a more certain cost estimate should provide higher confidence that a funding shortfall would not occur. Cost estimates are more uncertain the farther into the future they are projected.

Joint Waste Owners' estimated total costs for the approaches at a conceptual design level were validated by others as "suitable for their purpose of assessing the magnitude of the costs of alternative management methods" [71]. The magnitude and timing of these costs in the near term and long term as well as the present value of these costs are important considerations in the analysis of economic viability.

For Deep Geological Disposal in the Canadian Shield and for the Centralized Storage (above or below ground), incremental transportation costs (by road) were estimated based on a total distance estimate for the transport of all used nuclear fuel to each illustrative ER.

A summary of the economic viability analysis for the three management approaches in terms of their benefits, risks and costs is presented below and detailed in Table 7.5-1.

Benefits

The economic benefits related to the implementation of the management approaches are discussed under *Community Well Being,* Community Economic Health (Section 8.0).

The cost estimates for all three management approaches are reasonable, provided the design that is implemented is similar to that costed. Differences in total cost, expenditure scheduling and cost uncertainty exist, but are within reasonable bounds at the conceptual design stage, and reflect differences in philosophy. No one approach is superior in all respects. All three approaches represent well thought-out concepts for managing used nuclear fuel safely compared with cost estimates in other jurisdictions. With the exception of transportation costs, economic viability is independent of the ERs in which an approach would be implemented.

Risks

Cost estimates are more uncertain the farther into the future they are projected. Similarly, reasonable surety is more difficult to assess for dates farther ahead in time. With respect to the time-dependence of estimate certainty and the provision of surety, Deep Geological Disposal has the most certain estimates as the vast majority of costs would be incurred in the near term. It is

[71] ADH Technologies Inc. & Charles River Associates Inc., *Validation of Cost Estimating Process for Long-Term Management of Used Nuclear Fuel*, prepared for the Nuclear Waste Management Organization, April 2004.

also the easiest to develop surety for, as major activity ceases with facility close-out in year 154. The need for major rebuilding operations on a regular basis in perpetuity undermines the current generation's ability to estimate costs and provide surety with respect to Centralized Storage and Storage at Nuclear Reactor Sites.

Thus, Deep Geological Disposal should provide a higher confidence that funding shortfalls will not occur that would threaten the assured continuation of necessary operations, compared with the other approaches.

Contingency allowances included in the cost estimates are comparable, as a percentage of cost estimates across the four common project stages, for the three approaches, as all approaches have been subject to similar levels of conceptual design and cost estimation.

Costs

Economic viability was assessed using non-discounted cash flows (costs) and present value costs. Using non-discounted cash flows for cost comparisons between the three approaches is helpful in outlining the timing of the future costs. Utilizing present value costs of each approach for comparison purposes is also an accepted practice and is utilized for financial planning.

The present value cost estimates for Deep Geological Disposal, Centralized Storage (above and below ground), and Storage at Nuclear Reactor Sites (new above ground technology) as per Joint Waste Owners' estimates are $6.2 billion, $3.4 to 3.8 billion, and $4.4 billion, respectively (January 2004 dollars) - for the 3.7 million fuel bundle scenario.

Deep Geological Disposal has the lowest total single operational cycle (non-discounted) cost (approximately $16.2 billion, spanning to year 154 when the facility is closed). The Storage at Nuclear Reactor Sites approach has the highest non-discounted cost over one operational cycle ($2.42 billion, spanning between year 55 and 320 across the seven current reactor sites). However, Storage at Nuclear Reactor Sites and Centralized Storage have many operational cycles and significantly higher life cycle costs (non-discounted). For example, Deep Geological Disposal has the lowest costs over 10,000 years ($13.7 billion for non-discounted facility costs), as it is decommissioned after one operational 'cycle'. Centralized Storage and Storage at Nuclear Reactor Sites are rebuilt at regular cycles and have significantly higher costs (non-discounted) over 10,000 years.

Deep Geological Disposal and Centralized Storage approaches have transportation costs in the order of $1.2 billion (non-discounted). Site location can significantly affect this cost. Storage at Nuclear Reactor Sites does not have such a transportation component.

Table 7.5-1: Summary of Economic Viability Analysis – A Comparison of Management Approaches: Benefits, Risks and Costs

Measure or Indicator	Benefits	Risks	Costs
Total Costs for Each of the Project Stages (Four stages: Interim Storage and Retrieval; Representative Transportation; Siting/Approval, Design & Construction, Initial Operations (i.e., all used nuclear fuel in place inside the facility(ies)); and Monitor, Operate, and Rebuild (i.e., One Cycle)	• The economic benefits related to the implementation of the management approaches are discussed in Section 8 under Community Economic Health. • The cost estimates for all three management approaches are reasonable, provided the design that is implemented is similar to that costed. Differences in total cost, expenditure scheduling and cost uncertainty exist, but are within reasonable bounds at the conceptual design stage and reflect differences in philosophy. No one approach is superior in all respects. All three approaches represent well thought-out concepts for managing used nuclear fuel safely compared with cost estimates in other jurisdictions. With the exception of transportation costs, economic viability is independent of the ERs in which an approach would be implemented.	• Risks are presented below, under the measures: Contingency Costs Across Project Stages; Consideration of Issues Related to Certainty of Cost Estimates; and Qualitative Discussion of Other Measures	• There is a significant difference in cost between approaches for different project stages: • Deep Geological Disposal in the Canadian Shield has the highest cost for the Interim Storage and Retrieval stage[72] ($2.4 billion – year 2002 dollars, not discounted) and Storage at Nuclear Reactor Sites has the lowest ($1.3 billion – year 2002 dollars, not discounted) – this stage occurs up to year 59. • Deep Geological Disposal in the Canadian Shield has the highest cost for the Siting/Approval, Design & Construction, Initial Operations stage ($10.1 billion – year 2002 dollars, not discounted) and Centralized Storage (below ground) has the lowest ($2.6 billion – year 2002 dollars, not discounted) – this stage occurs up to year 59. • Storage at Nuclear Reactor Sites has the highest cost for the Monitor, Operate and Rebuild (One Cycle) stage ($17.6 billion – year 2002 dollars, not discounted) and Deep Geological Disposal in the Canadian Shield has the lowest ($2.6 billion – year 2002 dollars, not discounted) – this stage occurs up to year 154 for Deep Geological Disposal in the Canadian Shield and up to year 347 for the other approaches. • The results highlight broad differences in costs between the approaches over the project stages and show that Deep Geological Disposal in the Canadian Shield has higher upfront costs but lower subsequent costs than the other two approaches.

[72] Financial liabilities to be funded through the Nuclear Fuel Waste Act Trusts do not include Interim Storage and Retrieval Costs. While these costs add to the total liability of the Joint Waste Owners, and possibly impact their future capacity to borrow money, they are not an element of the cost estimate database or the responsibility of the NWMO.

Table 7.5-1: Summary of Economic Viability Analysis – A Comparison of Management Approaches: Benefits, Risks and Costs

Measure or Indicator	Benefits	Risks	Costs
Transportation Cost (Incremental transportation cost over and above the representative transportation costs)	• There is no transportation costs associated with Storage at Nuclear Reactor Sites. A representative transportation cost for the other two approaches is in the range of $1.2 billion (2002 dollars, not discounted).	• Risks are presented below, under the measures: Contingency Costs Across Project Stages; Consideration of Issues Related to Certainty of Cost Estimates; and Qualitative Discussion of Other Measures.	• The incremental transportation costs for Deep Geological Disposal in the Canadian Shield or Centralized Storage (above or below ground) have a similar range and vary across economic regions by up to $900 million (2002 dollars, not discounted). Incremental transportation costs are greater for economic regions located longer distances from the majority of the used nuclear fuel (i.e., southern Ontario). • For both Deep Geological Disposal in the Canadian Shield and Centralized Storage (above or below ground) management approaches across the illustrative ERs, the incremental transportation costs are potentially significant compared with the cost of the management approaches in the near term. Specifically, for Deep Geological Disposal in the Canadian Shield, the incremental transportation cost for all illustrative ERs would range from a marginal decrease to an increase of up to 6% of the total cost in the near term, and for Centralized Storage (above or below ground), the incremental transportation cost for all illustrative ERs would range from a marginal decrease to an increase of up to 14% of the total cost in the near term.

Table 7.5-1: Summary of Economic Viability Analysis – A Comparison of Management Approaches: Benefits, Risks and Costs

Measure or Indicator	Benefits	Risks	Costs
Costs Over Time (considered on an annual and cumulative basis over a 10,000 year period)	• Deep Geological Disposal in the Canadian Shield has the majority of costs in the early years, but has a much lower total cost over the 10,000 year assessment period compared with Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites that have costs far into the future. These costs are illustrated on Figure 7.4-1 through 7.4-4 (to year 1,000).	• Risks are presented below, under the measures: Contingency Costs Across Project Stages; Consideration of Issues Related to Certainty of Cost Estimates; and Qualitative Discussion of Other Measures.	• Deep Geological Disposal in the Canadian Shield has the highest short-term cumulative cost[73] ($10.1 billion – year 2002 dollars, not discounted) up to year 59, when all facilities (for all three approaches) are filled with used nuclear fuel, while Centralized Storage (below ground) has the lowest cumulative cost ($2.8 billion – year 2002 dollars, not discounted) for the same period. • Storage at Nuclear Reactor Sites has the highest cumulative cost ($67 billion – year 2002 dollars, not discounted) up to year 1,000 (i.e., the "long-term" period selected for this study – see Section 2.5.1), while Deep Geological Disposal in the Canadian Shield has the lowest cumulative cost ($12.8 billion – year 2002 dollars, not discounted) over the same period. • Storage at Nuclear Reactor Sites has the highest cumulative cost ($673 billion – year 2002 dollars, not discounted) up to year 10,000, while Deep Geological Disposal in the Canadian Shield has the lowest cumulative cost ($13.7 billion – year 2002 dollars, not discounted) over the same period. • The present value cost estimates for Deep Geological Disposal, Centralized Storage (above / below ground), and Storage at Nuclear Reactor Sites (new above ground technology) as per Joint Waste Owners' estimates are $6.2 billion, $3.4 to 3.8 billion, and $4.4 billion, respectively (January 2004 dollars) - for the 3.7 million fuel bundle scenario. • The results highlight significant differences in cumulative costs between the approaches over time and show that Deep Geological Disposal in the Canadian Shield has higher cumulative costs in the near term, but lower cumulative costs in the long term compared with the other two approaches.

[73] The cumulative costs do not include Interim Storage and Retrieval or Representative Transportation.

Table 7.5-1: Summary of Economic Viability Analysis – A Comparison of Management Approaches: Benefits, Risks and Costs

Measure or Indicator	Benefits	Risks	Costs
Contingency Costs Across Project Stages (Cost estimates include contingency)	**RISKS** • For all three approaches, near-term costs have accounted for some variability by including contingency in the cost estimates for every project stage, with the exception of interim storage and retrieval, for which no information on contingency was available. The contingency amounts are significant and are on the order of 20% for cost per project stage, with the exception of the transportation stage that includes approximately 13% contingency. As noted by others[74], even though the level of project detail is conceptual for the three management approaches, with the added contingencies, the cost estimate accuracy is plus or minus 33 %, which is typical of cost estimates prepared using conceptual design information. • The contingency costs that have been added to each project stage for all three approaches are related to possible changes in work scope for the conceptual designs that have been prepared. They are not related to other potential changes in the project scope, such as changes in the final design of the management approaches or due to delays in project schedule. In addition, certain items are not typically considered in conceptual designs, such as costs for institutional strengthening within communities that may be affected by implementation of management approaches. As the implementation of a long-term management approach for used nuclear fuel in Canada is still in a planning phase, it is likely that in the future, the project scope will change and with it the estimated costs and related contingency cost requirements.		
Consideration of Issues Related to Certainty of Cost Estimates	• Cost estimates are more uncertain the farther into the future they are projected. Similarly, reasonable surety is more difficult to assess for dates farther ahead in time. With respect to the time-dependence of estimate certainty and the provision of surety, Deep Geological Disposal in the Canadian Shield has the most certain estimates as the vast majority of costs would be incurred in the near term. It is also the easiest to develop surety for, as major activity ceases with facility close-out in year 154. The need for major rebuilding operations on a regular basis in perpetuity undermines the current generation's ability to estimate costs and provide surety with respect to Centralized Storage and Storage at Nuclear Reactor Sites. • Thus, Deep Geological Disposal in the Canadian Shield should provide a higher confidence that funding shortfalls will not occur that would threaten the assured continuation of necessary operations compared with the other approaches.	• During final design, siting, environmental assessment and licensing, modifications to the design or schedule could result in significant cost increases for any of the three approaches. For example, the licensing and approval process, add-ons, more restrictive standards and other possibilities unforeseeable to the designers can easily lead to costs in excess of original estimates and the allowable contingencies. • Long-term management costs for the approaches (i.e., costs out to hundreds and thousands of years and beyond) are also based on current technology costs and assumptions as to frequency of events (e.g., repackaging). Such costs should be considered order-of-magnitude only - even assuming future generations choose to continue long-term storage using essentially 20th century technology. • It is not reasonable to assume that the financial markets of today will continue unchanged for the lifetime of the management approaches. Thus, elements related to interest rates, bond markets, financial institutions, and the ability to borrow are likely to change in the long term. However, it is reasonable to expect that the financial markets will remain intact in the near term, including the time period to put the used nuclear fuel in place in a facility for any of the three approaches (i.e., 59 years). • Although existing cost estimates are well done as noted above, they should be taken as general indications of possible costs, and not as highly accurate forecasts, at least not beyond the near term.	• Not applicable for this measure

[74] ADH Technologies Inc. & Charles River Associates Inc., *Validation of Cost Estimating Process for Long-Term Management of Used Nuclear Fuel*, prepared for the Nuclear Waste Management Organization, April 2004.

Table 7.5-1: Summary of Economic Viability Analysis – A Comparison of Management Approaches: Benefits, Risks and Costs

<table>
<tr><th>Measure or Indicator</th><th>Benefits</th><th>Risks</th><th>Costs</th></tr>
<tr><td>Qualitative Discussion of Other Measures</td><td colspan="3">RISKS
• The cost estimates provided for Storage at Nuclear Reactor Sites and Centralized Storage in the long term, though useful for comparative purposes, have a higher degree of uncertainty than those for Deep Geological Disposal in the Canadian Shield because the majority of their costs occur over the long term, whereas the majority of the costs for Deep Geological Disposal in the Canadian Shield are incurred in the near term.
• Costs for Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites impose a very large liability on future generations that not only must fund the cycles of maintenance, but they must also maintain the appropriate institutions to oversee the long-term management of used nuclear fuel. Concerns regarding financial surety are well placed, because the following may change dramatically over the near term let alone the long term:
▫ The financial viability of future utilities is not guaranteed, therefore there is no guaranteed private source of revenues to pay future costs. However, the government has contingencies that ensure a responsible authority will always manage and pay for the management of used nuclear fuel, assuming that our current governance structure remains in place for the long term.
▫ One can not predict how financial markets will be structured in the long term, let alone determine how current financing instruments (such as bonds, debt financing, etc.) might be used to finance cash requirements for management of used nuclear fuel.
▫ The governance models within Canada may change over the long term – Will there be a country called Canada, or provinces that will ensure some form of continuity in management oversight? History shows there are few institutions today that are older than a thousand years. There is a high risk of loss of some management continuity.
▫ How might the priorities of used nuclear fuel be altered in the future in periods of possible social disorder or other “catastrophic” events? The severity of such events would be much lower for Deep Geological Disposal in the Canadian Shield post closure (i.e., post year 154), as minimal financial resources and institutional involvement will likely be required in the long term, compared with the other two approaches, which will require significant financial resources and related institutional support for continued operation and rebuilding of infrastructure over the long term.
▫ The known or proven technologies that provided the basis for the conceptual designs and cost estimates for the three approaches may become unfounded with the passage of time. This would result in changes to future costs. For example, our ability to monitor environmental risks may become so advanced that we will discover the need to address environmental risks currently not considered, thus adding new costs to the management of used nuclear fuel. On the other hand, we may develop the ability to utilize used nuclear fuel as an input to other processes, thus making the used nuclear fuel an asset not a liability.
▫ Social values will change over time. Just consider the rapid and dramatic changes in social values over past 100 years to put this into perspective. How we value the “natural environment” for example will likely change. This means the safety, environmental and security risks that we consider today as “acceptable” may become unacceptable in the future. In this scenario, used nuclear fuel may need to be retrieved and managed differently. If so, additional financial resources may be needed for this “change in management” that is not currently accounted for in the cost estimates.
• In all these cases, financial surety considerations of today become meaningless in the future. If one is only concerned about the ability to marshal the necessary financial resources to complete the management of used nuclear fuel, then this suggests a focus on Deep Geological Disposal in the Canadian Shield. This management approach places used nuclear fuel in a “final” state with relatively little financial requirements over the very long term, compared with Centralized Storage (above or below ground) or Storage at Nuclear Reactor Sites. This means that the burden of financial surety is placed mostly in the hands of the current generation. However, should some of the other social and/or technology issues arise, then future generations may be burdened with our used nuclear fuel legacy to an even greater extent.</td></tr>
</table>

8.0 ANALYSIS OF COMMUNITY WELL-BEING

Objective: *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*[75].

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 a used nuclear fuel management facility. Depending on the sites that eventually are proposed for consideration, Canada’s Aboriginal peoples may have a particularly significant stake and the possible impact on their values must also be considered.

The analysis of community well-being is comprised of three sections as follows:

1. Analysis of community economic health;
2. Analysis of community social quality; and
3. Analysis of Aboriginal community quality.

Each of the analyses is presented in separate subsections with their own comparative analysis and discussion in relation to the three management approaches (i.e. Deep Geological Disposal in the Canadian Shield, Centralized Storage and Storage at Nuclear Reactor Sites) and the eleven illustrative economic regions.

It is important to understand that only the analysis of community economic health is conducted for each of the three used nuclear fuel management approaches with results compared across economic regions. The analysis for both community social quality and Aboriginal community quality is independent of the management approach. It focuses on a comparison of how populations within the illustrative economic regions are equipped to adapt to the economic and social changes that are linked to any of the used nuclear fuel management approaches.

[75] Nuclear Waste Management Organization, *Understanding the Choices – The Future Management of Canada’s Used Nuclear Fuel*, September 2004, page 62.

8.1 Goals of the Community Well-Being Analysis

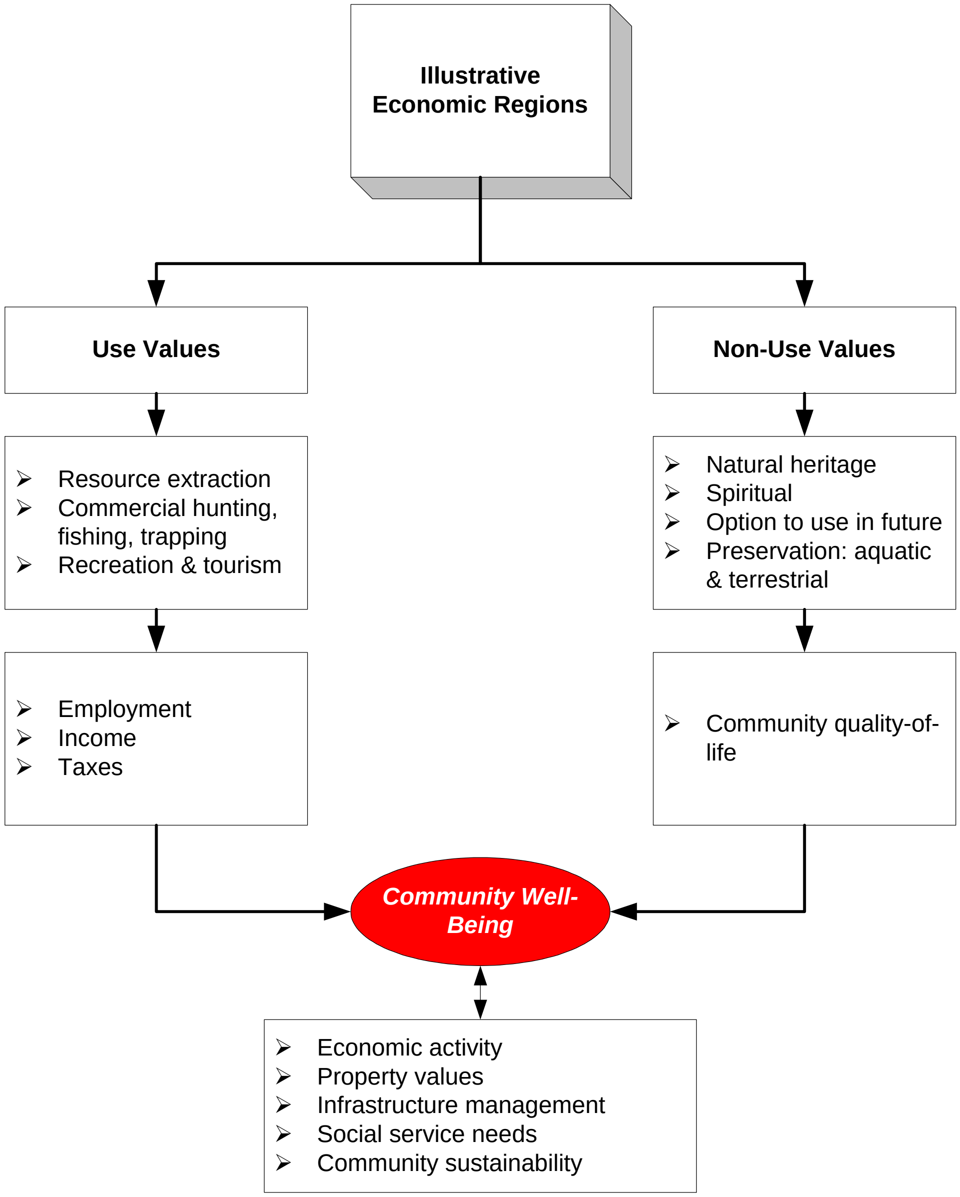
The goals of the analysis of community well-being were to:

1. Determine the expected economic impact on each illustrative economic region resulting from the possible introduction of any of the three used nuclear fuel management approaches;
2. Determine the community social quality implications from the introduction of the three used nuclear fuel management approaches;
3. Assess the economic and social impact with respect to the magnitude and timing of above impacts; and
4. Discuss the uncertainties and key issues of the economic and social impacts for each of the three used nuclear fuel management approaches.

To properly address each of these goals, it is necessary to identify specific influencing factors and measures that help to illustrate the nature and scope of impacts. In this regard, there are many influencing factors and measures that can be used. Some of these have been considered by the Assessment Team.[76] This report starts from the premise that the influencing factors and measures identified by the Assessment Team for Community Well-being are reasonable and representative of the very large range of possible factors.

It is understood that each illustrative economic region possesses many values important to local communities, which can be categorized into "use" and "non-use" values as illustrated in the Figure below. Use values, such as resource extraction, tourism, recreation, and the possible development of a used nuclear fuel management facility will lead to "spin-off" economic benefits. Equally important, non-use values such as natural heritage, spiritual values, and biological preservation offer benefit to local, regional, provincial and national stakeholders, who might feel impacted by the presence of a used nuclear fuel management facility in a particular location.

[76] Nuclear Waste Management Organization, *Understanding the Choices – The Future Management of Canada's Used Nuclear Fue*l, September 2004, page 63.



The challenge for this study team was to incorporate the many diverse factors identified by the Assessment Team, while recognizing that many of these factors are constrained by data availability that would enable a meaningful analysis. For example, the Assessment Team rightly identified changes in "real estate values" as an important impact consideration. However, it is understood that real estate values are affected by a wide range of factors (e.g., population dynamics, economic trends, social preferences, etc.) as well as proximity to a possible used nuclear fuel management facility during and after construction. The time required to accurately measure and "filter" the potential real estate value impact from a possible used nuclear fuel management facility, apart from all other influencing factors was beyond this study scope. While recognizing the importance of this and some other factors, effort has been made to discuss the possible impact from a qualitative perspective.

Other influencing factors identified by the Assessment Team are more easily measured because of the availability of appropriate data. This study team conducted two internal workshop sessions to map out the Assessment Team's influencing factors for Community Well-being against data availability to enable quantitative analysis, and to identify which factors can be incorporated into a qualitative discussion. Equally important, these workshop sessions helped to group the Assessment Team's factors into similar impact categories, thus ensuring that if one factor in this group was selected for quantitative analysis it would provide a proxy for others.

The tight time constraints imposed on this study precluded any original research to develop an appropriate database for any of the influencing factors. More important, this study was restricted to a level of analysis no smaller than that of an economic region. As such, certain factors (like real estate values) could not be examined in any detail without reference to a specific community or site location.

In general, for Community Well-being, this study was able to quantitatively measure 16 of the 31 influencing factors identified by the Assessment Team. The remaining factors were addressed in qualitative discussion, where appropriate at various points in this section.

8.2 Influencing Factors and Measures Used in the Analysis of Community Well-Being

The measures and indicators used to quantify some of the values identified above are presented in Table 8.2-1. These measures and indicators have the following characteristics:

- They are commonly used measures for assessing economic and social impact on communities and regions linked to a major project;
- They are consistent with the measures and indicators considered and developed by the Assessment Team;
- They are measures that can be quantified with existing data compiled from Statistics Canada; and
- Results of analyses using these measures can easily be used to compare relative differences between economic regions and management approaches.

Some measures are based on quantitative information available in the literature or capable of being estimated within the timeframe available for the assessment. Their selection and evaluation builds on the approach used by GAL/GLL in similar studies and includes four principal assumptions:

- All economic regions have a unique mix of people, communities, economic base, and capabilities, worthy of detailed examination;
- Relative differences in potential economic and social impact between economic regions in the near and long terms are more important to highlight than the "absolute" measures for each;
- For those measures or indicators identified by the Assessment Team that do not have tangible means to quantify them, they should be highlighted and discussed based on past experience of GAL/GLL and published information sources; and
- In the case of community quality, it is valuable to identify relative areas of strength and weakness in being able to manage the opportunities and challenges posed by the implementation of either of the management approaches.

Table 8.2-1: Influencing Factors Considered in the Assessment of Community Well-Being

Influencing Factors used in Preliminary Comparative Assessment	Influencing Factors used in this Assessment	Measures used in this Assessment
Community Economic Health	Community Economic Health	Using a customized Input/Output model the following indicators of community economic health were measured: • Employment • Income • Taxes
Community Social/Cultural Quality Effect on Impacted Community Social Quality	Community Social Quality Effect on Impacted Community Social Quality	Using the sustainable livelihoods framework, the following indicators of community social quality were measured: Non-Aboriginal Communities • Social Capital: – Population – Population density – Labour force composition – Mobility (inter, intra, and external)

Influencing Factors used in Preliminary Comparative Assessment	Influencing Factors used in this Assessment	Measures used in this Assessment
		• Human Capital: – Educational achievement – Labour force – Unemployment – Life stress – self-identified – Dependency ratio – Number of health practitioners – Number of health specialists – Self-rated health – Life expectancy – Infant mortality – Asthma readmission rates – Nutrition status • Financial Capital: – Income level – Incidence of low income – Labour force – Tenant households spending more than 30% of income on gross rent – Owner households spending greater that 30% of income on mortgage and upkeep – Number of occupied private dwellings • Physical Capital: – Number of dwellings that require major repair Use of public transportation
		Aboriginal Communities • Human Capital: – Percentage of the experienced labour force working in the health sector, social sciences, education, government service and religion – Educational achievement which was measured as the percentage of the population aged 20-34 with a high school graduation certificate and/or some postsecondary – Unemployment • Financial Capital: – Percent of population that own a primary dwelling – Median total income of persons aged 15 and older – Percent of labour force working in the business, finance and administration sectors • Physical Capital: – Percent of labour force using public transportation – Number of Community Access (Internet) program sites – Number of SchoolNet sites Another indicator used for developing the profiles for aboriginal communities is the Community Well-being index (CWB), which is based on four indicators (education, income, housing and labour force activity).

The following influencing factors were discussed in this study qualitatively, where appropriate and feasible:

- *Effect on Impacted Community Social Quality:*
  - Impact on community infrastructure services
  - Polarization
  - Preservation of open, undeveloped, green space
    - Development growth rate
  - Long-term stability
  - Proximity to facility/operations

- *Public Perception, Fears and Attitude:*
  - Freedoms
  - Privacy

- *Number, Size, Nature of Communities Impacted:*
  - Host communities
    - Existing vs. new
    - Number

- *Effect on Impacted Community Economic Health:*
  - Real estate values
  - Risks of property damage/contamination
  - Other private/public property values

8.3 Methods and Details of Community Well-Being Analysis

This section outlines the methods and assumptions for the economic modelling, used to determine community health, and the sustainable livelihoods framework used to determine community social quality and Aboriginal community social quality. It does not address where and how qualitative discussions regarding the other influencing factors were handled.

8.3.1 Method for Measuring Community Economic Health

Our process for assessing the economic impact of each management approach for used nuclear fuel involves the use of Input/Output modelling. This modelling approach is similar to that employed by various government ministries across Canada, such as the Ontario Ministry of Natural Resources, when investigating the economic impact of proposed ventures such as this. An Input/Output (I/O) model is a complex tool that essentially simulates the working economy.

One can develop a “high level” I/O model for the entire Canadian economy, but this means one can not assess impact differences between regions with accuracy. Yet if one attempts to develop an I/O model of an individual community, it becomes very difficult because of data constraints.

Working with Econometric Research Limited[77], the study team developed an I/O model for each of the eleven illustrative economic regions, the six host provinces, and one national I/O model. Together, these 18 unique models were used to develop economic impact results at three levels: National, Provincial, and Economic Region. Moreover, each of these models was simulated with three “shocks”, namely: the investment expenditure for each of the three used nuclear fuel management approaches described in previous sections of this report.

These 18 models enabled the study team to determine the distribution of economic impact. Specifically, employment, income and tax generation opportunities were developed for the economic region, their host province, and Canada as whole. These results enable one to visualize how much of the total employment, income and tax benefits “leak” out of each economic region and province.

Developing an I/O model for each the economic regions required extensive “calibration”. Statistical data regarding expenditure and production patterns in each region were synthesized from Statistics Canada and formed the basis of each I/O model. Investment expenditures for each management approach were calculated to determine the size, timing, category, and location of expenditures.

Uniqueness of the Economic Impact Model

The impact model used here is a special application of a generic model (Regional Impact Model: RIM) developed by Econometric Research Limited. The model is based on a custom technology that integrates input-output analysis and location theory. The system has been applied to a variety of programs and projects in almost every province of Canada. Examples include the Economic Impact of Tourism in Niagara Falls, the Economic Impact of West Edmonton Mall, the Economic Impact of the Frigate Program, the Economic Impact of Solid Waste Management Programs in Ontario, and the Economic Impact of Casino Gaming in British Columbia.

The model utilizes a large set of economic and technical databases that are regularly published by Statistics Canada. A short list includes the inter-provincial input-output tables, employment by sector, taxes by type of tax and level of government collecting it, prices of products, and utilities used in physical and energy units.

[77] Econometric Research Limited (ERL) is a firm located in Ontario specializing the design and implementation of Input/Output models for assessing the economic impact of development projects of this nature. The Principal of ERL is Dr. Atif Kubursi, who led the I/O model design and development for this assignment.

Terminology and Assumptions

When investments in any of the three used nuclear fuel management approaches are made on activities like excavation, construction or operation, this creates a domino effect throughout the regional, provincial and national economies. Expenditures for goods and services circulate and re-circulate within the economy, multiplying the effects of the original set of expenditures on all economic activities. This process is referred to as the economic ***multiplier effect***. It operates at several levels:

- The initial operational expenditures on wages and materials are generally referred to as the direct costs of operation and their effects are referred to as the ***initial (direct) effects***.
- Subsequent purchases by suppliers of materials and services to sustain the original and derivative expenditures are called the ***indirect effects***.
- The ***induced effects*** emerge when employees in the sectors stimulated by initial direct and indirect expenditures spend their incomes on consumer goods and services.

Economic impact analysis is a useful mathematical tool capable of quantifying the patterns and magnitudes of interdependence among sectors and activities. It is predicated on two fundamental propositions:

- First, regardless of the inherent value of primary activities such as construction or operation and maintenance, to the extent that these activities involve the use of scarce resources, they generate economic consequences that can be measured and compared.
- Second, economic impacts are only partially captured by assessing direct expenditures. In as much as the economy is a complex whole of interdependent and interacting activities, there are some significant indirect and induced impacts associated with these direct expenditures. Invariably most of the indirect and induced impacts are larger than the direct impacts.

The proposed management approaches for used nuclear fuel involve an extremely long time horizon. It is reasonable to expect that much will change throughout this time period in terms of:

- Development of new technology;
- Changing population dynamics;
- Evolution of social values;
- Shifting forms of governance models and social order; and
- Environmental changes (such as those brought about by climate change).

Given the nature and scope of this analysis, these or other likely changes were not taken into consideration in the economic model. However, these important factors were addressed in qualitative discussions regarding the benefits, risks and costs of the management approaches.

The economic impact analysis is conducted for each management approach. The focus of the analysis is directed to the cost implications for one life cycle. Specifically, after each management option has completed its initial "waste in place" phase, the time period to the end of the next complete facility rebuild is considered as one "life cycle". For example, the life cycle for Centralized Storage (either above or below ground) is 300 years.

Output of the Economic Model

Using data and output from the Economic Viability assessment (refer to Section 7), the Input-Output model generated the following three measures for two phases of each used nuclear fuel management approach:

Used Nuclear Fuel Management Approach	Used Nuclear Fuel in Place	First Cycle of Monitor, Operate and Rebuild
Deep Geological Disposal in the Canadian Shield[78]	Years 1-59	Years 60-175
Storage at Nuclear Reactor Sites	Years 1-54	Years 55-320
Centralized Storage (either above or below ground)	Years 1-47	Years 48-347

It is important to note that activities and processes for Storage at Nuclear Reactor Sites and Centralized Storage will continue cyclically for thousands of years. In an attempt to simply illustrate the magnitude and range of possible economic and social consequences from implementing either of the management approaches, only the above two implementation phases were examined in detail. However, benefit, risk and cost implications in the long term were considered and discussed for all management approaches.

8.3.2 Method for Measuring Community Social Quality

Community well-being relates to a broad range of factors as described by the Assessment Team. These factors include both qualitative and quantitative factors and measures. One of the quantitative aspects of this complex objective is the capacity of the people of each of the illustrative economic regions to adapt to the significant change (shocks) represented by the siting, design, construction and maintenance of a used nuclear fuel facility. Term ***"adaptive capacity"*** is used to capture this concept. Adaptive capacity is the ability of a person or community to adjust to change, take advantage of opportunities presented by change, and/or cope with the consequences of change.

[78] With Deep Geological Disposal in the Canadian Shield, there would be no need to rebuild the facility.

To characterize adaptive capacity, profiles of each illustrative economic region were created based on the ***Sustainable Livelihoods Framework***[79] and existing quantitative data sets. These profiles enable comparisons between economic regions to illustrate similarities and differences in terms of adaptive capacity. In addition, specific profiles for Aboriginal communities within each illustrative economic region were created to enable comparisons between Aboriginal communities to illustrate similarities and differences in terms of their adaptive capacity.

The Sustainable Livelihoods Framework presents the main factors that affect people's livelihoods in terms of "capitals": social capital, human capital, physical capital, financial capital and natural capital. In comparing economic regions, we assume that the people within an economic region have greater or lesser adaptive capacity based on the relative strength of the livelihood assets present in the economic region. Due to the lack of available data related to natural capital – existing data for which comparisons of economic regions would be possible – it was not possible to include this capital in the quantitative comparative analysis. However, this aspect of community well-being is discussed qualitatively later in this section.

It must be stressed that the Sustainable Livelihoods Framework and the comparisons of adaptive capacity are most useful in making comparison between economic regions. One should not interpret results in absolute terms (i.e., it is less accurate to say that a particular economic region scored a 2.5, than to say that the same economic region scored less than another region by 0.5, for example). The aim of the Framework and the comparisons of adaptive capacity are to help stakeholders with different perspectives to engage in debate and dialogue. It is expected that future debate and dialogue will focus on ways and means to help people become more resilient and better able to capitalize on the positive aspects of future investment in either of the management approaches and how best to deal with negative events.

In the context of siting, designing, constructing and maintaining a storage facility for used nuclear fuel – a major change by any definition - the economic region comparisons help us to:

- Identify possible ways to support people and communities in building their livelihood assets;
- Identify ways to encourage responsive support from institutions and organizations; and
- Identify avenues that people and communities might choose to harness change for social and economic enhancement.

The Framework suggests that all people tend to desire to maximize all their "capitals", and balance them for personal and community sustainability.

79 www.livelihoods.org/info/info_guidancesheets.html

The definitions below are used to characterize each of the capitals in the Sustainable Livelihoods Framework. We attempted to capture the essence of these definitions using quantitative indicators from existing data sets. Only data sets that enable comparisons across the economic regions were used. The data sets included those available from Statistics Canada and Health Canada. In most cases, data was available at the Census Division level only and was then aggregated to the level of economic regions.

Indicators were selected based on a combination of data availability, time required to access the data, and professional judgement. Recognizing that the selection of indicators is subject to debate, a "basket" of indicators for each capital was developed to minimize bias.

Readers may disagree with the choice of specific indicators, desire to see other indicators included, or disagree with the grouping of indicators. Using this framework, others may re-evaluate the impact of change on their community or groups of communities within an economic region with an alternative set of indicators that they deem more appropriate.

As previously noted, the Sustainable Livelihoods Framework is based on five capitals. In order for individuals and communities to achieve and maintain a sustainable livelihood, the Framework suggests that people tend to maximize these capitals and achieve a balance between capitals. These five capitals are:

- ***Social Capital*** that consists of networks and connectedness that increase people's trust and ability to work together;
- ***Human Capital*** which consists of skills, knowledge, ability to work, and good health;
- ***Physical Capital*** which consists of infrastructure and producer goods;
- ***Financial Capital*** which consists of available stocks and inflows of money;
- ***Natural Capital*** which consists of natural resource stocks and intangible public goods – atmosphere, biodiversity; divisible assets – trees, water, land, etc.

In collecting indicators around each capital, an index is produced for each capital, not unlike the Community Well-Being index[80]. The Sustainable Livelihoods Framework provides insight into

[80] The Community Well-Being (CWB) Index is a means of examining the well-being of individual Canadian communities. Various indicators of socio-economic well-being, including education, income, housing, and labour force activity, are derived from the 2001 Census of Canada and combined to give each community a well-being "score" between 0 and 1.
The CWB Index measures:
- Education
  - Functional literacy (The proportion of the population, age fifteen and older, with at least a grade nine education may be interpreted as a proxy for functional literacy)
  - High-school plus (The most important benefit being "the process of enlarging people's choices")
- Labour force
  - Participation in the Labour Force (expressed as a percentage of the population twenty years of age and over, rather than Statistics Canada's standard of fifteen years)

the different dimensions of well-being in terms of social, human, financial, physical and natural dimensions. Both measures are used in this assessment.

Given the limitations in available data for deriving indicators of natural capital, this capital is not subject to comparison among economic regions. Only two indicators of physical capital were readily available for this analysis, which limits the strength of this capital as an index.

Profiles for Aboriginal communities within each economic region required the use of a different set of indicators due to the limited level of detail available from Canadian data sources. A decision was made to create profiles on three Sustainable Livelihood Capitals only: namely: human, financial, and physical.

For Aboriginal communities within each economic region we also include a comparison using the Community Well-Being index. This is included due to the availability of reasonably appropriate data (www.ainc-inac.gc.ca/pr/ra/cwb/index_e.html).

8.3.3 Transforming Social Indicators into Capital Indices

The following steps were used to transform individual indicators into capital indices:

1. The range for a given indicator is determined using the values for each of the Census Divisions (n=45).
2. The lowest value for a given indicator is selected as point "zero", and the highest value is considered as 5 (the highest value in the index). *Note: It should not be interpreted that any economic region which scores a zero for any of the measured capital indicators, is completely deficient in that capital. A zero score simply means that an economic region has the lowest quantity or value for that measure relative to the other 10 economic regions that it is being compared with.*
3. The range of values for a given indicator is divided by 5 to apply the indicator values to a scale (0 to 5).
4. The actual value of an indicator in each Census Division receives a "weight" according to its position on the scale (0 to 5).
5. The average for the economic region is calculated by dividing the sum of all the weighted values for the Census Divisions within that economic region by the number of Census Divisions in that ER.

- Employed Labour Force Participants (refers to the employed labour force expressed as a percentage of the total labour force aged fifteen years and over)

- Income (indicative of one's ability to purchase the necessities, comforts and conveniences that, cumulatively, enhance one's quality of life)
- Housing
  - Housing quantity (One important consideration in the assessment of housing conditions relates to crowding.)
  - Housing quality (Housing quality is operationalized as the proportion of the population living in residences that are not in need of major repairs)

(Reference: www.ainc-inac.gc.ca/pr/ra/cwb/index_e.html)

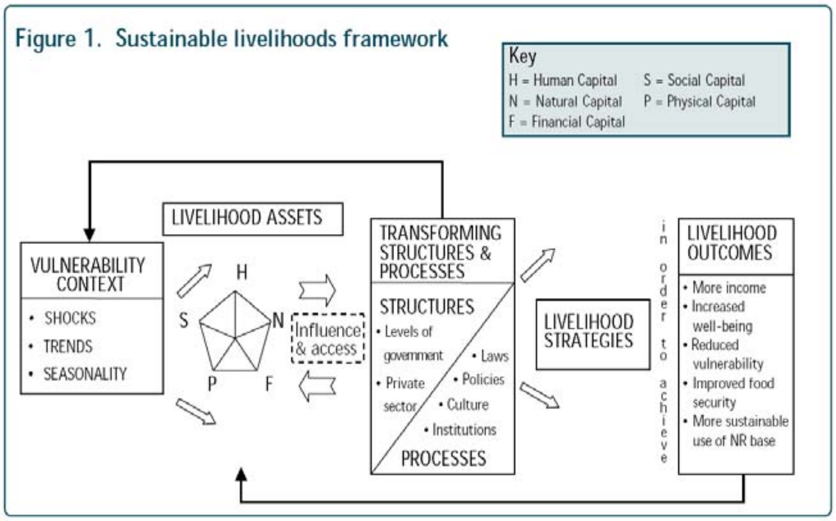


Figure 1. Sustainable livelihoods framework

Source: UK Department for International Development (DFID)

8.4 Results of the Community Well-Being Analysis

This section presents the results for the community economic health, community social quality and Aboriginal community quality in three separate subsections. It should be noted that these sub-sections present and discuss results of the quantitative analysis on the measures and indicators identified in Table 8.2-1. Qualitative considerations of measures and indicators are introduced throughout the remainder of this section.

8.4.1 Community Economic Health

The results relating to the economic health of communities in the economic regions used to illustrate the economic impact from the development of the three used nuclear fuel management approaches is presented in three following subsections.

Deep Geological Disposal in the Canadian Shield

Using data and information from the Economic Viability analysis, the economic impact on the three indicators of economic health were determined for Deep Geological Disposal in the Canadian Shield in three provinces and four illustrative economic regions. The change in the three indicators of income, employment and tax generation is detailed in Table 8.4-1.

Given the magnitude of the investment required to construct and operate a Deep Geological Disposal facility, the size and distribution of economic consequences is not surprising. To fully appreciate the magnitude and nature of these impacts, it is prudent to examine the results in two phases:

1. Used Nuclear Fuel in Place (including siting, design, construction and initial operations); and
2. Monitor, Operate and Close.

Deep Geological Disposal in the Canadian Shield: Used Nuclear Fuel in Place

The economic impact linked to the first phase of Deep Geological Disposal in the Canadian Shield, called “used nuclear fuel in place” and detailed in Table 8.4-1, starts with an initial investment of about $10.1 billion, which rapidly grows to $14.2 billion in spin-off (multiplier) benefits to all of Canada. It is estimated that an additional $2.2 billion would benefit economies outside of Canada as well. This means about 86% of the total economic benefit remains within Canada.

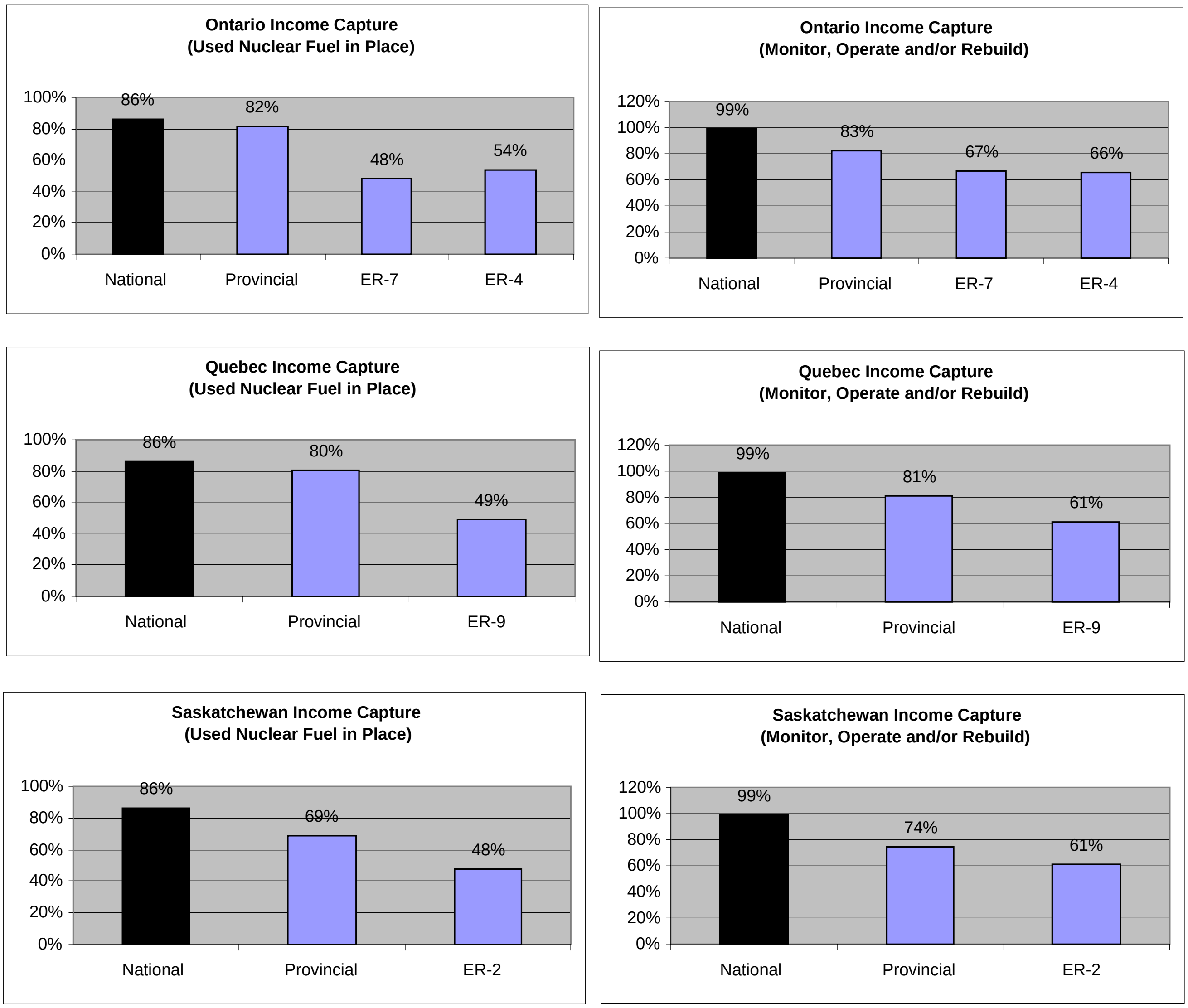
To further illustrate the distribution of benefits from investing in Deep Geological Disposal in the Canadian Shield in any of the four illustrative economic regions, consider how income is distributed by province and region (Figure 8.4-1). The distribution of employment and tax generation benefits follow a pattern similar to income.

Table 8.4-1: Economic Impact on Income, Employment and Taxes from Deep Geological Disposal in the Canadian Shield for Two Phases of Operation

	Initial Expenditure	Canada	External	Ontario			Quebec		Saskatchewan	
				Province	ER-7	ER-4	Province	ER-9	Province	ER-2
Used Nuclear Fuel in Place ($,000) One Time Expenditure	$ 10,084,434									
Monitor, Operate and/or Rebuild ($,000) Annual Expenditures	$ 109,879									
INCOME (,000s)										
Used Nuclear Fuel in Place										
Direct		$ 6,049,903		$ 5,056,947	$ 4,948,961	$ 5,451,098	$ 6,016,855	$ 6,016,855	$ 5,760,617	$ 5,760,617
Indirect & Induced		$ 8,188,337		$ 8,428,057	$ 2,926,567	$ 3,473,126	$ 7,219,992	$ 2,041,742	$ 5,630,230	$ 2,114,517
Total (One Time Benefit)		$ 14,238,240	$ 2,242,536	$ 13,485,004	$ 7,875,528	$ 8,924,224	$ 13,236,847	$ 8,058,597	$ 11,390,847	$ 7,875,134
Monitor, Operate and Close										
Direct		$ 77,645		$ 77,292	$ 75,160	$ 74,586	$ 78,751	$ 78,751	$ 76,445	$ 76,445
Indirect & Induced		$ 90,735		$ 80,904	$ 52,264	$ 50,920	$ 76,929	$ 37,182	$ 65,323	$ 40,914
Total (Annual Benefit)		$ 168,380	$ 22,972	$ 158,196	$ 127,424	$ 125,506	$ 155,680	$ 115,933	$ 141,768	$ 117,359
EMPLOYMENT										
Used Nuclear Fuel in Place										
Direct				84,244	83,126	88,412	152,295	152,295	118,921	118,921
Indirect & Induced				118,581	59,429	64,156	120,866	47,015	93,738	44,403
Total				202,824	142,554	152,568	273,162	199,311	212,659	163,324
Monitor, Operate and Close										
Direct				1,397	1,370	1,364	1,913	1,913	2,044	2,044
Indirect & Induced				1,219	854	834	1,305	657	1,158	723
Total				2,616	2,223	2,198	3,218	2,570	3,203	2,768

	Initial Expenditure	Canada	External	Ontario			Quebec		Saskatchewan	
				Province	ER-7	ER-4	Province	ER-9	Province	ER-2
TAXES (,000S)										
Used Nuclear Fuel in Place										
Federal (One Time Benefit)				$ 2,389,666	$ 1,498,913	$ 1,652,564	$ 3,014,718	$ 1,882,586	$ 2,450,493	$ 1,774,565
Provincial				$ 1,660,854	$ 924,686	$ 1,055,237	$ 2,299,201	$ 1,446,533	$ 1,461,413	$ 1,048,708
Local				$ 405,091	$ 180,244	$ 221,908	$ 631,563	$ 394,389	$ 604,578	$ 437,815
Monitor, Operate and Close										
Federal (Annual Benefit)				$ 27,653	$ 23,022	$ 22,679	$ 35,376	$ 26,516	$ 31,898	$ 27,026
Provincial				$ 19,694	$ 16,094	$ 15,896	$ 27,661	$ 21,369	$ 19,311	$ 16,569
Local				$ 5,035	$ 3,942	$ 3,916	$ 7,411	$ 5,555	$ 7,870	$ 6,668

Figure 8.4-1: Distribution Total Income (Value Added) Captured in the Three Illustrative Provinces and Four Economic Regions for Deep Geological Disposal in the Canadian Shield



If the Deep Geological Disposal facility were located in any one of the three illustrative provinces (i.e., Saskatchewan, Ontario, or Quebec), the total economic benefit that would remain within each province is substantial, yet there appears to be some variation between the four economic regions used to illustrate the economic impact. For example, if located in Saskatchewan (regardless of location within the province), the first phase of operations (used nuclear fuel in place) would mean about 69% of the total income[81] (about $11.4 billion) remains within Saskatchewan during the duration of this phase of operation. If located in Ontario or Quebec, the

[81] Income includes all salaries and wages paid to labour and business profits. In economics, income is measured as valued added.

total income from the first phase of operations that remains in each respective province is 82% and 80%, respectively (Figure 8.4-2).

Ontario and Quebec appear to capture a higher percentage of income available for this first phase of operations, likely because they have greater access to labour, support services and supply industries relative to other provinces.

The analysis further indicates how much of the economic benefit from the first phase of Deep Geological Disposal in the Canadian Shield falls within the four illustrative economic regions. For example, if the facility were to be located in ER-2, then about 48% of the total income generated in Canada would be available to be captured in that economic region alone (Figure 8.4-1). In comparison to the other illustrative economic regions, it is evident that each is equivalent in the amount of income that would remain within their respective regions, ranging from 48% to 54%.

An alternative and more simplified comparison of the distribution and capture of income benefits resulting from the first phase of Deep Geological Disposal in the Canadian Shield is presented in Table 8.4-2. This clearly shows that the benefits of this management approach provide economic benefits to all Canadians, but most of the value remains within the host province and host economic region.

Table 8.4-2: Summary of the Percent Income Retained at the National, Provincial and Regional Levels From the First Phase of Operations for Deep Geological Disposal in the Canadian Shield

Economic Regions	Used Nuclear Fuel in Place % Income Retained		
	Within Canada	Within Province	Within ER
ER-7	86%	82%	48%
ER-4			54%
ER-9		80%	49%
ER-2		69%	48%

Although the employment and tax benefits follow a similar pattern as the income benefits, it is instructive to summarize the net distribution of all measured benefits for the four illustrative economic regions (Table 8.4-3).

Table 8.4-3: Distribution and Comparison of Economic Benefits for the Four Illustrative Economic Regions in the First Phase of Deep Geological Disposal in the Canadian Shield

Economic Regions	Used Nuclear Fuel in Place						
	Income Capture ($ Billons)		Tax Capture ($ Billions)			Employment Capture FTE's	
	Direct	Indirect & induced	Federal	Provincial	Local	Direct	Indirect & induced
ER-7	$ 4.95	$ 2.93	$ 1.50	$ 0.92	$ 0.18	83,126	59,429
ER-4	$ 5.45	$ 3.47	$ 1.65	$ 1.06	$ 0.22	88,412	64,156
ER-9	$ 6.02	$ 2.04	$ 1.88	$ 1.45	$ 0.39	152,295	47,015
ER-2	$ 5.76	$ 2.11	$ 1.77	$ 1.05	$ 0.44	118,921	44,403

For income and employment, the direct benefits are those that are a result of on-site expenditures for labour and supplies. These one-time values are significant in each of the economic regions. The indirect and induced benefits come about as a result of expenditures by labour on such things as food, entertainment, clothing and shelter. Likewise, the distribution of tax benefits to three levels of government, indicate that the federal government receives most of the tax benefit, followed by the respective provinces, then the local governments within each region. There are no exceptions to this in any region for any used nuclear fuel approach.

It is important to note that the degree of economic benefits discussed in this subsection are one-time and will be distributed over the duration of this phase of activity only; namely from years 1 to 59. In the case of Deep Geological Disposal in the Canadian Shield, the level of expenditures after year 59 tail off dramatically. This scenario is very similar in nature to the ***"boom/bust cycle"*** of most single resource dependent communities with a limited resource life. The economic stress and dislocation of such events are dramatic for community residents if a strategy has not been put in place to manage this cycle.

The nature and magnitude of social costs linked to the above "boom/bust" cycle will vary by economic region and by communities within a region. Generally, it is reasonable to anticipate a dramatic escalation in property values as economic activity and employment builds up to service the construction and operation phases of this management approach. Other community consequences might include increased demand for infrastructure and social services such as water and sewage management, schools, and recreational facilities. Having built some of these services to support increased population and housing, if the population declines after the initial project is completed, there might be significant out-migration from the local community(ies) closely linked to the project. In this event, the local community might experience a significant loss in tax base and no longer be able to maintain the "built-up" infrastructure. Stress on local families and community businesses might increase, leading to a chain of other social costs, such as increased crime and drug/alcohol abuse.

Deep Geological Disposal in the Canadian Shield: Monitor, Operate and Close

Following initial placement of used nuclear fuel in the deep geological facility, annual monitoring and operations account for an annual expenditure of about $110 million until year 154. This annual expenditure continues to generate spin-off (multiplier) benefits of about $168 million throughout Canada (Table 8.4-1).

From Table 8.4-4, it is evident that nearly all the income generated (i.e., 99%) in this second phase of operations stays within Canada and that the economic regions capture a higher and equivalent percentage of benefits (i.e., between 61% and 66%), compared to the first phase of operations.

Table 8.4-4: Summary of the Percent Income Retained at the National, Provincial and Regional Levels From the Second Phase of Operations for Deep Geological Disposal in the Canadian Shield

Economic Regions	Monitor, Operate & Close % Income Retained		
	Within Canada	Within Province	Within ER
ER-7	88%	83%	67%
ER-4			66%
ER-9		81%	61%
ER-2		74%	61%

The size and distribution of all three economic benefit measures from the monitoring and operations phase of the Deep Geological Disposal approach are summarized in Table 8.4-5.

Table 8.4-5: Distribution and Comparison of Economic Benefits for the Four Illustrative Economic Regions in the Second Phase of Deep Geological Disposal in the Canadian Shield

Economic Regions	Used Nuclear Fuel in Place						
	Income Capture ($ Billons)		Tax Capture ($ Billions)			Employment Capture FTE's	
	Direct	Indirect & induced	Federal	Provincial	Local	Direct	Indirect & induced
ER-7	$ 75.2	$ 52.3	$ 23.0	$ 16.1	$ 3.9	$ 1,370	$ 854
ER-4	$ 74.6	$ 50.9	$ 22.7	$ 15.9	$ 3.9	$ 1,364	$ 834
ER-9	$ 78.8	$ 37.2	$ 26.5	$ 21.4	$ 5.6	$ 1,913	$ 657
ER-2	$ 76.4	$ 40.9	$ 27.0	$ 16.6	$ 6.7	$ 2,044	$ 723

The economic benefits from the second phase of the Deep Geological Disposal approach are annualized up to year 154. Once again, there is little difference in economic benefit between the economic regions. In summary, locating Deep Geological Disposal does not appear to have a significant difference in any economic region within the Canadian Shield. Specifically all appear to receive very large income, employment and tax benefits.

However, this management approach has the potential for serious social and economic costs during and after implementation of this approach. These cost considerations will be discussed at the end of this section.

Storage at Nuclear Reactor Sites

Using data and information derived from the Economic Viability analysis, the economic impact on the three indicators of economic health (income, employment, and taxes) were determined for four provinces and six economic regions in two cost phases:

1. Used nuclear fuel in place (including siting, design, construction and initial operations); and
2. Monitor, Operate and Rebuild.

In this approach to managing used nuclear fuel, economic benefits accrue to all economic regions simultaneously, but to different degrees, depending on the nature and size of investment required at each site.

Storage at Nuclear Reactor Sites: Used Nuclear Fuel in Place

The economic impact linked to the first phase of Storage at Nuclear Reactor Sites, called “used nuclear fuel in place” and detailed in Table 8.4-6, starts with different investment levels at each reactor site ranging from $2.2 billion in ER-6 (Pickering and Darlington) to $35 million in ER-3 (Whiteshell) and ER-8 (Chalk River). Regardless of the initial investment, each investment at these reactor sites generates spin-off (multiplier) benefits throughout Canada; for example, an initial investment of $2.2 billion in ER-6 multiples to a wider benefit of $3 billion across Canada in terms of income generation. In this example, it is estimated that an additional $0.5 billion would benefit economies outside of Canada.

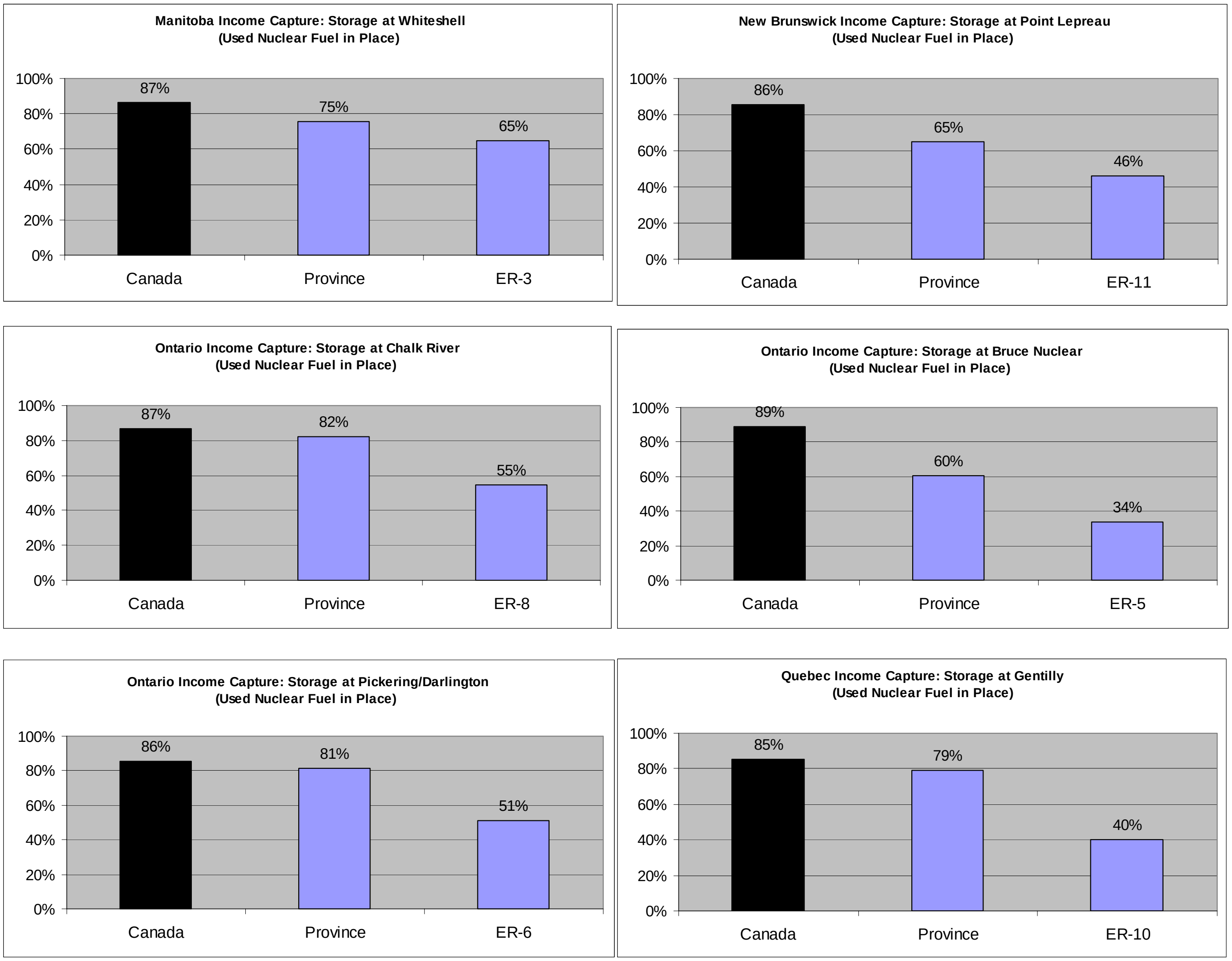
The economic benefits to Canadians from this first phase of Storage at Nuclear Reactor Sites will be spread over 54 years. The distribution of benefits over this time period, in relation to income generation, is illustrated for each economic region and province in Figure 8.4-2. It is evident that between 85% to 89% of the total benefit from Storage at Nuclear Reactor Sites remains in Canada and that each province captures a significant share of the spin-off benefits initiated in their jurisdictions. Moreover, the economic regions that host these reactor sites capture between 34% (ER-5) to 65% (ER-3) of the benefit, as represented by total income. As previously mentioned, employment and tax benefits are distributed in similar fashion.

Table 8.4-6: Economic Impact on Income, Employment and Taxes from Storage at Nuclear Reactor Sites for Two Phases of Operation

	Initial Expenditure ($,000)	
	Used Fuel in Place	Monitor, Operate and Rebuild
Manitoba		
Whiteshell	$ 35,225	$ 2,636
New Brunswick		
Point Lepreau	$ 536,367	$ 7,268
Ontario		
Chalk River	$ 35,003	$ 2,620
Bruce	$ 1,408,798	$ 19,408
Pickering/Darlington	$ 2,234,274	$ 31,169
Quebec		
Gentilly	$ 635,830	$ 4,702

Initial Expenditure	Manitoba				New Brunswick				Ontario												Quebec			
	External	Canada	Prov	ER-3	External	Canada	Prov	ER-11	External	Canada	Prov	ER-8	External	Canada	Prov	ER-5	External	Canada	Prov	ER-6	External	Canada	Prov	ER-10
Value Added ($,000)																								
Used Nuclear Fuel in Place																								
Direct		21,945	21,877	21,877		293,539	275,678	275,678		21,775	19,878	19,878		748,270	614,316	614,316		1,222,206	1,042,184	1,042,184		334,842	334,527	334,527
Indirect & Induced		29,550	22,966	16,618		427,360	270,462	113,853		29,354	28,561	12,436		1,864,146	1,153,432	378,777		1,783,323	1,806,120	751,276		500,868	437,692	56,674
Total	7,979	51,495	44,843	38,495	120,444	720,899	546,140	389,531	7,929	51,129	48,439	32,314	317,339	2,612,416	1,767,748	993,093	503,745	3,005,529	2,848,304	1,793,460	142,049	835,710	772,219	391,201
Monitor, Operate and Rebuild																								
Direct		1,865	1,889	1,889		4,175	4,058	4,058		1,854	1,809	1,809		10,188	9,172	9,172		16,894	16,048	16,048		2,862	2,924	2,924
Indirect & Induced		2,174	1,727	1,631		5,620	3,553	2,072		2,161	1,963	1,293		14,778	14,305	7,353		23,920	22,327	13,612		3,767	3,152	1,373
Total	554	4,039	3,616	3,520	1,528	9,795	7,611	6,130	550	4,015	3,772	3,102	4,164	24,966	23,477	16,525	6,675	40,814	38,375	29,660	998	6,629	6,076	4,297
Employment																								
Used Nuclear Fuel in Place																								
Direct			556	556			7,819	7,819			332	332			9,950	9,950			16,875	16,875			7,400	7,400
Indirect & Induced			377	315			5,271	2,761			409	237			16,290	7,901			25,713	14,435			7,178	1,743
Total			933	871			13,090	10,580			741	569			26,240	17,851			42,588	31,310			14,578	9,143
Monitor, Operate and Rebuild																								
Direct			50	50			94	94			33	33			140	140			248	245			63	63
Indirect & Induced			28	27			70	41			30	21			213	126			335	227			52	24
Total			78	77			164	135			63	54			353	266			583	472			115	87
Taxes ($,000)																								
Used Nuclear Fuel in Place																								
Federal			10,764	9,372			120,368	87,986			8,672	6,133			312,147	186,615			502,590	337,348			173,577	89,544
Provincial			6,191	5,306			70,906	51,553			6,034	3,916			228,853	120,653			365,221	215,594			132,321	68,567
Local			1,269	1,105			12,192	8,912			1,477	822			59,787	25,562			94,614	44,598			36,363	18,759
Monitor, Operate and Rebuild																								
Federal			868	845			1,641	1,327			661	561			4,036	2,910			6,590	5,262			1,366	970
Provincial			489	478			1,002	823			471	389			3,156	2,183			5,102	3,845			1,059	779
Local			102	100			166	134			120	95			894	579			1,435	984			286	203

Figure 8.4-2: Distribution of Total Income Captured in Four Illustrative Provinces and Six Economic Regions for Storage at Nuclear Reactor Sites



An alternative and more simplified comparison of the distribution and capture of income benefits resulting from the first phase of Storage at Nuclear Reactor Sites is presented in Table 8.4-7. This clearly shows that of this approach of managing used nuclear fuel provides economic benefits to all Canadians. Most of the value stays within the host provinces, while the value that remains in the host economic region is more variable.

Table 8.4-7: Summary of the Percent Income Retained at the National, Provincial and Regional Levels From the First Phase of Operations for Storage at Nuclear Reactor Sites

Economic Regions	Used Nuclear Fuel in Place % Income Retained		
	Within Canada	Within Province	Within ER
ER-3	87%	75%	65%
ER-11	86%	65%	46%
ER-8	87%	82%	55%
ER-5	89%	60%	34%
ER-6	86%	81%	51%
ER-10	65%	79%	40%

Although the employment and tax benefits follow a similar pattern as the income benefits, it is instructive to summarize the net distribution of all measured benefits for the six illustrative economic regions, (Table 8.4-8).

Table 8.4-8: Distribution and Comparison of Economic Benefits for the Six Illustrative Economic Regions in the First Phase of Operations for Storage at Nuclear Reactor Sites

Economic Regions	Used Nuclear Fuel in Place						
	Income Capture ($ Thousands)		Tax Capture ($ Thousands)			Employment Capture FTE's	
	Direct	Indirect & Induced	Federal	Provincial	Local	Direct	Indirect & induced
ER-3	$ 21,877	$ 16,618	$ 9,372	$ 5,306	$ 1,105	556	315
ER-11	$ 275,678	$ 113,853	$ 87,986	$ 51,553	$ 8,912	7,819	2,761
ER-8	$ 19,878	$ 12,436	$ 6,133	$ 3,916	$ 822	332	237
ER-5	$ 614,316	$ 378,777	$ 186,615	$ 120,653	$ 25,562	9,950	7,901
ER-6	$ 1,042,184	$ 751,276	$ 337,348	$ 215,594	$ 44,598	16,875	14,435
ER-10	$ 334,527	$ 56,674	$ 89,544	$ 68,567	$ 18,759	7,400	1,743
TOTAL	**$ 2,308,460**	**$ 1,329,634**	**$ 716,998**	**$ 465,589**	**$ 99,758**	**42,932**	**27,392**

The total amount of employment (in the form of “full-time-equivalents” (FTEs)) generated in the first phase of operations for Storage at Nuclear Reactor Sites is about 44,000 FTEs (the total of direct and indirect/induced employment). As in previous cases, the Federal Government receives the largest share of tax revenues during this initial operation phase.

Storage at Nuclear Reactor Sites: Monitor, Operate and Rebuild

Following initial placement of used nuclear fuel in the storage facilities at the Nuclear Reactor Sites, annual monitoring and operations and periodic facility rebuilds account for an annual expenditure of between $2.6 million at the Whiteshell and Chalk River reactor sites to $31.2 million at the combined Pickering and Darlington sites for the next 10,000 years. The annual expenditures at each reactor site continue to generate significant annual spin-off (multiplier) benefits throughout Canada (Table 8.4-6). For example, in ER-3, initial annual expenditures are about $2.6 million, which multiply in value to $4.0 million annually across Canada and $3.6 million annually within Manitoba, in terms of income generation.

A summary of the distribution of annual income retained in Canada (Table 8.4-9), the provinces and the six economic regions that contain the reactor sites indicates a much higher capture rate of economic benefit to the economic regions and their host provinces, relative to the first phase of operations (Table 8.4-7).

Table 8.4-9: Summary of the Percent Income Retained at the National, Provincial and Regional Levels From the Second Phase of Operations for Storage at Nuclear Reactor Sites

Economic Regions	Monitor, Operate & Rebuild % Income Retained		
	Within Canada	Within Province	Within ER
ER-3	88%	79%	77%
ER-11	87%	67%	54%
ER-8	88%	83%	68%
ER-5	86%	81%	57%
ER-6	86%	81%	62%
ER-10	87%	80%	56%

The magnitude and distribution of the impact on employment, taxes and income for the second phase of Storage at Nuclear Reactor Sites is presented in Table 8.4-10. The total employment generated across all reactor sites and affected economic regions is estimated at about 682 FTEs each year for the next 10 millennia, using today's measures.

Likewise, the total annual tax revenue generation to all three levels of government is estimated at just over $22 million. Once again, the Federal Government is the largest recipient, and the amount of tax benefit to each economic region varies according the amount of used nuclear fuel managed at each site.

Table 8.4-10: Distribution and Comparison of Economic Benefits for the Six Illustrative Economic Regions in the Second Phase of Operations for Storage at Nuclear Reactor Sites

Economic Regions	Monitor, Operate & Rebuild						
	Income Capture ($ Thousands)		Tax Capture ($ Thousands)			Employment Capture FTE's	
	Direct	Indirect & Induced	Federal	Provincial	Local	Direct	Indirect & induced
ER-3	$ 1,889	$ 1,631	$ 845	$ 478	$ 100	50	27
ER-11	$ 4,058	$ 2,072	$ 1,327	$ 823	$ 134	94	41
ER-8	$ 1,809	$ 1,293	$ 561	$ 389	$ 95	33	21
ER-5	$ 9,172	$ 7,353	$ 2,910	$ 2,183	$ 579	140	126
ER-6	$ 16,048	$ 13,612	$ 5,262	$ 3,845	$ 984	245	227
ER-10	$ 2,924	$ 1,373	$ 970	$ 779	$ 203	63	24
TOTAL	$ 35,900	$ 27,334	$ 11,875	$ 8,497	$ 2,095	625	466

Centralized Storage, Either Above or Below Ground

Using data and information from the Economic Viability assessment, the economic impact on the three indicators of economic health were determined for Centralized Storage, either above or below ground, in four provinces and six economic regions. The change in the three indicators of income measured by “value added”, employment and tax generation is detailed in Table 8.4-11.

Given the magnitude of the investment required to construct and operate a Centralized Storage facility, the size and distribution of economic consequences is not surprising. To fully appreciate the magnitude and nature of these impacts, it is prudent to examine results in two phases:

1. Used nuclear fuel in place (including siting, design, construction and initial operations); and
2. Monitor, Operate and Rebuild.

A separate cost estimate was provided for below and above ground Centralized Storage facilities, as discussed in the Economic Viability analysis.

Given that the two expenditure patterns were similar in nature and magnitude, it was decided to evaluate one “blended” average cost stream for both above and below ground Centralized Storage approaches.

Table 8.4-11: Economic Impact on Income, Employment and Taxes from Centralized Storage, Either Above or Below Ground for Two Phases of Operation

	Initial Expenditure	Canada	External	British Columbia		Ontario				Quebec		Saskatchewan	
				Province	ER-1	Province	ER-7	ER-4	ER-6	Province	ER-9	Province	ER-2
Used Nuclear Fuel in Place	$ 3,100,000												
Operations	$ 44,143												
Value Added (,000s)													
Used Nuclear Fuel in Place													
Direct		$ 1,914,533		$ 1,946,659	$ 1,946,659	$ 1,740,289	$ 1,719,246	$ 1,816,973	$ 1,740,289	$ 1,922,424	$ 1,922,424	$ 1,817,494	$ 1,817,494
Indirect & Induced		$ 2,572,236		$ 2,264,981	$ 1,778,147	$ 2,504,409	$ 1,020,479	$ 1,126,677	$ 1,229,226	$ 2,236,088	$ 669,824	$ 1,764,319	$ 733,774
Total		$ 4,486,770	$ 702,299	$ 4,211,640	$ 3,724,806	$ 4,244,698	$ 2,739,725	$ 2,943,650	$ 2,969,515	$ 4,158,512	$ 2,592,247	$ 3,581,813	$ 2,551,268
Monitor, Operate & Rebuild													
Direct		$ 23,737		$ 24,727	$ 24,727	$ 21,623	$ 21,623	$ 21,411	$ 22,413	$ 24,554	$ 24,554	$ 22,620	$ 44,143
Indirect & Induced		$ 33,498		$ 28,982	$ 25,015	$ 32,193	$ 16,860	$ 16,598	$ 19,152	$ 27,597	$ 10,135	$ 22,968	$ 6,630
Total		$ 57,235	$ 9,431	$ 53,709	$ 49,742	$ 53,816	$ 38,483	$ 38,009	$ 41,565	$ 52,151	$ 34,689	$ 45,588	$ 50,773
Employment													
Used Nuclear Fuel in Place													
Direct				44,246	44,246	29,079	28,862	29,891	29,079	50,122	50,122	39,650	39,650
Indirect & Induced				36,774	30,771	36,117	20,110	20,966	22,599	37,803	15,477	29,922	15,214
Total				81,020	75,017	65,196	48,972	50,856	51,678	87,925	65,599	69,572	54,864
Monitor, Operate & Rebuild													
Direct				454	454	337	337	335	347	447	447	469	469
Indirect & Induced				460	397	482	289	283	321	448	163	383	191
Total				914	851	819	626	618	668	895	610	852	660
Taxes (,000s)													
Used Nuclear Fuel in Place													
Federal				$ 1,012,561	$ 905,167	$ 756,828	$ 520,099	$ 549,891	$ 561,284	$ 947,817	$ 605,632	$ 784,733	$ 584,976
Provincial				$ 568,055	$ 503,590	$ 529,282	$ 324,765	$ 350,655	$ 351,663	$ 726,761	$ 465,763	$ 469,953	$ 346,279
Local				$ 119,400	$ 106,737	$ 130,563	$ 64,992	$ 73,477	$ 70,582	$ 198,560	$ 126,875	$ 193,608	$ 144,323
Monitor, Operate & Rebuild													
Federal				$ 12,477	$ 11,560	$ 9,220	$ 6,757	$ 6,664	$ 7,324	$ 11,513	$ 7,625	$ 9,653	$ 7,500
Provincial				$ 7,150	$ 6,655	$ 7,281	$ 5,052	$ 5,006	$ 5,385	$ 8,857	$ 6,113	$ 5,896	$ 4,692
Local				$ 1,471	$ 1,363	$ 2,089	$ 1,336	$ 1,335	$ 1,389	$ 2,412	$ 1,597	$ 2,382	$ 1,850

Centralized Storage, Either Above or Below Ground: Used Nuclear Fuel In Place

As in the previous management approaches for used nuclear fuel, the initial expenditure for Centralized Storage, either above or below ground, (estimated at $3.1 billion) generates considerable spin-off (multiplier) benefits throughout the Canadian economy at all levels of government. Using income generation as an example, the initial expenditure of $3.1 billion in this first phase of operations generates a total income benefit of almost $4.5 billion. Because some expenditures will "leak out" to other economies, countries outside of Canada will benefit with about $700 million of income (Table 8.4-11)

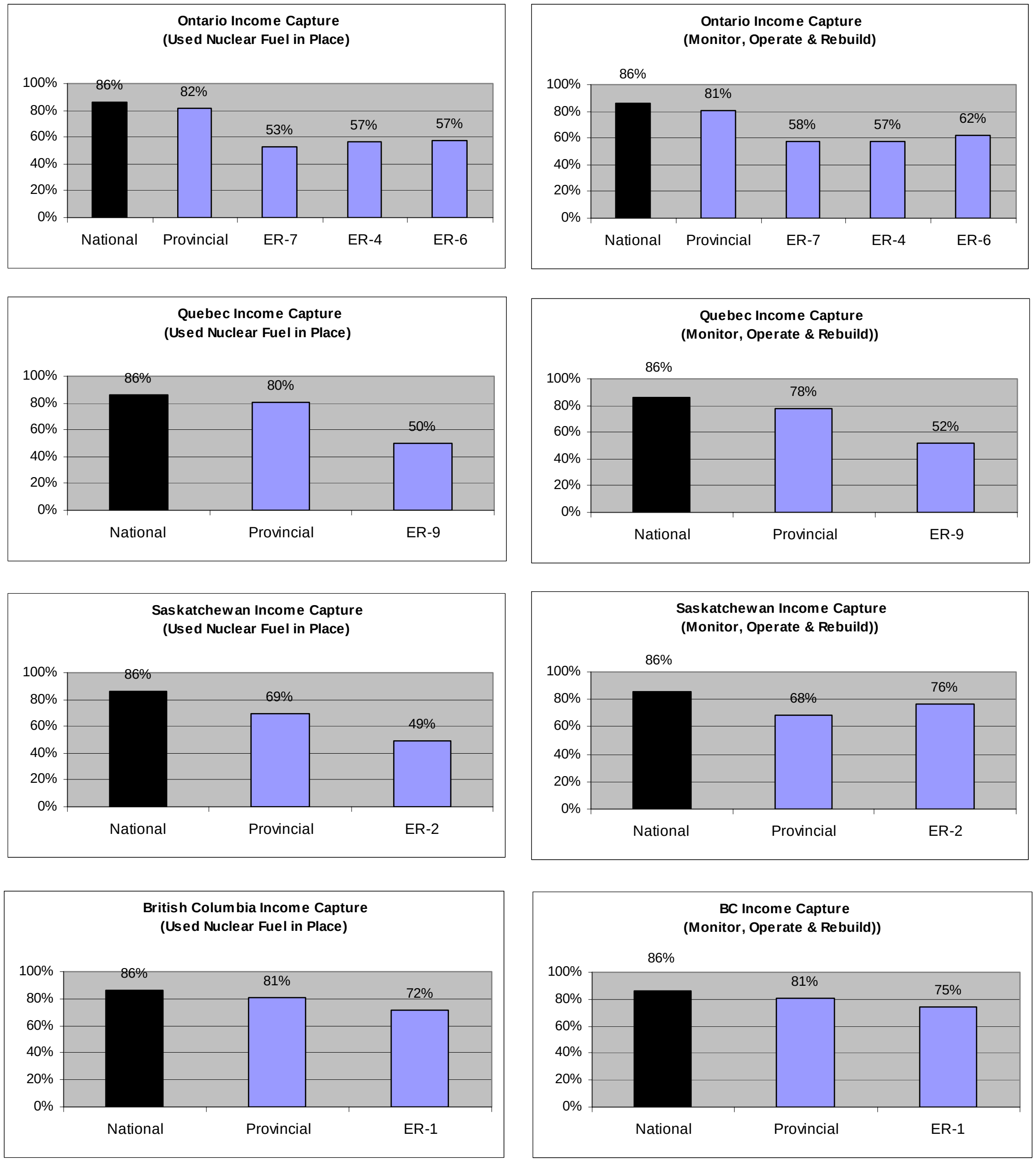
The distribution of income benefits between provinces and economic regions is illustrated in Figure 8.4-3. The following observations are worth noting:

1. Canada captures about 87% of the total income benefit, as summarized in Table 8.4-12.
2. Saskatchewan captures less of the potential income benefit at this scale (i.e., 69%) compared to the other three provinces which capture about 80% of the income benefit.
3. ER-1 captures a much higher share of the income benefit (71%), compared to all other regions which capture between 49-57%.

Table 8.4-12: Summary of the Percent of Income Retained at the National, Provincial and Regional Levels From the First Phase of Operations for Centralized Storage (Above or Below Ground)

Economic Regions	Used Nuclear Fuel in Place % Income Retained		
	Within Canada	Within Province	Within ER
ER-1	86%	81%	72%
ER-7		82%	53%
ER-4			57%
ER-6			57%
ER-9		80%	50%
ER-2		69%	49%

Figure 8.4-3: Distribution of Total Income Captured in Four Illustrative Provinces and Six Economic Regions for Centralized Storage, Either Above or Below Ground



The employment and tax benefits that are generated in the first phase of Centralized Storage are significant, (Table 8.4-13).

Table 8.4-13: Distribution and Comparison of Economic Benefits for the Six Illustrative Economic Regions in the First Phase of Operations for Centralized Storage (either above or below ground)

Economic Regions	Used Nuclear Fuel in Place						
	Income Capture ($ Millions)		Tax Capture ($ Millions)			Employment Capture FTE's	
	Direct	Indirect & Induced	Federal	Provincial	Local	Direct	Indirect & induced
ER-1	$ 1,946.7	$ 1,778.1	$ 905.2	$ 503.6	$ 106.7	44,246	30,771
ER-7	$ 1,817.0	$ 1,020.5	$ 520.1	$ 324.8	$ 65.0	28,862	20,110
ER-4	$ 1,817.0	$ 1,126.7	$ 549.9	$ 350.7	$ 73.5	29,891	20,966
ER-6	$ 1,740.3	$ 1,229.2	$ 561.3	$ 351.7	$ 70.6	29,079	22,599
ER-9	$ 1,922.4	$ 669.8	$ 605.6	$ 465.8	$ 126.9	50,122	15,477
ER-2	$ 1,817.5	$ 733.8	$ 585.0	$ 346.3	$ 144.3	39,650	15,214

The following observations regarding employment and tax benefits are worth noting:

1. As in previous long-term management approaches, the amount of tax revenues generated are significant and the federal government is again the largest beneficiary. For example, in ER-1 the federal taxes (about $905 million) represent about 60% of the total tax revenues, while local governments account for only 7% of the tax revenues.
2. Total employment benefits for the first phase are significant, but vary between economic regions, where ER-9 derives the largest direct employment benefit, while ER-1 derives the largest indirect and induced employment benefits. This means that ER-1 not only has sufficient services and amenities for labour to spend their wages on personal goods and services, but that British Columbia residents tend to shop locally (in the region) compared to other regions.[82]

Centralized Storage, Either Above or Below Ground: Monitor, Operate & Rebuild

Following initial placement of used nuclear fuel in Centralized Storage (above or below ground), annual monitoring, operations and cyclical facility rebuilds account for an annual expenditure of about $44 million for the next 10,000 years. The annual expenditures continue to generate significant annual spin-off (multiplier) benefits throughout Canada (Table 8.4-11). For example, in ER-1, the initial annual expenditure multiplies in value to about $57 million annually across Canada and $54 million annually within BC, in terms of income generation. A comparison of the distribution of income benefits for this second phase of operations is presented in Figure 8.4-3.

A summary of the distribution of annual income retained in Canada (Table 8.4-14), the provinces and the six illustrative economic regions indicates a roughly equivalent benefit to the economic regions and their host provinces relative to the first phase of operations, (Table 8.4-12).

[82] This can be stated because the consumer expenditure patterns for each economic region have been incorporated into the I/O model used to generate the economic impact results.

Table 8.4-14: Summary of the Percent of Income Retained at the National, Provincial and Regional Levels From the Second Phase of Operations for Centralized Storage (Above or Below Ground)

Economic Regions	Monitor, Operate & Rebuild % Income Retained		
	Within Canada	Within Province	Within ER
ER-1	86%	81%	75%
ER-7		81%	58%
ER-4			57%
ER-6			62%
ER-9		78%	52%
ER-2		68%	76%

A summary of the income, employment and tax benefits to each of the illustrative economic regions is presented in Table 8.4-15. Compared to the first phase of operations, the net impact on employment and taxes among the economic regions is relatively equivalent; however, ER-1 appears to capture a much higher proportion of indirect/induced employment and income benefits compared to the other regions.

Table 8.4-15: Distribution and Comparison of Economic Benefits for the Six Illustrative Economic Regions in the Second Phase of Operations for Centralized Storage (above or below ground)

Economic Regions	Monitor, Operate & Rebuild						
	Income Capture ($ Millions)		Tax Capture ($ Millions)			Employment Capture FTE's	
	Direct	Indirect & Induced	Federal	Provincial	Local	Direct	Indirect & induced
ER-1	$ 1,946.7	$ 1,778.1	$ 11.6	$ 6.7	$ 1.4	454	397
ER-7	$ 1,719.2	$ 1,020.5	$ 6.8	$ 5.1	$ 1.3	337	289
ER-4	$ 1,817.0	$ 1,126.7	$ 6.7	$ 5.0	$ 1.3	335	283
ER-6	$ 1,740.3	$ 1,229.2	$ 7.3	$ 5.4	$ 1.4	347	321
ER-9	$ 1,922.4	$ 669.8	$ 7.6	$ 6.1	$ 1.6	447	163
ER-2	$ 1,817.5	$ 733.8	$ 7.5	$ 4.7	$ 1.9	469	191

8.4.2 Comparative Analysis of Community Health

The comparative analysis of the three approaches for managing used nuclear fuel indicates unique differences, as summarized in Table 8.4-16. All three approaches generate very significant economic benefits. ***However, Deep Geological Disposal in the Canadian Shield provides the greatest economic benefits in the near term compared to Storage at Reactor Sites or Centralized Storage (above or below ground).*** Specifically, between 143,000 to 199,000 full-time equivalent (FTE) jobs are created in the in the near term with Deep Geological Disposal, almost eight times greater than Centralized Storage and about two times that of Storage at Nuclear Reactor Sites.

Storage at Nuclear Reactor Sites is the option that simultaneously develops facilities at all seven current reactor sites, with benefits distributed between regions according to the size of the respective facilities and the volume of used nuclear fuel.

In the long term, only Centralized Storage and Storage at Nuclear Reactor Sites require any significant ongoing maintenance and rebuilding activities. As such, the economic spin-off benefits continue cyclically for thousands of years. This accounts for the apparent high economic benefits for these two approaches during the monitoring, operating and rebuilding phases of Tables 8.4-16 to 8.4-18.

Table 8.4-16: Community Economic Health – Comparative Analysis of Approaches

Management Approach	Income		Employment (FTEs)		Local Taxes	
	Used Nuclear Fuel In Place	Monitor & Operate	Used Nuclear Fuel In Place	Monitor & Operate	Used Nuclear Fuel In Place	Monitor & Operate
Deep Geological Disposal in the Cdn. Shield	$7.9 billion to $8.9 billion	$117 million/yr to $125 million/yr	89,000 to 124,000	1,375/yr to 1,750/yr	$180 million to $438 million	$4 million/yr to $7 million/yr
Storage at Nuclear Reactor Sites	$3.6 billion across all reactor sites	$63 million/yr across all reactor sites	44,000 across all reactor sites	682/yr across all reactor sites	$100 million across all reactor sites	$2 million/yr across all reactor sites
Centralized Storage (above or below ground)	$2,551 million to $3,724 million	$35 million/yr to $51 million/yr	31,000 to 45,000	381/yr to 532/yr	$65 million to $144 million	$1.3 million/yr to $1.9 million/yr

Each of the three economic health measures (income, employment, and taxes) are different by economic region, as detailed in Table 8.4-17 for near-term impacts, and Table 8.4-18 for long-term impacts. Specifically, in the near term (i.e., getting used nuclear fuel in place), if Deep Geological Disposal in the Canadian Shield is selected, then ER-4 captures the greatest income, but ER-9 captures the greatest employment, while ER-2 captures the highest local taxes.

Table 8.4-17: Community Well-Being - Comparative Analysis of Approaches within Economic Regions for Used Nuclear Fuel in Place (Near-Term/One-Time Benefits)

Management Approach	Illustrative (Destination Economic Region)	Income ($,000)	Employment (FTEs)	Local Taxes ($,000)
Deep Geological Disposal in the Cdn. Shield	ER-2	7,875,134	163,324	437,815
	ER-4	8,924,224	152,568	221,908
	ER-7	7,875,528	142,554	180,244
	ER-9	8,058,597	199,311	394,389
Storage at Nuclear Reactor Sites	ER-3	38,495	871	1,105
	ER-8	32,314	569	822
	ER-6	1,793,460	31,310	44,598
	ER-5	993,093	17,851	25,562
	ER-10	391,201	9,143	18,759
	ER-11	389,531	10,580	8,912
	Total	3,638,094	70,324	99,758
Centralized Storage (above or below ground)	ER-1	3,724,806	75,017	106,737
	ER-2	2,551,268	54,864	144,323
	ER-4	2,943,650	50,856	73,477
	ER-6	2,969,515	51,678	70,582
	ER-7	2,739,725	48,972	64,992
	ER-9	2,592,247	65,599	126,875

This ranking of benefit capture changes as one moves to Storage at Nuclear Reactor Sites. In this case, ER-6 (the largest urban centre in Canada) captures the major share of all three economic health indicators by a wide margin. Given that the two largest nuclear facilities in Canada are located in this economic region, the result is not surprising. However, each of the other economic regions that continue to host and manage used nuclear fuel continues to capture significant economic benefits in their respective regions and provinces.

In the near term, the ranking of benefit capture changes yet again when considering Centralized Storage as an option. In this case, ER-1 captures the largest income and employment benefits, but ER-2 captures the greatest local taxes. It should be noted that in all cases, the detailed analysis shows that the federal government captures the largest tax revenues, followed by the respective provinces, leaving the local community level the least tax revenue benefit. Moreover, no matter which approach is selected or in what economic region, income, employment and tax benefits are found across Canada. These differences between economic regions reflect the inherent capability of some regions to capture and retain more of the employment and income benefits because of the structure of their supporting economies.

In the long term, both Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground) provide significant benefits to their respective economic regions. Yet, in most cases ER-6 (the largest urban centre) stands to gain the most economic benefit, because of its closer proximity to the largest skilled labour pool in Canada and other supporting services and infrastructure.

However, it is important to consider that no matter what the size of the economic benefit might be, in some remote regions (i.e., ER-2, ER-4, or ER-9) the reported economic capture in these areas will be even more significant when compared to the scale of their existing economic base of activities. Given the very large investments required to implement any of the alternative management approaches (as reported in the Economic Viability analysis) the communities in rural and remote regions of Canada will require significant assistance in coping with the economic and social “shock” of such projects. Assistance will be essential to enable these communities to effectively participate in the planning process and realize employment and income opportunities.

Table 8.4-18: Community Well-Being Comparative Analysis of Approaches within Economic Regions for Monitor, Operate and Rebuild (Long-term Annual Benefits)

Management Approach	Illustrative (Destination Economic Region)	Income ($,000)/yr	Employment (FTEs)/yr	Local Taxes ($,000)/yr
Deep Geological Disposal in the Canadian Shield	ER-2	117,359	2,768	6,668
	ER-4	125,506	2,198	3,916
	ER-7	127,424	2,223	3,942
	ER-9	125,506	2,570	5,555
Storage at Nuclear Reactor Sites	ER-3	3,520	77	100
	ER-8	3,102	54	95
	ER-6	29,660	472	984
	ER-5	16,525	266	579
	ER-10	4,297	87	203
	ER-11	6,130	135	134
	Total	63,234	1,091	2,095
Centralized Storage (above or below ground)	ER-1	49,742	851	1,363
	ER-2	50,773	660	1,850
	ER-4	38,009	618	1,335
	ER-6	41,565	668	1,389
	ER-7	38,483	626	1,336
	ER-9	34,689	610	1,597

Despite the very positive economic benefits resulting from all three approaches, there are a variety of social and economic costs that are attendant with projects of this nature, particularly when sited in rural and remote regions of Canada. For example, the eventual "boom and bust" cycle of large project implementations involving thousands of workers and billions of dollars in expenditures may precipitate the following consequences:

- Housing and land values will rapidly spike at the outset and crash upon project completion; and
- The large influx of workers will increase demand for social and physical infrastructure services which will become oversized and inefficient once the project is completed.

These and other social issues must be addressed early on at the project planning stage. One essential element involves ensuring that communities are well equipped to cope and adapt to the social and economic changes that are attendant with such "mega-projects". The tools and considerations for this are the topic of the next two subsections which address social community quality and Aboriginal community quality.

8.5 Community Social Quality

This section provides a brief profile of how the total of all communities in each illustrative economic region score in their capacity to adapt to the influx of economic activity resulting from the possible introduction of any one of the three used nuclear fuel management approaches. Analysis of Aboriginal community impacts is presented in Section 8.7. In both cases the impact on community quality is independent of the approach for long-term used nuclear fuel management.

Community Social Quality: Social Capital

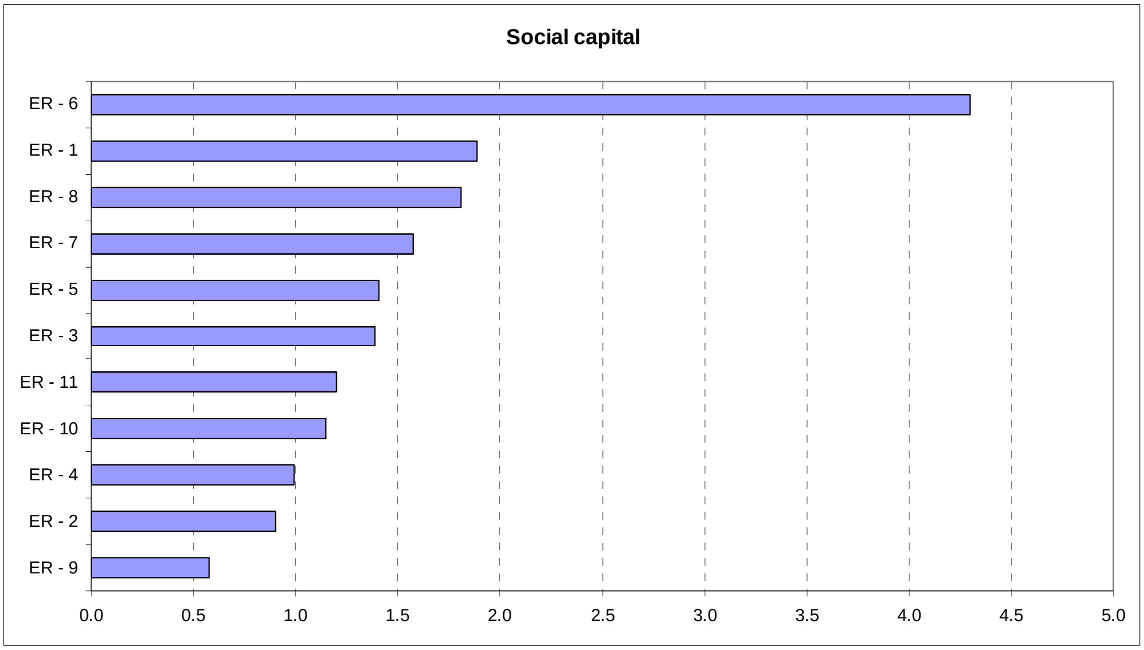
The "weights" measured for each of the selected indicators for the Social capital is detailed in Table 8.5-1.

Table 8.5-1: Scoring Social Capital by Economic Region

Economic Region	Social Capital		
	Density	Labour Force	Mobility
ER-8	0.14	1.88	3.41
ER-7	0.14	1.01	3.58
ER-6	5.00	4.23	3.67
ER-5	0.14	1.04	3.05
ER-4	0.01	1.07	1.89
ER-10	0.22	0.79	2.44
ER-9	0.00	0.83	0.91
ER-3	0.03	1.39	2.74
ER-11	0.14	1.85	1.60
ER-2	0.00	0.42	2.28
ER-1	0.03	1.28	4.35

When linking all three social indicators into the one measure for social capital, the ranking of social capital by economic region is illustrated in Figure 8.5-1. What stands out is how ER-6 out-ranks all other regions, followed by ER-1 and the other regions in Ontario. Of more importance, the rural and remote regions of Saskatchewan (ER-2), Ontario (ER-4) and Quebec (ER-9), mark very low in social capital.

Figure 8.5-1: Ranking of Social Capital by Economic Region



<u>Community Social Quality: Human Capital</u>

The “weights” measured for each of the selected indicators for the human capital is detailed in Table 8.5-2:

Table 8.5-2: Scoring Human Capital by Illustrative Economic Region

Economic Region	Human Capital			
	Education	Labour force	Unemployment	Life stress
ER-8	3.25	2.31	1.00	3.15
ER-7	2.94	1.47	0.62	3.48
ER-6	4.19	1.15	0.44	2.90
ER-5	2.63	0.68	0.24	2.93
ER-4	2.68	2.15	1.59	3.45
ER10	2.28	0.93	0.82	4.09
ER-9	0.66	3.95	2.69	4.67
ER-3	2.00	1.03	0.35	3.51
ER-11	2.90	1.04	2.06	2.01
ER-2	0.00	4.83	5.00	1.26
ER-1	3.35	1.55	1.69	3.48

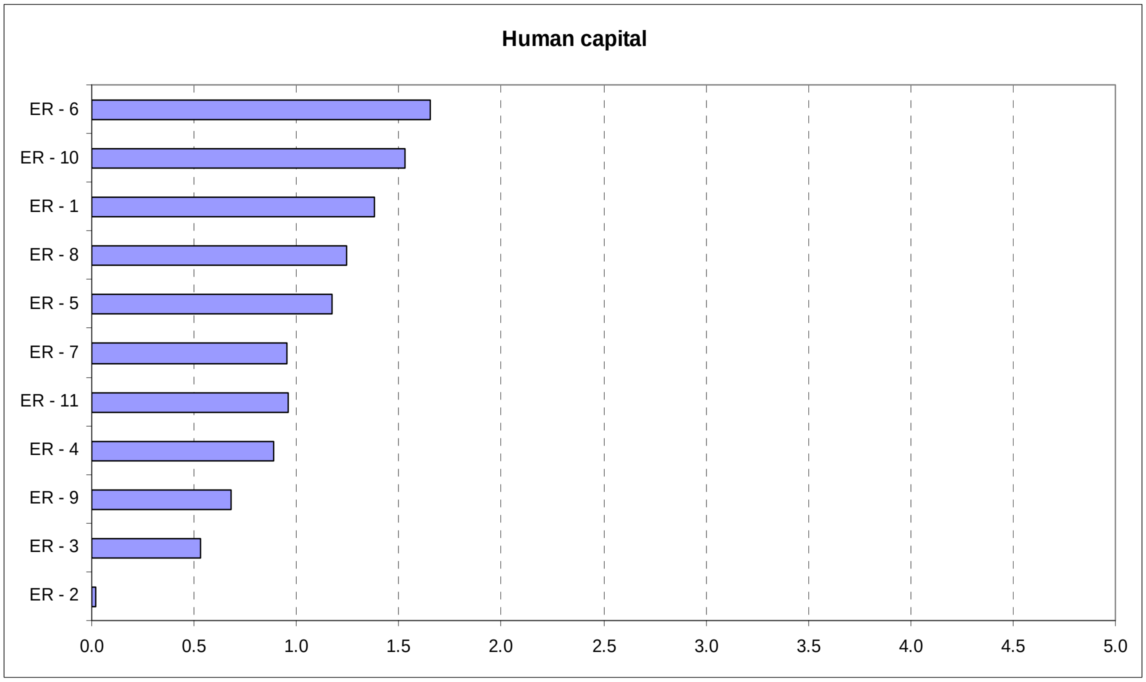
Economic Region	Human Capital (Continued)			
	Dependency	Practitioners	Specialists	Self-rated health
ER-8	1.80	2.54	2.51	2.51
ER-7	2.89	1.47	0.60	2.34
ER-6	0.55	1.19	1.69	3.21
ER-5	2.72	1.07	0.79	3.08
ER-4	1.43	1.62	1.19	1.55
ER-10	0.92	1.47	1.41	2.56
ER-9	1.31	2.11	0.94	2.75
ER-3	2.76	1.22	0.00	2.01
ER-11	1.20	2.05	1.83	0.36
ER-2	5.00	2.56	0.47	1.11
ER-1	2.25	2.94	1.41	4.28

Economic Region	Human Capital (Continued)			
	Life expectancy	Infant mortality	Asthma	Nutrition status
ER-8	3.20	2.11	2.78	3.16
ER-7	3.39	0.97	3.37	3.62
ER-6	4.46	0.71	1.17	3.92
ER-5	3.56	0.87	0.99	4.15
ER-4	2.57	1.52	2.67	2.67
ER-10	3.09	1.63		4.40
ER-9	0.00	4.98		1.35
ER-3	3.38	2.55	2.68	1.60
ER-11	3.15	0.84		1.31
ER-2	3.75	1.21	4.66	2.09
ER-1	4.01	0.74	3.57	3.79

Upon linking all twelve human capital indicators into one measure for human capital, a somewhat different picture arises in relation to the ranking of economic regions (Figure 8.5-2). Although

ER-6 ranks highest, ER-10 is a close second with ER-1 and ER-8 not far behind. What is similar to social capital is the relatively low ranking of the same rural and remote communities in Ontario, Quebec and Saskatchewan, but with the inclusion of Manitoba's ER-3.

Figure 8.5-2: Ranking of Human Capital by Economic Region



Community Social Quality: Physical Capital

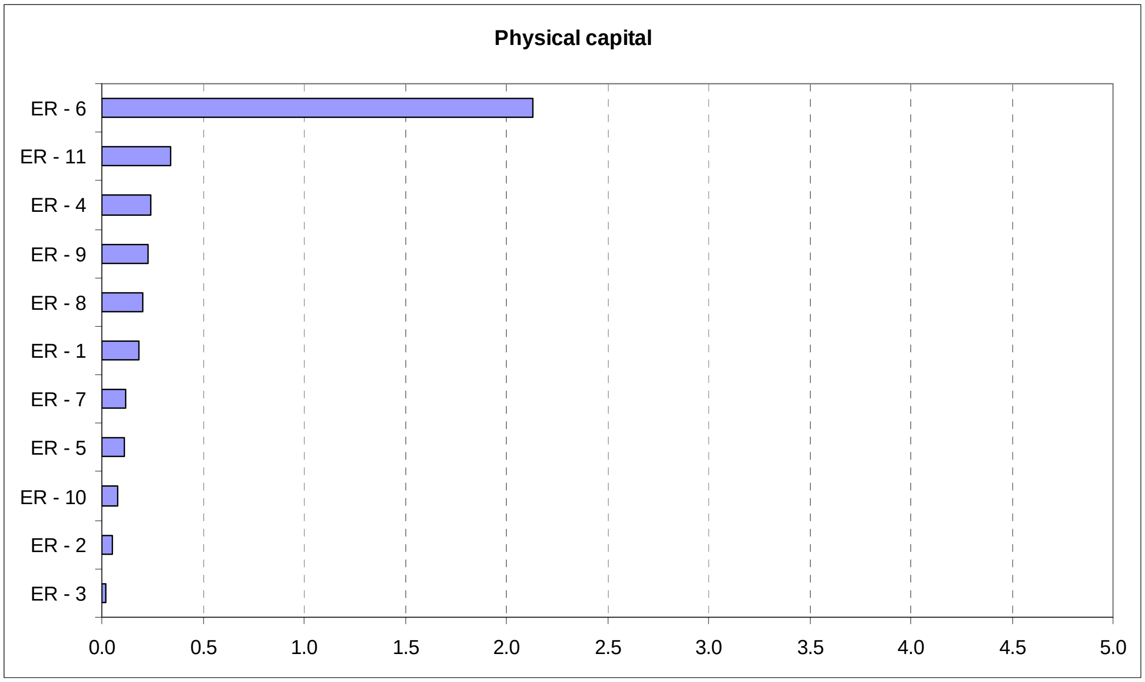
The “weights” measured for each of the selected indicators for the physical capital is detailed in Table 8.5-3:

Table 8.5-3: Scoring Physical Capital by Economic Region

Economic Region	Physical Capital	
	Public transport	Major repairs
ER-8	0.20	1.06
ER-7	0.12	1.00
ER-6	2.13	0.33
ER-5	0.11	0.95
ER-4	0.24	1.63
ER-10	0.08	0.89
ER-9	0.23	2.83
ER-3	0.02	1.49
ER-11	0.34	1.42
ER-2	0.05	5.00
ER-1	0.18	0.74

Despite the limited use of physical indicators, when both are merged into one physical capital measure (Figure 8.5-3), it is appears that all economic regions, except ER-6, lack the physical infrastructure to support any of the three management approaches for used nuclear fuel.

Figure 8.5-3: Ranking of Physical Capital by Economic Region



Community Social Quality: Financial Capital

The "weights" measured for each of the selected indicators for the financial capital is detailed in Table 8.5-4:

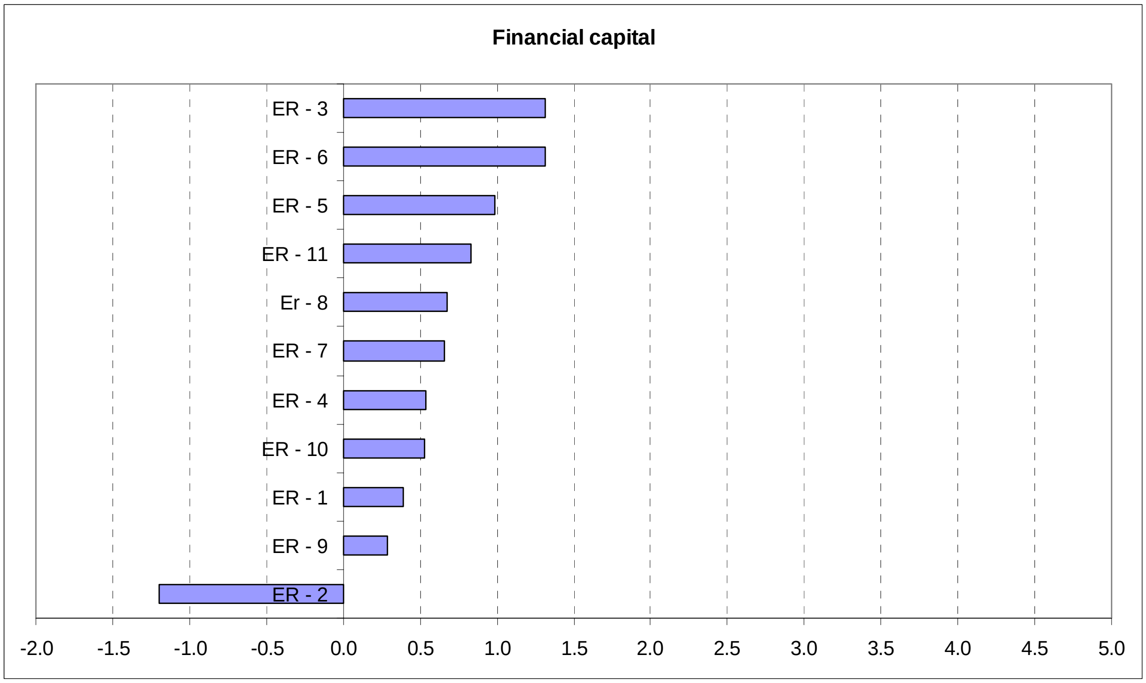
Table 8.5-4: Scoring Financial Capital by Economic Region

Economic Region	Financial Capital		
	Tenants' spending	Labour force	Own Economic Regions' spending
ER-8	3.18	1.22	1.84
ER-7	4.48	1.31	2.80
ER-6	3.77	3.92	3.87
ER-5	3.58	0.94	1.27
ER-4	4.26	1.99	2.10
ER-10	2.69	1.27	0.98
ER-9	0.83	0.63	0.62
ER-3	2.63	1.65	0.62
ER-11	3.26	2.02	0.91
ER-2	3.02	0.00	0.98
ER-1	4.53	1.80	3.18

Economic Region	Financial Capital (Continued)		
	Low income	Median Income	Private dwellings
ER-8	1.02	1.50	3.50
ER-7	0.68	1.37	4.08
ER-6	1.07	4.05	3.52
ER-5	0.31	1.72	3.84
ER-4	1.56	1.00	3.36
ER-10	1.43	0.54	3.25
ER-9	1.24	2.14	0.52
ER-3	0.56	1.54	4.57
ER-11	1.69	1.10	3.61
ER-2	5.00	0.00	0.00
ER-1	1.19	1.03	3.48

Upon linking the indicators for financial capital into one measure for financial capital, a different and interesting picture arises when comparing the economic regions (Figure 8.5-4). Specifically, ER-3 and ER-6 are the highest ranking regions in this capital, but no one region has an abundance of financial capital that can be leveraged to cope with the opportunities and challenges posed by any of the three management approaches for used nuclear fuel. Of more importance is that ER-2 scores a negative value for financial capital largely because of its high incidence of low income families.

Figure 8.5-4: Ranking of Financial Capital by Economic Region



Community Well-Being Index

The Community Well-Being (CWB) Index is a means of examining the well-being of individual Canadian communities. Various indicators of socio-economic well-being, including education, income, housing, and labour force activity, were derived from the 2001 Census of Canada and combined to give each community a well-being "score" between 0 and 1.

The CWB Index measures:

- ***Education***
  - Functional literacy (the proportion of the population, age fifteen and older, with at least a grade nine education may be interpreted as a proxy for functional literacy)
  - High-school plus (the most important benefit being "the process of enlarging people's choices")
- ***Labour force***
  - Participation in the Labour Force (expressed as a percentage of the population twenty years of age and over, rather than Statistics Canada's standard of fifteen years)
  - Employed Labour Force Participants (refer to the employed labour force expressed as a percentage of the total labour force aged fifteen years and over)
- ***Income*** (indicative of one's ability to purchase the necessities, comforts and conveniences that, cumulatively, enhance one's quality of life)

- ***Housing***
    - Housing quantity (One important consideration in the assessment of housing conditions related to crowding.)
    - Housing quality (Housing quality is ‘operationalized’ as the proportion of the population living in residences that are not in need of major repairs.)

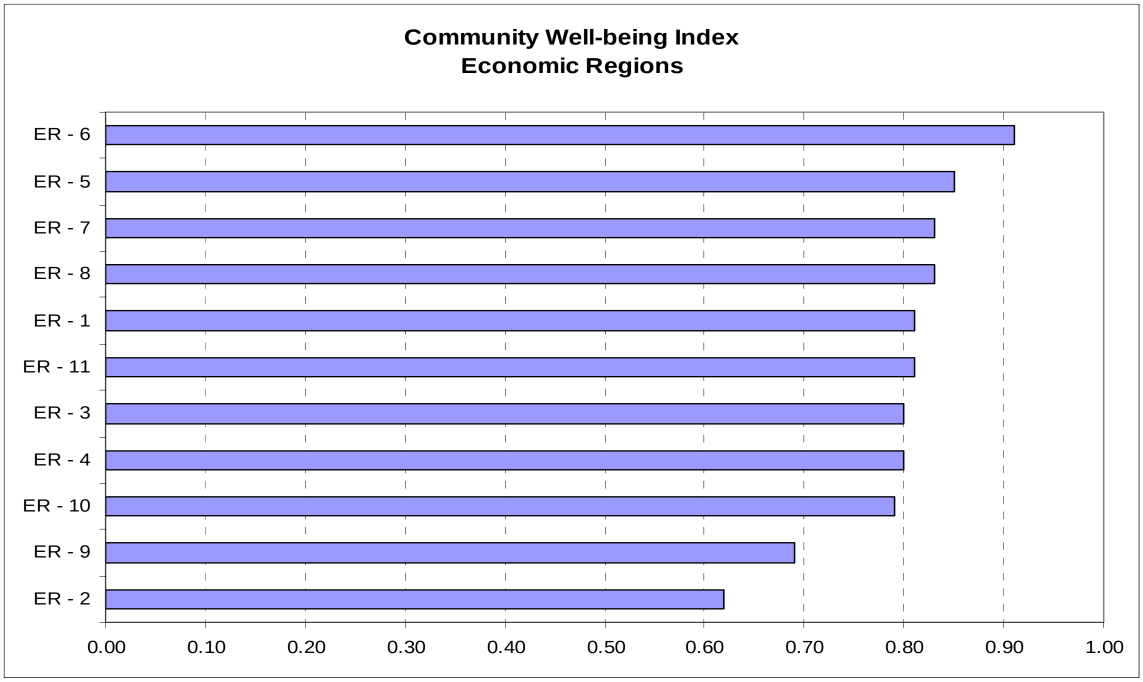
The scores from the CWB index for each of the illustrative economic regions are detailed in Table 8.5-5:

Table 8.5-5: Scores from the CWB Index for the Illustrative Economic Regions

ER	CWB
ER-8	0.83
ER-7	0.83
ER-6	0.91
ER-5	0.85
ER-4	0.8
ER-10	0.79
ER-9	0.69
ER-3	0.8
ER-11	0.81
ER-2	0.62
ER-1	0.81

These same scores are graphically illustrated in Figure 8.5-5, which shows that most economic regions are roughly equivalent, with the exception of the rural and remote regions of Saskatchewan and Quebec.

Figure 8.5-5: Comparison of CWB Index by Economic Region



Summary of Community Social Quality

Based on the value measured for each capital and region discussed above, a comparison of the four capitals is presented below as a means to illustrate trends and issues that will provide the basis for a more detailed assessment at the end of this section (Table 8.5-6).

Table 8.5-6: Comparison of Economic Regions Based on Their Capital Measures

Economic Regions	Above Average Score				Below Average Score			
	Social	Human	Physical	Financial	Social	Human	Physical	Financial
ER-8	√	√		√		√		
ER-7	√			√		√	√	
ER-6	√	√	√	√				
ER-5		√		√	√		√	
ER-4					√	√	√	√
ER-10		√			√		√	√
ER-9					√	√	√	√
ER-3				√	√	√	√	
ER-11			√	√	√	√		
ER-2					√	√	√	√
ER-1	√	√					√	√

Comparison Between Sustainable Livelihood Framework and Community Well-Being

The following section is an attempt to compare the results from the ranking of each economic region based on the Community Well-Being (CWB) index and the ranking from the Sustainable Livelihood Framework (SLF).

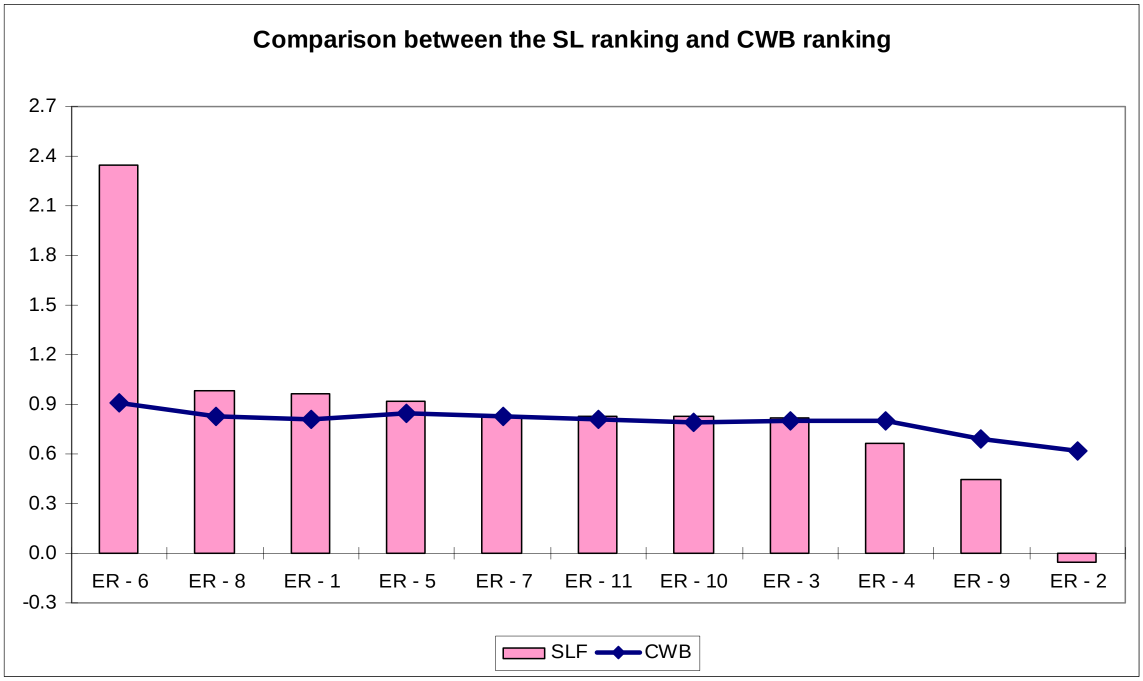
As both rankings are based on the same set of data (Census 2001), the comparison will serve as a "quality control" step for the results obtained previously through the SLF approach.

To compare both results the following steps were completed:

- CWB index
  - The average CWB index for each ER was calculated as the sum of the CWB index for all the communities within each ER divided by the number of communities.
- SLF
  - As the modified SLF is based on four capitals, in order to come up with a single value, the sum of all the capitals for each ER was divided by the number of capitals.

As shown below (Figure 8.5-6), both rankings are almost identical. The ER with the highest value in both cases is ER-6 (with a CWB index of 0.91 out of a maximum of 1, and with a SLF value of 2.35 out of a maximum of 5), while the ER with the lowest value is ER-2 (with a CWB index of 0.62 and a SFL value of -0.06).

Figure 8.5-6: Comparison Between the SL Ranking and CWB Ranking



8.6 Aboriginal Community Quality

This subsection provides a summary analysis of the three Sustainable Livelihood capitals used to describe the Aboriginal communities within the illustrative economic regions. Like the social community quality analysis (Section 8.5), the analysis is independent of the approach for managing used nuclear fuel. The focus here is on assessing how Aboriginal communities are positioned to adapt to the opportunities and challenges that are associated with the very large project expenditures described in the Economic Viability analysis

<u>Aboriginal Community Quality: Human Capital</u>

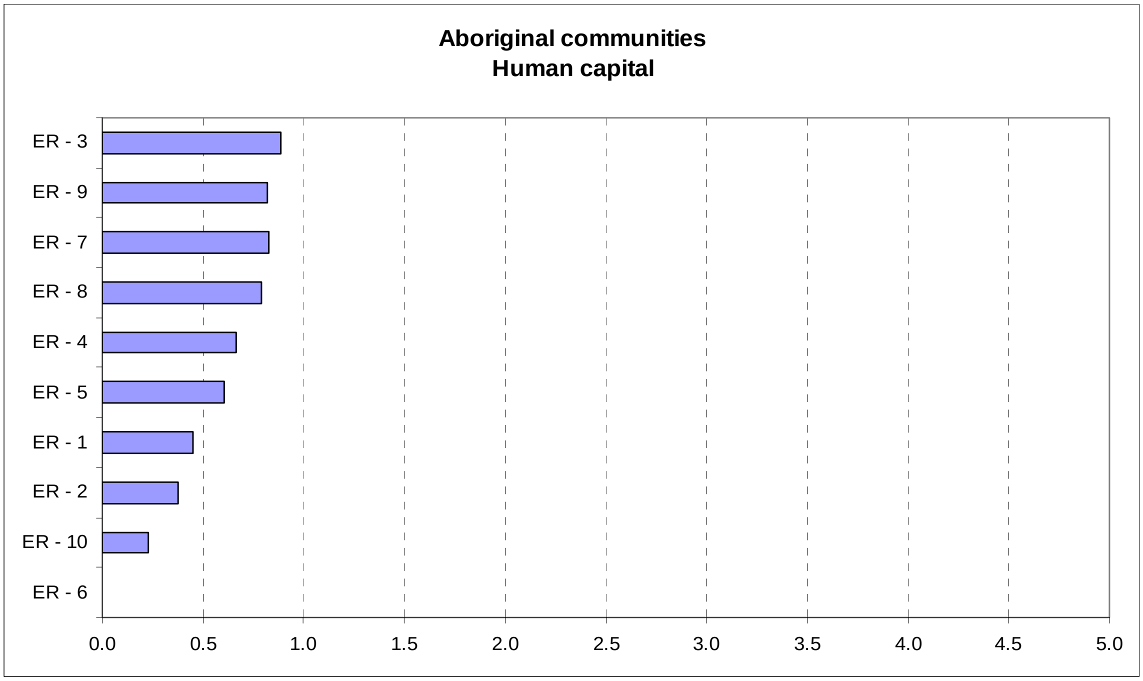
The results of the analysis for Aboriginal communities in terms of their human capital are detailed in Table 8.6-1.

Table 8.6-1: Scoring of Aboriginal Human Capital by Economic Region

Economic Regions	Human capital		
	Unemployment	Education	Labour force
ER-8	0.36	1.67	1.07
ER-7	0.32	1.68	1.11
ER-6	N/A	0.00	0.00
ER-5	0.87	1.04	1.65
ER-4	1.01	1.64	1.37
ER-10	0.75	0.71	0.72
ER-9	0.64	1.20	1.89
ER-3	1.78	2.84	1.60
ER-2	1.53	1.08	1.59
ER-1	1.35	1.50	1.20

Upon linking the above three capital indicators into one measure for Aboriginal human capital, (Figure 8.6-1), the following observations are evident. The economic region with the highest level of human capital for the Aboriginal communities is ER-3 (with 0.89 out of the maximum of 5), while ER-6 has the lowest level (with 0.00). However, none of the communities score very high on the 5-point scale used to compare communities across regions. The reason why ER-6 scores so low is that very few “status” Aboriginals reside in that region.

Figure 8.6-1: Ranking of Aboriginal Human Capital by Economic Region



Aboriginal Community Quality: Financial Capital

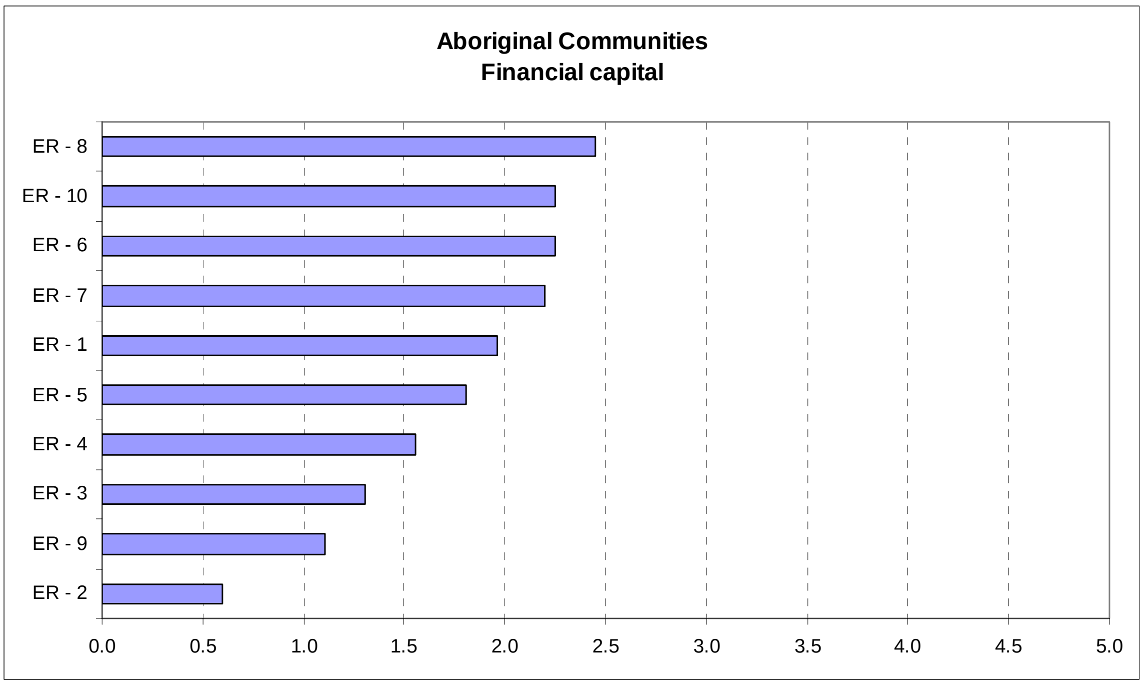
The results of the analysis for Aboriginal communities in terms of their financial capital is detailed in Table 8.6-2.

Table 8.6-2: Scoring Aboriginal Financial Capital by Economic Region

Economic Regions	Financial Capital		
	Home Ownership	Income	Labour Force
ER-8	3.87	1.98	1.50
ER-7	3.15	2.62	0.82
ER-6	2.00	N/A	2.50
ER-5	3.95	0.86	0.60
ER-4	2.54	1.50	0.63
ER-10	3.99	1.79	0.97
ER-9	0.17	2.36	0.78
ER-3	2.03	0.82	1.06
ER-2	0.41	0.68	0.69
ER-1	2.87	2.04	0.97

After linking the Aboriginal financial indicators into one measure for Aboriginal financial capital (Figure 8.6-2), a significantly different comparative picture emerges. The more heavily populated centres, (like ER-8, ER-6, ER-7, ER-10 and ER-1) tend to rank higher in Aboriginal financial capital. Of interest, the more rural economic regions continue to rank lower, with ER-2 the lowest.

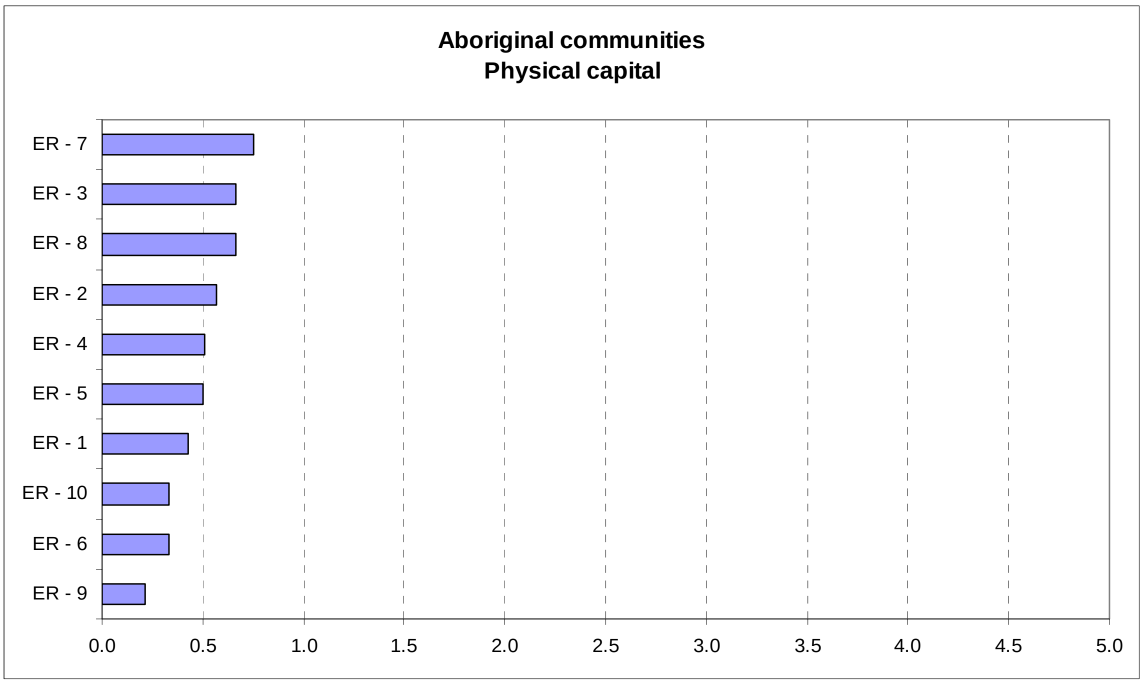
Figure 8.6-2: Ranking of Aboriginal Financial Capital by Economic Region



Aboriginal Community Quality: Physical Capital

The use of physical capital for the Aboriginal communities is limited by the few indicators used to explain differences and issues by economic regions. When linking the three indicators for Aboriginal physical capital into one capital measure the following picture emerges (Figure 8.6-3).

Figure 8.6-3: Ranking of Aboriginal Physical Capital by Economic Region



All Aboriginal communities ranked very low in physical capital and the ranking itself does not correlate with size of populations or proximity to large urban centres.

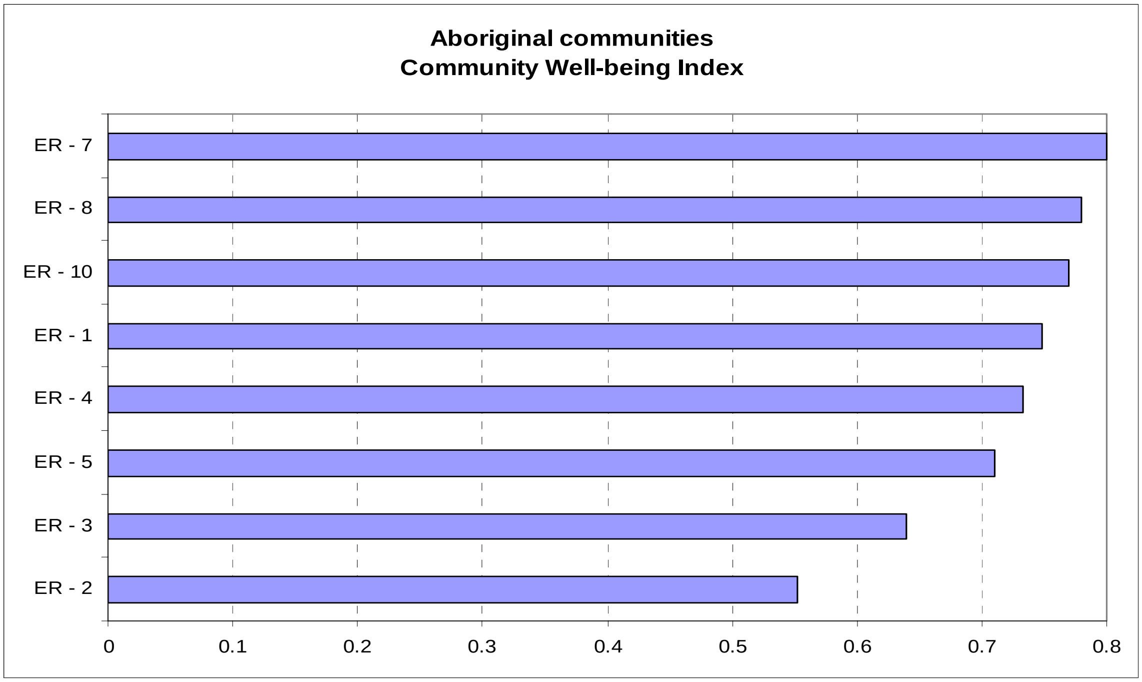
Community Well-being Index

The Community Well-being Index, previously described, was used to analyze how Aboriginal communities within each economic region scored. As the data for this index were gathered from a different source, the number of Aboriginal communities represented in this analysis is presented in Table 8.6-3, and the results of this comparison are illustrated in Figure 8.6-4.

Table 8.6-3: Number of Aboriginal Communities Used for the CWB Index (by ER)

Economic Region	Number of Aboriginal Communities for which data could be found
ER-8	1
ER-7	4
ER-6	0
ER-5	1
ER-4	21
ER-3	3
ER-10	2
ER-9	0
ER-11	0
ER-2	19
ER-1	28

Figure 8.6-4: Comparison of CWB Index Measures for Aboriginal Communities by Economic Region



As in the previous analysis, most economics score highly, with the exception of ER-2. No measure for ER-9 was available for this analysis. However, based on this information, Aboriginal communities in rural and remote regions tended to score below the populated regions.

Summary of Aboriginal Community Quality

Based on the value measured for each capital and region analyzed in this section, a summary comparison of the three Aboriginal capitals is presented below as a means to illustrate trends and issues that will provide the basis for a more detailed assessment at the end of this section (Table 8.6-4).

Table 8.6-4: Summary of Aboriginal Quality Measures

Economic Region	Above Average Measure			Below Average Measure		
	Human	Physical	Financial	Human	Physical	Financial
ER-8	√	√	√			
ER-7	√	√	√			
ER-6			√	√	√	
ER-5	√	√	√			
ER-4	√	√				√
ER-10			√	√	√	
ER-9	√				√	√
ER-3	√	√				√
ER-2		√		√		√
ER-1			√	√	√	

It is interesting to note that the economic regions with all three Aboriginal capitals above the average score for the eleven illustrative regions include ER-8, ER-7 and ER-5, while the economic regions that have two of the capitals below the group average include ER-6, ER-9, ER-10 and ER-2.

8.7 Other Socio-Economic Values

The foregoing analysis for community economic health, and community quality presented and discussed information that was measured by the study team. Absent from the quantitative analysis are the many values that communities may wish to protect or preserve, as well as a range of costs that may arise from the introduction of any one of the used nuclear fuel management approaches.

8.7.1 Community Values

Community values that may be negatively impacted include to varying degrees any of the following:

- Increased road congestion during construction
- Increased noise, dust and other nuisances
- Increase in the number of “transient” labour and other support workers
- Changes in community “character”, such as the loss of a rural town atmosphere
- Change in rural/remote wilderness experiences if road or air access is increased

The last two examples are most relevant if the Deep Geological Disposal or the Centralized Storage approaches are located in rural or remote areas of Canada. Although these values are very important to local residents, these values also hold some value to other Canadians located in urban centres. For example, residents of major population centres, place some value on knowing "wilderness" and wildlife are protected, because they either wish to visit such areas or simply know that they exist for future generations. No attempt was made to measure these values in this study.

8.7.2 Community Costs

There are a variety of costs that may arise within local and/or regional communities associated with any of the management approaches that add to overall costs, including but not limited to the following:

- Development of municipal infrastructure services to support increased labour and their families during peak construction periods
- Requirement for added social services during and after peak development activities to help address rising stress on families and local businesses as they cope with possible job and business losses
- Social stresses my include for example: increased crime and drug/alcohol abuse
- Property values are bound to rise and fall in direct proportion to the level of development activity. This means that certain property value protection measures will be required, as has been the case in numerous other rural and remote communities linked to single industry development activities.

8.8 Summary of Community Well-Being Analysis – A Comparison of Management Approaches

Community well-being is about how various communities might be affected from the introduction of any one of the three management approaches for used nuclear fuel. The comparison was based on a combination of quantitative and qualitative analyses. Economic impacts were measured using ***Input/Output*** models specifically developed for each of the eleven illustrative economic regions. Community capacities to adapt to the opportunities and challenges of the management approaches were measured using the ***Sustainable Livelihoods Framework***, specifically tailored to each of the eleven illustrative economic regions. Drawing on published literature and the study team's own experience in this field, qualitative discussion regarding community impacts were also provided.

The analysis for this objective was divided into three separate components as follows:

1. ***Community economic health.*** Using a customized Input/Output model for each of the eleven illustrative economic regions, the following measures were used to assess economic impacts:

    - Income
    - Employment
    - Tax revenues

    It is assumed that higher levels of employment, income and taxes are preferred by economic regions and the host provinces.

2. ***Community social quality***. The Sustainable Livelihoods Framework was used to assess the strengths of the following four "capitals", as a means to assess how well the eleven illustrative economic regions might be able to leverage the employment and income opportunities offered in their region, and cope with the challenges of adjusting to this change, for either of management approaches:

    - Human capital
    - Social capital
    - Financial capital
    - Physical capital

3. ***Aboriginal community quality.*** The Sustainable Livelihoods Framework was again used to assess the strengths of the following "capitals", as a means to assess how well Aboriginal communities in the eleven illustrative economic regions might be able to leverage the employment and income opportunities offered in their region, and cope with the challenges of adjusting to this change, for either of management approaches:

    - Human capital
    - Financial capital
    - Physical capital

    For both community social quality and Aboriginal community quality, it is assumed that higher scores for each "capital" are preferable, and that a balanced mix of capitals is also more preferable.

A detailed summary of the community well-being analysis for the three management approaches in terms of their benefits, risks and costs is presented below and is summarized in Table 8.8-1.

8.8.1 Community Economic Health

Benefits

All three approaches generate very significant economic benefits, in the form of thousands of new jobs and billions of dollars of new income to people and businesses across Canada, particularly in host provinces and economic regions.

In the near term, ***Deep Geological Disposal in the Canadian Shield*** provides the greatest economic benefits compared with Storage at Nuclear Reactor Sites or Centralized Storage (above or below ground). Specifically, between 89,000 and 124,000 full-time equivalent (FTE) jobs are created in the near term with Deep Geological Disposal in the Canadian Shield, almost eight times greater than ***Centralized Storage (above or below ground)*** and about two times greater than ***Storage at Nuclear Reactor Sites.*** For Deep Geological Disposal in the Canadian Shield, the difference in income, employment, and tax benefits in the illustrative economic regions examined is generally small.

Storage at Nuclear Reactor Sites is the only management approach that simultaneously develops facilities at all seven current reactor sites, with benefits distributed between economic regions according to the size of the respective facilities and the volume of used nuclear fuel. This means that the economic region hosting Darlington and Pickering nuclear reactor sites (i.e. ER-6), will be the recipient of the greatest economic benefits in terms of employment opportunities, income and tax revenues to all levels of government. However, each of the other economic regions that continue to host and manage used nuclear fuel also continues to capture significant economic benefits in their respective regions and provinces.

In the long term, only Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites require any significant ongoing maintenance and rebuilding activities. As such, the economic spin-off benefits continue cyclically for thousands of years to the benefit of future generations. This accounts for the apparent high economic benefits for these two management approaches during the monitoring, operating and rebuilding phases for each. However, it is a reasonable assumption that the operations of these two approaches is likely to change over time and therefore so will the economic benefits measured here.

Each of the three economic health measures (income, employment, and taxes) is different by economic region in the near term and long term. Specifically, in the near term (i.e. getting all used nuclear fuel in place), if Deep Geological Disposal in the Canadian Shield is selected, then ER-4 captures the greatest income, but ER-9 captures the greatest employment, while ER-2 captures the highest local taxes, in some cases by wide margins. These three illustrative economic regions are rural with low population densities and are generally dependent on resource-based industries such as forestry and mining. The fourth economic region (ER-7) is more diverse economically and has a relatively higher population density.

In the near term, the ranking of benefit changes yet again when considering Centralized Storage (above or below ground). In this case, ER-1 (which is located the greatest distance from used nuclear fuel sources) captures the largest income and employment benefits. The economic region is relatively prosperous, with a medium level of population density and a highly diverse economic base, with industrial manufacturing, extensive agriculture and forestry operations, and successful tourism and recreational sectors. This mix also provides a solid base for support industries and services that can supply the Centralized Storage management approach.

In comparison, the most remote economic region (ER-2) could capture very high employment and income benefits, on par with the other regions examined, but there tends to be slightly more "leakage" of benefits to other regions which can provide some of the support services inherent to a more urban structure.

In the long term, both Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground) provide very significant benefits to their respective economic regions. Yet, in most cases, the more urban economic regions like ER-1 and ER-6 stand to gain the most economic benefit.

Risks

Despite the very positive economic benefits resulting from all three approaches, there is a variety of social and economic costs that are attendant with projects of this nature, particularly when sited in rural and remote regions of Canada. For example, the eventual "boom and bust" cycle of large project implementations involving thousands of workers and billions of dollars in expenditures may precipitate the following consequences:

- Housing and land values will rapidly spike at the outset and crash upon project completion; and
- The large influx of workers will increase demand for social and physical infrastructure services, which will become oversized and inefficient once the project is completed.

These and other social issues must be addressed early on in the project planning stage. One essential element involves ensuring that communities are well equipped to cope and adapt to the social and economic changes that are attendant with such "mega-projects".

The risk of inaction in the near term carries significant consequences. It is necessary to plan beforehand how the communities within an economic region can participate in the benefits offered by each management approach, as well as how they will deal with the inevitable economic decline following closure or waiting for the next cyclical investment. The risk to communities and regions that might host Storage at Nuclear Reactor Sites is less compared to Centralized Storage or disposal management approaches. This is because these communities and associated regions already host temporary used nuclear fuel management facilities and for the most part have a more urban character with greater employment and servicing opportunities compared to rural and remote regions.

Costs

Along with the economic benefits, each of the alternative management approaches bring a wide range of potential social and economic costs that must be managed over the near and long terms. Such costs may likely include:

- Rising costs for basic services during the active phases of operations;
- Labour shortages and wage rate inflation also during the active phases of operations;
- With increased wealth and population growth, increases in crime and other social issues rise;
- Change in the nature and character of communities in the region, particularly those that are in close proximity to either Deep Geological Disposal or Centralized Storage;
- The impact on community character is likely to be less for Storage at Nuclear Reactor Sites since they already contain temporary used nuclear fuel handling facilities;
- A significant cost may be the impact on local housing. All available space gets absorbed by workers on the project and there is displacement and dislocation of long-term residents who cannot pay the escalating prices for accommodation.

During the “bust” or decline period(s), social and economic costs abound, such as:

- Loss of personal and family wealth;
- Out-migration;
- Increased financial and personal stress;
- Business closures and loss of supporting services;
- Increased crime and other social disorders;
- Drug / alcohol abuse;
- Reduced maintenance of public infrastructure and equipment; and
- Decline and loss of social services.

8.8.2 Community Social Quality

Benefits

The more urbanized (populated) economic regions of Canada tend to score higher in their sustainable livelihood capitals. That is, they have more of the attributes and factors that make up each of the four capitals measured in this study. This means that they are better suited to coping with (i.e., managing) the various social and economic issues raised in the previous section.

However, most of the technically feasible (ideal) locations for Deep Geological Disposal in the Canadian Shield occur in rural and remote regions that tend to contain fewer of the necessary capitals (facilities) to cope with the “shock” of boom and bust activities and/or take advantage of the opportunities offered by all three of management approaches.

Risks

There is risk of inaction or lack of recognition that rural and remote regions and communities will require greater assistance to enhance their adaptive capacities for change. Failure to act early on the investments in community capitals (human, social, physical, and financial capitals) may impair these communities in their ability to participate in negotiations as well as participate in the benefits from increased employment opportunities.

Costs

The comparisons of economic regions based on the Sustainable Livelihoods Framework, indicates that there are distinct differences among economic regions in terms of adaptive capacity.

The data suggests that ER-6 has a much higher adaptive capacity than all of the other economic regions. The data further suggest that ER-2, ER-9, ER-3, ER-10, ER-11, and ER-4 may have the lowest adaptive capacity of the economic regions profiled. ER-2, in particular, is consistently low among the indicators selected to characterize adaptive capacity. These differences are also revealed when the Community Well-being Index is used to compare the results from this analysis.

For example, relative to the other economic regions profiled, ER-6’s social capital index is more than twice as high as the social capital for any other ER profiled. This economic region also has the highest value on the Community Well-being Index.

ER-6 has the highest population density, the highest percentage of the labour force participating in the natural and applied sciences and related occupations, and the second highest percentage of population gains from population mobility. ER-6 also has the highest human capital index, as represented by the largest percentage of the population with post-secondary qualifications; a relatively low unemployment rate; the lowest dependency ratio; the highest life expectancy among the economic regions; and the lowest infant mortality rate. In terms of financial capital, ER-6's median household income indicator is twice that of any other economic region profiled.

ER-2 could be characterized as having the lowest adaptive capacity among economic regions profiled. It also has the lowest value among the economic regions on the Community Well-being Index.

ER-2 shares the lowest population density with ER-9, and has the lowest percentage of the labour force participating in the natural and applied sciences and related occupations. This ER has the lowest human capital index as represented by the lowest percentage of the population with post-secondary qualifications; the highest unemployment rate; a high percentage of the population reporting life stress; and the highest dependency ratio. In terms of financial capital, ER-2's median household income indicator is the lowest among the economic regions, and it has the highest incidence of low income. The percentage of the experienced labour force that works in business, finance and related occupations is also lowest in this economic region.

Implications

In comparing economic regions, we assume that the people within an economic region have greater or lesser adaptive capacity based on the relative strength of the livelihood assets present in the economic region. In the context of siting, designing, constructing and maintaining a facility for the management of used nuclear fuel – a major change by any definition - the ER comparisons help to:

- Identify possible ways to support people and communities in building their livelihood assets;
- Identify ways to encourage responsive support from institutions and organizations; and
- Identify avenues that people and communities might choose to harness change for social and economic enhancement.

Economic regions with relatively low adaptive capacity will likely face significant challenges in the basic process of engaging with NWMO even in preliminary discussions of possible siting. The analysis flags the need for early measures to build the capacity of people within such economic regions to effectively participate in discussions, dialogue and any required negotiations. Failure to employ early measures to build the capacity of people in economic regions with relatively low adaptive capacity could easily be characterized as "unfair".

People with the following attributes are unlikely to be able to engage fairly in discussions, dialogue and required negotiations:

- Focused on simply maintaining their livelihoods;
- Dealing with life stress;
- Caring for children and the elderly;
- Living on relatively low incomes;
- Living in sparsely populated areas where transportation and communication challenges are many;
- Do not have post-secondary qualifications;
- Have access to few experienced and employed professionals who could assist them in shaping discussions and required negotiations; and
- Have a variety of health challenges to deal with.

The same can also be said for the ability for such people to harness the social and economic opportunities represented by a facility for the management of used nuclear fuel in their economic region.

As a result, the siting of a facility for the management of used nuclear fuel in an economic region with low adaptive capacity will require that significant attention be devoted to working with the population and the institutions and organizations that serve the population, in order to identify meaningful and tangible ways for improving livelihoods and adaptive capacity.

8.8.3 Aboriginal Community Quality

Benefits

Aboriginals in more urban economic regions tend to have greater adaptive capacity to manage the issues and opportunities offered by all three management approaches, compared to the more rural and remote regions. However, most Aboriginal populations and communities are located in the rural and remote economic regions examined in this report.

Some rural and remote regions differ in their adaptive capacity because of past experiences in participating in mega-scale projects. This is particularly true of northern Quebec which has experienced a very large hydro electric development in the James Bay region. A recent study by Cooke *et. al*., 2004, indicates that Aboriginal communities in southern BC, southeastern Ontario and the Yukon have the highest well-being. This finding tends to support the results of this study's analysis.

Risks

The risk of inaction is high. There is an urgent need for investment in Aboriginal community services, infrastructure and institutions to enable effective and meaningful discussions with the NWMO and others.

Costs

A recent report from Indian and Northern Affairs Canada (INAC) notes that registered Indians "continue to have shorter life expectancy, lower educational attainment, and lower average annual incomes than do other Canadians"[83] The report notes that the gap in quality of life between registered First Nations people and other Canadians narrowed between 1981 and 2001, but that progress on narrowing the gap stalled between 1996 and 2001. The report further indicates that well-being varies more among Aboriginal communities than among other Canadian communities. The Aboriginal communities that have the highest well-being, according to the authors of this report, are concentrated in southern British Colombia, southeastern Ontario and the Yukon. Ninety-two Aboriginal communities appear in the bottom 100 of Canadian communities in 2001, while only one First Nation appears in the top 100.

The data reviewed here tend to support the findings of the INAC report discussed above. The comparisons of Aboriginal communities within the economic regions based on the Sustainable Livelihoods Framework, indicates that there are distinct differences among Aboriginal communities within regions in terms of adaptive capacity.

The data suggests that Aboriginal communities within ER-7, ER-8 and ER-5 have a relatively higher adaptive capacity than the Aboriginal communities in other economic regions. The data further suggest that Aboriginal communities in ER-2, ER-9, ER-10 and ER-6 may have the lowest adaptive capacity among Aboriginal communities of the economic regions profiled in this analysis. ER-2, in particular, is consistently low among the indicators selected to characterize adaptive capacity.

In comparison to aboriginal communities in the other economic regions, aboriginal communities in ER-7 have the lowest level of unemployment, the second highest level of educational achievement, the highest level of income, a relatively high level of home ownership, and relatively high levels of access to public transportation and public Internet access.

In comparing the overall populations of the economic regions, ER-2 is characterized as having the lowest adaptive capacity of all the regions profiled. The data for the Aboriginal communities

[83] Cooke, Beavon and McHardy, *Measuring the Well-Being of Aboriginal People*: *An application of the United Nations' Human Development Index to Registered Indians in Canada, 1981 – 2001*, 2004.

within this economic region reveal a similar pattern, which is accentuated by the above noted gap in the quality of life between registered First Nations people and other Canadians.

Aboriginal communities in ER-2 have the lowest ranking on the Community Well-being Index; the second highest level of unemployment; the third lowest level of educational achievement; the third lowest level of experienced labour force participation in the business, finance and administration sector; the lowest level of income; the second lowest level of home ownership; and at present, the lowest level of public Internet access.

Implications

Aboriginal communities within the economic regions with relatively low adaptive capacity will likely face far greater challenges on the basic process of engaging with NWMO than non-Aboriginal populations. As with the comparison of economic regions, the analysis of Aboriginal populations flags the need for early measures to build the capacity of Aboriginal people to effectively participate in discussions, dialogue and any required negotiations. Failure to employ early measures to build the capacity of Aboriginal people in economic regions with relatively low adaptive capacity could easily be characterized as "unfair".

As a result, the siting of any one of the three approaches in an economic region with an Aboriginal population with low adaptive capacity will require significant attention to working with the communities and the institutions and organizations that serve them, to identify meaningful and tangible ways to improve livelihoods and improve adaptive capacity.

Table 8.8-1: Summary of Community Well-Being Analysis – A Comparison of Management Approaches: Benefits, Risks and Costs

Objective	Benefits	Risks	Costs

Community Well-Being
Economic Health
 	
Influencing Factors:
- Income
- Employment
- Tax revenues
	• All three approaches provide significant economic benefits. No matter which management approach is ultimately used, and no matter what site location is preferred, economic benefits accrue to all Canadians, but the host province and region stand to capture the majority of employment, income and tax benefits.
	• In the near term (less than 175 years), Deep Geological Disposal in the Canadian Shield provides the greatest income, employment and tax benefits by a factor of two compared to storage at nuclear sites, and by a factor eight compared to Centralized Storage.
	• In the long term (after year 175), only Storage at Nuclear Reactor Sites and Centralized Storage generate any significant economic benefits form ongoing maintenance and cyclical facility rebuilding. Consequently, economic employment and income generating benefits continue for thousands of years. However, the most urbanized region tends to gain the most economic benefit in absolute terms.
	• Storage at Nuclear Reactor Sites is the only approach that simultaneously develops facilities at all seven current reactor sites, with benefits distributed to economic regions according to the size of their respective facilities and the volume of used nuclear fuel.
	• Centralized Storage and Deep Geological Disposal in the Canadian Shield management approaches require significant expenditures for transportation, which add thousands of jobs and income the whole of Canada, and is independent of site location.
		• Despite the very positive economic benefits resulting from all three management approaches, there is a variety of social and economic costs that are attendant with projects of this magnitude, particularly when sited in rural and remote regions of Canada.
		• "Boom and bust" cycles linked to each of the management approaches involves thousands of workers and billions of dollars of expenditures with the following likely effects:
		  ◦ Housing and land values will rapidly spike at the outset of project implementation and will crash upon project completion;
		  ◦ The large influx of short-term and temporary workers will increase demand for social and physical infrastructure services, which will become oversized and inefficient upon project completion; and
		  ◦ Local and regional governments cannot count on sustainable financing and tax revenues to manage life-cycle replacement and costing management of all support services and infrastructure with large swings in labour force activity.
		• The predicted employment, income and tax benefits are based on a current interactive model of the Canadian economy using data from the 2001 census. It is certain that as technology, governance, and other social dynamics evolve, these predictions of employment, income and tax benefits will provide inaccurate. However, for the short-term projections, it is reasonable to use this method of economic forecasting.
			• Along with the economic benefits, each of the alternative management approaches bring a range of social and economic costs that must be managed. Such costs may likely include:
			  ◦ Rising costs for basic services during the first phase of operations;
			  ◦ Labour shortages and wage rate inflation also during the first phase of operations;
			  ◦ With increased wealth and population growth, increases in crime and other social issues rise;
			  ◦ Change in the nature and character of communities in the region, particularly those that are in close proximity to either Deep Geological Disposal or Centralized Storage;
			  ◦ The impact on community character is likely to be less for Storage at Nuclear Reactor Sites since they already contain temporary used nuclear fuel handling facilities.
			• During the "bust" or decline period(s), social and economic costs abound, such as:
			  ◦ Loss of personal and family wealth
			  ◦ Out-migration
			  ◦ Increased financial and personal stress
			  ◦ Business closures and loss of supporting services
			  ◦ Increased crime and other social disorders
			  ◦ Drug / alcohol abuse

Table 8.8-1: Summary of Community Well-Being Analysis – A Comparison of Management Approaches: Benefits, Risks and Costs

Objective	Benefits	Risks	Costs

Community Well-Being
Social Community Quality
- Using the Sustainable Livelihoods Framework
- Four Capitals:
  - Social Capital
  - Human Capital
  - Physical Capital
  - Financial Capital
	• The more urbanized (populated) economic regions of Canada tend to score higher in their sustainable livelihood capitals. That is, they have more of the attributes and factors that make up each of the four capitals measured in this study.
	• However, most of the technically feasible locations for Deep Geological Disposal in the Canadian Shield occur in rural and remote regions that tend to contain fewer of the necessary capitals (facilities) to cope with the "shock" and/or take advantage of the opportunities offered by all three of management approaches.
		• There is risk of inaction. Failure to act early on the investments in community capitals (human, social, physical, and financial capitals) may impair these communities in their ability to participate in negotiations as well as participate in the benefits from increased employment opportunities.	• The costs are independent of management approach but tend to be greatest in rural and remote economic regions.
			• The various costs identified in community economic health can be managed; But this requires long-term planning and investment in the some or all of the Sustainable Livelihood Framework "Capitals".
			• The analysis of the all eleven economic regions shows that there are distinct differences among the regions in relation to their capacity to adapt to the positive and negative "shock(s)" that are linked to all three management approaches.
			• It is evident that the more rural and remote regions have the lowest adaptive capacity. Some remote regions have at the present time very high unemployment rates, a lower educated workforce, higher life stresses and the least opportunities for self-improvement. Thus, should either Centralized Storage or Deep Geological Disposal in the Canadian Shield locate in such a region, the local population is least capable of adapting to the new employment opportunities. This might mean that employment opportunities may go to non-residents who reside in the region only for the duration of the project activity.
			• The Sustainable Livelihoods Framework helps one to:
			  • Identify possible ways to support people and communities in building their livelihoods assets in the face of incoming activities linked to all three management approaches;
			  • Identify ways to encourage responsive support from institutions and organizations; and
			  • Identify avenues that people and communities might choose to harness change for social and economic enhancement.

Table 8.8-1: Summary of Community Well-Being Analysis – A Comparison of Management Approaches: Benefits, Risks and Costs

Objective	Benefits	Risks	Costs

			• Many of the rural and remote economic regions examined in this study face significant challenges in the basic process of engaging with the NWMO even in preliminary discussions of possible siting. The analysis flags many needs for early measures to build the capacity of people within these rural and remote regions to effectively participate in discussions, dialogue and employment opportunities offered by each of the alternative management approaches.
			• A sample of the required investments in personal and community capitals in rural and remote regions includes the following:
			  • Job training programs
			  • Affordable housing, property value protection
			  • Financing assistance for needed infrastructure (e.g. roads, schools, recreational facilities, etc.)
			  • More health care services
			  • Management training and assistance in planning for the "boom/bust' cycle(s)

Table 8.8-1: Summary of Community Well-Being Analysis – A Comparison of Management Approaches: Benefits, Risks and Costs

Community Well-Being
Aboriginal Community Quality
 	
- Using the Sustainable Livelihoods Framework
- Three Capitals:
  - Financial Capital
  - Human Capital
  - Physical Capital
	• Aboriginals in more urban economic regions tend to have greater adaptive capacity to manage the issues and opportunities offered by all three management approaches, compared to the more rural and remote regions.
	• Some rural and remote regions differ in their adaptive capacity because of past experiences in participating in mega-scale projects.
	• A recent study by Cooke *et. al*.[1] indicates that aboriginal communities in southern BC, southeastern Ontario and the Yukon have the highest well-being.
		• The risk of inaction is high. There is an urgent need for investment in Aboriginal community services, infrastructure and institutions to enable effective and meaningful discussions with the NWMO and others.	• Cooke *et. al*, 2004, indicate that 92 Aboriginal communities appear in the bottom 100 of Canadian communities in 2001, while only one First Nation appears in the top 100.
			• This study indicates that the Sustainable Livelihood capitals measured for Aboriginal communities in the illustrative economic regions tend to score poorly in the rural and remote regions.
			• Lack of social, human, and physical capitals make it very difficult for Aboriginals to engage in effective and meaningful dialogue with the NWMO and to participate in the many economic benefits linked to each of the management approaches.
			• Likewise, as the "boom & bust" cycle hits any of the regions, Aboriginal communities will be affected like all others in having to cope with a wide range of social and infrastructure issues. To an even greater extent than non-Aboriginal people, Aboriginal communities with the following attributes and constraints are unlikely to be able to engage fairly on discussions, dialogue and community preparation activities:
			  • Simply maintaining their livelihoods;
			  • Dealing with life stress;
			  • Caring for children and the elderly;
			  • Living on relatively low incomes;
			  • Living in sparsely populated areas where transportation and communication challenges are many;
			  • Few people with post-secondary education;
			  • Having few experienced and employed professionals who could assist in shaping discussions and required negotiations; and
			  • Having a variety of health challenges to deal with.
			• These and other issues need to managed at the outset through invest in long-term community planning, infrastructure services, and institutional strengthening.

[1] Cooke, Beavon and McHardy, *Measuring the Well-Being of Aboriginal People: An application of the United Nations' Human Development Index to Registered Indians in Canada, 1981 – 2001*, 2004.

9.0 ANALYSIS OF ENVIRONMENTAL INTEGRITY

9.1 Context for the Analysis of Environmental Integrity

Objective: *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)*[85].

Operation effects may occur in the near term (i.e., up to 175 years) or long into the future (i.e., >175 years). The analysis of environmental integrity includes all of the components of a management approach, including construction and operation of the facility, transportation of used nuclear fuel to the site, and long-term management.

This section provides an analysis of the risks to environmental integrity for each of the management approaches. The risks associated with the management approaches are dependent on the sensitivity of the environment in which they would be implemented within a particular economic region. Economic regions are not homogeneous, as they contain different and varied environments and environmental conditions (e.g., wilderness areas versus urbanized areas). This analysis was completed at the level of an economic region and as such is different from a site-specific analysis. A specific environmental assessment would need to be completed as part of any siting studies. However, regardless of the particular economic region, it is assumed that all management approaches can be implemented without causing any significant adverse environmental effects, by applying good engineering practices and meeting all industrial safety regulations and by applying standard mitigation measures and best management practices during the construction and operation of the facility.

9.2 Influencing Factors and Measures Used in the Analysis of Environmental Integrity

Measures are required to allow a comparative assessment of the benefits, risks and costs with respect to the environmental integrity of implementing each approach. It is assumed that all approaches are capable of being implemented without causing any significant environmental effects that cannot be avoided or mitigated using current environmental best management practices. Different environmental effects may result from implementing the same approach in different ecological settings or economic regions. In addition, there may be different

[85] Nuclear Waste Management Organization, *Understanding the Choices – The Future Management of Canada's Used Nuclear Fuel*, September 2004, page 67.

environmental effects between approaches. The indicators and measures used in the assessment are presented in Table 9.2-1 and include:

- Commonly used measures of environmental integrity, such as presence of sensitive habitats and presence of rare, endangered or threatened species/habitats;
- Commonly used measures of the significance of effects on a receptor, such as likelihood of occurrence, severity, ability to monitor and permanence of the effect;
- Consideration and development of the influencing factors used by the Assessment Team, including likelihood of impact to resources and significance of effect on the impacted receptor;
- Measures that are capable of being quantified for each approach, including the number of sensitive habitats and number of rare, endangered or threatened species/habitats; and
- Measures that allow possible differences between approaches to be highlighted, including those that may occur across illustrative economic regions.

The measures are based on quantitative information available in the literature or capable of being estimated within the timeframe available for the assessment. Their selection and evaluation builds on the approach used by GAL/GLL in similar studies and includes five principal assumptions:

- Risks to the environment result from potential **physical disturbances**, **radioactive releases** and **conventional contaminant releases**, including both normal and off-normal/accident scenarios;
- Ecological receptors include both the physical environment (e.g., air, water, soil) and the biophysical environment (e.g., animals, plants, fish);
- The overall risk to the environment is a function of the **likelihood of a pathway** by which an effect may reach an ecological receptor: the more likely a pathway, or the greater number of pathways, the greater likelihood of an effect;
- The overall sensitivity of an environment is a function of its **ecozones** or **forest regions** within each illustrative region. These ecozones may be characterized by the presence of sensitive habitats or rare, endangered or threatened species which provide a useful indicator of their relative sensitivity: the greater the number of sensitive habitats, the more sensitive the environment;
- The overall significance of an environmental effect is a function of the **likelihood, severity, ability to detect and permanence** of the effect: the greater the likelihood, severity and permanence, and lower the ability to detect, the greater the significance of the effect on the environment; and
- **Current experience** with environmental assessment provides a useful and appropriate basis for predicting and comparing the benefits and risks of implementing each of the approaches in the near and long term at the geographic level of an economic region (i.e., not a siting study).

Table 9.2-1: Influencing Factors and Measures Used in the Analysis of Environmental Integrity

Influencing Factors Used in Preliminary Comparative Assessment	Influencing Factors Used in this Analysis	Measures Used in this Analysis
Risk Scenario • Expected conditions (normal operation) • Off-normal scenarios	Type of Impacts of Construction and Operations Activities (normal conditions and accident conditions) • Physical disturbances • Radioactive releases • Conventional contaminant releases	Identification and qualitative analysis of the pathways between construction and operation activities and the environmental receptors
Likelihood of Impact to Resource • Expected conditions (normal operation) • Off-normal scenarios	Likelihood of Pathway to Receptor • Normal conditions • Accident conditions	Identification and qualitative analysis of the likely pathways by which stressors could act on the environmental receptors
Number/Sensitivity Elements of Ecosystem Potentially Impacted • Species • Watershed • Wetlands • Cultural/archaeological • Land use and extent • Aesthetics	Receptors or Resources Potentially Affected • Natural environment • Human environment	• Ecozones • Forest regions • Presence of sensitive habitats • Presence of rare, endangered or threatened species/habitats
Significance of potential Consequences to Impacted Resource	Significance of Effect on Impacted Receptor	• Likelihood of occurrence of effect • Severity of effect • Ability to detect and/or monitor effect • Permanence of effect

The following influencing factors were assessed qualitatively and are discussed in Section 9.4.5:

- Related to the *Number/Sensitivity of Elements of Ecosystems Potentially Impacted*
  - Cultural archaeological historical properties
  - Land usage
- Related to *Stresses Imposed by the Approach*
  - Wastes produced by the approach
  - Biological stressors
- Related to *Off-Normal Scenarios*
  - Significant change in environmental conditions

9.3 Methods and Details of Environmental Integrity Analysis

The analysis of potential environmental effects is based on a step-wise analysis that considers the types of activities that are expected to occur during construction and operation of the facilities, including the transportation of the used nuclear fuel to the sites (Stressors), and the environmental components that could be affected by these activities (Receptors). The analysis therefore considers the characteristics of the environment, noting where there are habitats of sensitive species, since these will be more susceptible to disruptive influences.

The approach to this analysis of potential effects at the economic region level is based on risk assessment principles, and is shown on Figure 9.3-1 (see Appendix A). The analysis process is described in the following sections. The intent of the analysis procedure is to identify those environments where effects of construction and operation of the facilities are likely to have a minimal impact on the environment.

9.3.1 Define Features of the Environment

Before any analysis can be undertaken, the features of the natural environment in each of the illustrative economic regions need to be identified and described. To facilitate the analysis, the ecozones within each of the illustrative economic regions were determined based on the ecozone definitions in the Atlas of Canada. Since forest type is often a major factor in determining which animal and plant species are present, the consideration of each zone also included characterization of the forest region. Such features do not follow the boundaries of the economic regions of Canada. Thus, a particular ecozone or forest region may be found in only one economic region or may span several economic regions.

9.3.2 Characterize Features of the Natural Environment

Following the definition of the features of the environment (i.e., the ecozones and forest regions), each ecozone was characterized. The analysis was based on the identification of “receptors”, which are those components, usually plant or animal species, that are likely to be directly or indirectly affected. Since these will ultimately be the receptors of any adverse effects from the construction or operation of the sites, they must be characterized before final site selection is undertaken, to ensure that environmental considerations have been included in the site selection process.

Additionally, since the presence of rare or endangered species or habitats is a major conservation concern, these receptors are considered as more sensitive and warrant special consideration. The description of each ecozone, therefore, includes an analysis of the sensitivity of each area based on the numbers and types of sensitive receptors. As part of the detailed environmental integrity analysis, each ecozone was defined in terms of the following characteristics:

- Geology, including soil characteristics;
- Hydrology, including major water features;
- Vegetation species, including tree and shrub species;
- Animal species, including mammals, fish, amphibians, reptiles, birds and insects; and
- Rare, threatened or endangered species.

In addition to the above features, any prominent or distinctive features of the ecozone were described along with any existing stressors on the environment (e.g., human impacts) in that zone.

9.3.3 Identify and Characterize the Project Works and Activities

As part of the environmental integrity analysis, the activities associated with each of the management approaches were described and the potential stressors identified. Stressors were identified for both normal conditions and off-normal conditions in the construction phase, near-term operations (<175 years) and long-term operations (>175 years). This identified where and how the facilities will interact with the environment. Many of the activities were common to all three management approaches, such as site preparation, and their stressors were likely to be similar, while other factors, such as transportation, differed considerably between options.

Each of the stressors was characterized by three types of impacts:

- **Physical Impacts**, which includes any activity that may result in land-clearing, loss of soils, construction access and construction of buildings;
- **Radiological Impacts**, which includes any activity that may result in a release of radionuclides; and
- **Conventional Contaminant Impacts**, which includes any activity that may result in a release of conventional contaminants, such as chemicals or dust.

For analysis under normal conditions, it was assumed that standard mitigation measures and best management practices will be employed at all sites. It was also assumed that all access roads will be constructed to current best management practices and will minimize the effects of construction runoff at stream crossings.

9.3.4 Identify Pathways Between the Project and the Environment

The interaction between the activities involved in the construction and operation of the facilities with the environment was considered (Pathways). Pathways are the different means by which the stressors could enter and affect the environment. If there are no means by which a stressor can enter the environment, there is no potential for effects or risks.

For each project activity, the pathway to the environment was identified. For construction-related impacts, pathways may include the loss of soil to air and deposition on vegetation, and loss of soils to water. Under accident (i.e., off-normal) scenarios, pathways could include failure of water collection systems that result in releases to water courses or failures of the air filtration systems that result in releases to outside air.

9.3.5 Identify Receptors Present in Defined Pathways

This step considers which receptors are present in the defined pathways, and thereby, whether there is the potential for exposure to the stressor. Only where there is a pathway is there a potential for a receptor to be exposed, and only where there is receptor is there the potential for an effect or risk to be present. The degree of exposure to the stressor; the sensitivity of the receptor to the stressor; the length of time that the stressor acts upon the receptor and the ability of the receptor to recover once the stressor is removed are all factors that determine the severity of the potential effect (discussed further in Section 9.3.6).

9.3.6 Identify and Assess Potential Effects

The analysis of potential effects on the environment considers the major project activities (Stressors); the major features of each ecozone (Receptors); and the interactions between the two (Pathways). The analysis considered normal conditions and accident scenarios. Those areas where there is a potential for adverse effects were identified.

The analysis in this report was based on a qualitative analysis, as this was not a siting study. The potential effects were assessed on the basis of knowledge of standard construction practices, and the descriptions of the management approaches. The assessment considered the general features of each of the ecozones where facilities could be located. It should be noted that there are many differences in the features of the environment within and across economic regions. Once sites have been selected, more detailed quantitative analysis can and should be undertaken.

Where there was a potential effect, the following four criteria were determined:

- The likelihood of occurrence of the effect;
- The ability to monitor and detect impacts early, before irreversible effects can occur;
- The severity of the effect (i.e., magnitude and extent); and
- The permanence of the effect should it occur.

The criteria for determining the above parameters are described in the following sections. If necessary, following the analysis of potential effects, those mitigation measures which may reduce the likelihood or magnitude of an adverse effect occurring were described.

Likelihood of Occurrence

The likelihood of occurrence of an off-normal effect was defined as high (likely), low (unlikely) or very low (very unlikely, less than one in a million). These probabilities are based on a number of existing peer-reviewed studies available for dry used nuclear fuel storage (similar in concept to Storage at Nuclear Reactor Sites) and for deep geological repositories (Deep Geological Disposal in the Canadian Shield). The probabilities are the same as those presented in the assessment of public health and safety (Section 4) and worker health and safety (Section 5).

Likelihood of occurrence does not apply to normal conditions as these are the conditions that are expected (i.e., they are likely to occur).

Ability to Monitor or Detect

The ability to monitor a site for potential adverse effects is a significant factor in the detection and remediation of any adverse effects. Detecting an impact early could prevent adverse effects and could result in less impact to the environment and more rapid remedial activities.

Monitoring potential was defined by the level of access to the site and to monitoring points, both for the near term and the long term. It also considers the general level of activity at the site, since those sites where there is a constant or frequent activity have a greater potential for early detection of potential impacts compared to those sites where there is infrequent activity. Level of access, including distance from local centres is a factor, since travel times can affect the level of monitoring activity.

For each normal and off-normal project activity, monitoring potential was assigned a value of good, moderate or poor. A facility which is located in a remote location, has infrequent activity and is difficult to access would receive a ‘poor’ monitoring potential.

Severity

The severity of an effect was determined based on the magnitude and extent of the effect. This factor considers the area that could be affected through an activity or accident. In particular, this addresses whether the impact of the activity will be confined to the immediate area, and will extend locally, regionally or nationally. The severity will be affected by other factors, such as the frequency and ease of monitoring, the nature of the stressor and the types of habitats and/or species that could be affected. This factor also considers the potential duration of the effect.

Severity was assigned a value of low, moderate, high or severe. A far-reaching effect with potentially significant consequences in an ecozone which is more susceptible to impacts would be considered a ‘severe’ effect.

Permanence

This factor considers how readily the effects of a stressor can be remediated. This will be dependent on the type of stressor; the area affected; the media affected; and the pathways by which the stressor can act upon receptors. For the purposes of this study, releases of contaminants to surface water or groundwater, for example, are considered not easily reversible, while release to soils are considered reversible simply due to the absorbency of soils which will typically contain materials and thus limit the area of potential effect. Spills to surface water would result in large and usually relatively rapid dispersal, which in most cases would be not be easily reversible. Leaks to groundwater would result in slower dispersal and impact to the water body than spills to surface water.

The permanence of an effect was assigned a value of low (easily reversed) or high (not easily reversed).

9.3.7 Assess the Significance of Adverse Effects

Once the stressors and the receptors of potential environmental effects were identified and characterized, the severity of the effect was determined using the methodology outlined in Section 9.3.6. The significance of the effect is assessed with respect to effects on local communities or population of species, since these are the viable units of the ecosystem.

The assessment of significance was made based on the qualitative analysis presented in this report. As this is not a siting study, the actual effects of any of the management approaches cannot be exactly determined within the scope of this assessment. This assessment was made based on current experience with environmental assessment of similar waste management projects and provides a useful and appropriate basis for predicting and comparing the benefits and risks of implementing each of the approaches at the geographic level of an economic region. Overall, the greater the likelihood, severity and permanence, and the lower the ability to detect, the greater the significance of the effect.

9.4 Results of the Environmental Integrity Analysis

This section presents the results of the analysis of environmental integrity.

9.4.1 Define Features of the Environment

As part of the environmental integrity analysis, the ecozones were identified for each of the illustrative economic regions. The distribution of ecozones with respect to illustrative economic regions is shown on Figure 9.4-1 (see Appendix A). The ecozones in which facilities could be located include the Boreal Shield, the Boreal Plain, the Taiga Shield, the Mixedwood Plains, the

Atlantic Maritime and the Montane Cordillera. As well, since transportation from the reactor sites to Centralized Storage sites and Deep Geological Disposal in the Canadian Shield sites is being considered, the Prairie ecozone is also included in the analysis, as the transportation routes to the west will pass through this zone.

Since forest type is often a major factor in determining which animal and plant species are present, the forest region was also identified for each illustrative economic region. Figure 9.4-2 (see Appendix A) illustrates the forest regions across Canada.

Table 9.4-1 summarizes the ecozones and forest regions applicable to each illustrative economic region and management approach.

Table 9.4-1: Ecozones and Forest Regions by Illustrative Economic Region

Illustrative Economic Region	Management Approach	Ecozone	Forest Region
ER-1	o Centralized Storage	Montane Cordillera	• Montane • Columbian • Subalpine • Grasslands
ER-2	o Deep Geological Disposal in the Canadian Shield o Centralized Storage	Boreal Plains	• Boreal • Boreal Forest and Grass
		Boreal Shield	• Boreal
		Taiga Shield	• Boreal Forest and Barren
ER-3	o Storage at Nuclear Reactor Sites	Prairies	• Grasslands
		Boreal Shield	• Boreal • Boreal Forest and Grass • Great Lakes-St. Lawrence
		Boreal Plains	• Boreal Forest and Grass
ER-4	o Deep Geological Disposal in the Canadian Shield o Centralized Storage	Boreal Shield	• Boreal • Great Lakes-St. Lawrence
ER-5	o Storage at Nuclear Reactor Sites	Mixedwood Plains	• Great Lakes-St. Lawrence
ER-6	o Storage at Nuclear Reactor Sites o Centralized Storage	Mixedwood Plains	• Deciduous (Carolinian)
ER-7	o Deep Geological Disposal in the Canadian Shield o Centralized Storage	Mixedwood Plains	• Great Lakes-St. Lawrence
		Boreal Shield	• Great Lakes-St. Lawrence
ER-8	o Storage at Nuclear Reactor Sites	Mixedwood Plains	• Deciduous (Carolinian) • Great Lakes-St. Lawrence
ER-9	o Deep Geological Disposal in the	Boreal Shield	• Boreal
		Taiga Shield	• Boreal Barren

	Canadian Shield o Centralized Storage		
ER-10	o Storage at Nuclear Reactor Sites	Atlantic Maritime	• Great Lakes-St. Lawrence • Boreal
		Mixedwood Plains	• Great Lakes-St Lawrence
ER-11	o Storage at Nuclear Reactor Sites	Atlantic Maritime	• Acadian • Great Lakes-St. Lawrence • Boreal

9.4.2 Characterize Features of the Existing Environment

The features of each of the ecozones were described, with particular attention to those species or habitats considered sensitive. The following sections provide a brief overview of the key environmental features of each the ecozones considered[86].

Boreal Shield

The Boreal Shield (so named as this is the area where the Canadian Shield and boreal forest overlap) stretches ~3,800 km from the northwest corner of Saskatchewan to Newfoundland, running just north of Lake Winnipeg, the Great Lakes and the St. Lawrence River, and covering an area of ~1.8 million km^2. The Boreal Shield encompasses part of five illustrative economic regions: ER-2, ER-3, ER-7, ER-8 and ER-9.

Water is a prominent feature of the Boreal Shield, with 10% of the country's freshwater contained here. The ecozone is dotted with a myriad of lakes (of varying size, all significantly smaller than the Great Lakes), streams and wetlands which cover nearly 20% of the ecozone. Many of these lakes are isolated, independent aquatic units. Large expanses of the Boreal Shield remain largely untouched by anthropogenic influences; however, the natural system has been subject to pressures and impacts resulting from mining, forestry, hydroelectric generation and fisheries (largely in the southern areas of the ecozone).

Generally, the vegetative diversity of the Boreal Shield is lower than that of the more southern ecozones due to characteristics such as soil and climate. The number of plant species considered

[86] *Canada's Ecozones*, http://www.canadianbiodiversity.mcgill.ca/english/ecozones/ecozones.htm; Canadian Council of Environmental Areas, *Terrestrial Ecozones of Canada*, http://www.ccea.org/ecozones/terr.htm; World Wildlife Fund , *Terrestrial Ecoregions* , 2001, http://www.worldwildlife.org/wildworld/profiles/terrestrial_na.html; Environment Canada, *The State of Canada's Environment – 1996*, Part II, Canadian Ecozones, 2004. http://www.ec.gc.ca/soer-ree/English/SOER/1996report/Doc/1-6-1.cfm (last updated 10/19/2004); Natural Resources Canada, *Forest Ecozones of Canada*, 2003, http://www.cfl.scf.rncan.gc.ca/ecosys/classif/intro_eco_e.htm (last updated 10/27/2003); and The Atlas of Canada, Natural Resources Canada, *Table 1 - Species at Risk by Ecozone*, 2004, http://atlas.gc.ca/site/english/maps/environment/ecology/threats/speciesatrisk/risk_table.html (Modified 9/13/2004).

rare varies from zero in the northern regions of the ecozone, to as many as ten in the most southerly areas neighbouring the Great Lakes-St. Lawrence forest region. As with plants, the diversity and number of mammal species varies throughout the ecozone by latitude, habitat and time of year. A total of 36 rare, threatened or endangered species have been identified in the Boreal Shield, including species of mammals, fish, reptiles, birds, insects and invertebrates. In general, a greater number of these species are found in the southern portions of the ecozone.

Boreal Plains

The Boreal Plains has a landmass of approximately 650,000 km^2 and is directly to the north of the Prairies ecozone. Covering an area from northeastern British Columbia east to central Manitoba it encapsulates all or part of ER-2, ER-3 and ER-4. The Boreal Plains comprise a mostly flat to gently rolling landscape with numerous poorly drained depressions (wetlands, peat bogs, etc.) found throughout the ecozone. This ecozone is characterized by mixed deciduous and coniferous forest, which cover over 80% of the landscape. Most of the surface waters in the Boreal Plains are part of three watersheds: the Peace/Athabasca/Slave Rivers, Saskatchewan River, and Beaver River watersheds. Several unique ecological features are found in the Boreal Plains ecozone, including the Peace-Athabasca Delta, which is one of the largest freshwater deltas in the world. The wetlands of the Boreal Plains are also of significance to waterfowl as migration staging/resting areas and provide the principal breeding grounds of the endangered whooping crane.

Forestry has been the primary disturbance to natural areas in the Boreal Plains. Other existing stressors in this ecozone are the result of agriculture, coal mining, recreation and oil and gas exploration. Despite these stressors, this ecozone is relatively unpopulated and it is estimated that 50% of the ecozone is still in an unaltered or natural state.

The Boreal Plains possesses comparatively fewer species considered at risk (generally less than 15 throughout this ecozone), with southern portions of the ecozone containing the majority.

Mixedwood Plains

At only 176,000 km^2, the Mixedwood Plains is the smallest, yet the most biologically diverse and economically productive ecozone in Canada. The Mixedwood Plains encompasses all or part of five illustrative economic regions: ER-5, ER-6, ER-7, ER-8 and ER-10. This ecozone borders three of the Great Lakes (Ontario, Erie and Huron) and includes the shoreline of the St. Lawrence River to Quebec City, and therefore contains an abundance of freshwater. The Great Lakes ecosystem is the largest freshwater lake system in the world. The most prominent physical features in this ecozone are the Monteregian Hills near Montreal, the Oak Ridges Moraine near Toronto, and the Niagara Escarpment through Ontario. Other significant ecological and evolutionary features present in the Mixedwood Plains ecozone include freshwater marshes and dunes, bogs and fens, hardwood and conifer swamps and the rare and unique alvar communities, which represent a globally endangered habitat.

Being the most populous ecozone has meant that human activities have had a significant impact on the Mixedwood Plains ecozone. Anthropogenic activity has negatively impacted natural areas of this ecozone resulting in few areas/habitats that are untouched or in their natural state. The Mixedwood Plains has a degree of biological diversity unparalleled anywhere else in Canada. Because, it is also one of the most heavily impacted ecozones in Canada, it consequently has the largest number of rare, threatened or endangered species (ranging from 20 in the northern portions of the ecozone to over 100 in the southern portions). The Carolinian Zone (found in the Lake Erie Lowlands sub-ecoregion) contains the highest number of rare species and accounts for over 40% of Ontario's rare plants.

Overall, because of the extent of disturbance to which the Mixedwood Plains has been subjected, sensitivity to further, unrestrained, perturbation is likely to be high.

Taiga Shield

The Taiga Shield is one of the largest ecozones in Canada, encompassing 1.3 million km^2. With respect to climate, soils and biological features, it is essentially an ecological transitional area between the Arctic ecozones to the north and the Boreal Shield to the south. The Taiga Shield is also divided in two by Hudson Bay. A portion of the Taiga Shield is located in ER-2 and ER-9. An abundance of water (lakes, rivers, bogs and wetlands) covers the landscape and the cold climate promotes the presence of permafrost throughout this ecozone (with continuous permafrost present in northern areas). Severe climate, a short growing season and recent glaciation have all contributed to lower biological productivity and diversity in the Taiga Shield, unlike ecozones in the southern parts of Canada.

The transitional area of forests and tundra in the Taiga Shield allows for a not insignificant overlap of woodland and barren-ground caribou; the eastern half of the ecozone houses the world's largest migrating herd. Other unique features of the ecozone include the presence of widespread string bogs (considered among the most extensively developed in North America) and a small and quite rare population of land-locked freshwater seals in Quebec. Anthropogenic impacts in this ecozone are largely restricted to hydroelectric power generation and mining. Compared to southern ecozones, the Taiga Shield is relatively unpopulated and well over 90% of the ecozone remains in a natural and generally undisturbed state.

The diversity of plants in this ecozone is not nearly as great as in southern ecozones. The species that do exist here are adapted to a harsh climate and thin, nutrient-poor soils. Approximately fifty species of mammals inhabit the Taiga Shield ecozone throughout the year, either as transients or permanent residents. Similar to other northern ecozones, the Taiga Shield possesses relatively few species of biota that are considered at risk (approximately 20).

Montane Cordillera

The Montane Cordillera is the largest ecozone west of the prairie provinces (473,000 km^2) and is the most diverse (topographically) of all the ecozones in Canada, a reflection of its highly variable landscape and associated assortment of ecosystems. ER-1 is located entirely within the Montane Cordillera. This ecozone encompasses the Alberta Rocky Mountain foothills, as well as a network of mountain ranges (i.e., Rocky and Columbian) and valleys in British Columbia. The ecozone's terrain is rugged and largely mountainous; these mountains encircling several major plains and valleys. A number of ecological and evolutionary phenomena are, or have become, unique to the Montane Cordillera, such as fragmented pockets of grasslands.

Human impacts on this ecozone have taken several forms, with forestry being the primary industry and the human activity resulting in the greatest perturbation to natural ecosystems. Other anthropogenic influences include mining, agriculture, urbanization and oil and gas exploration. Less than 15% of the original wetlands in the Okanagan Valley remain, owing to activities associated with agriculture and urbanization.

The Montane Cordillera contains over 30 species at risk , many of which reside in the Okanagan Valley.

Atlantic Maritime

The Atlantic Maritime ecozone is one of the smallest in Canada and includes Nova Scotia, New Brunswick, Prince Edward Island and a portion of Quebec. Part of ER-10 and all of ER-11 are located in the Atlantic Maritime ecozone. This ecozone is broadly divided into two major areas or topographic formations: the northern extension of the Appalachians (or uplands) and the Northumberland Plain (or coastal lowlands). Some of the unique ecosystems found here include mixed-wood forest, sand dunes stretching along seaboards, and coastal islands. Other distinctive features of the ecozone include the Bay of Fundy and the Annapolis Valley (fruit growing region). Although representing only 2% of Canada's landmass, the Atlantic Maritime ecozone encompasses over 11,000 km of coastline.

Critical terrestrial, freshwater, and marine ecosystems exist in the Atlantic Maritime ecozone that provide habitat for numerous biotic components. Forested areas are the dominant features of the landscape and comprise anywhere from 75 to 90% of the land area, depending on location. Human activities in the Atlantic Maritime ecozone have had a significant impact on the natural environment. Since European settlement, over 65% of the original coastal marshes in Nova Scotia and New Brunswick have been drained and diked for creation of arable land or urbanization. The number of species at risk in this ecozone varies depending on location and habitat. Those areas with the highest number of species at risk include the south shore of the St. Lawrence River, the northern parts of New Brunswick, and the southern portion of Nova Scotia.

Prairies

The Prairies ecozone is an area of approximately 520,000 km^2 stretching from the Rocky Mountains of Alberta to the Red River valley of Manitoba. The Prairies ecozone does not contain any of the illustrative economic regions, however, one of the potential transportation routes pass through this ecozone. The terrain is largely flat to gently rolling, which has made it ideal for agriculture. Over 90% of the Prairies land area has been extensively converted for agricultural purposes, making it the most heavily impacted and anthropogenically altered of all the ecozones.

The Prairies ecozone contains a number of wetlands and a number of major rivers transect the ecozone, including the South Saskatchewan, Qu'Appelle, Red Deer, Battle, North Saskatchewan, Assiniboine, and Bow Rivers. Over half of the ecozone's wetlands have been drained to support agricultural activity or urban development. As well, much of the area's natural vegetation has been extirpated, with the little that does remain (as little as 3% in some areas) existing in highly fragmented and vulnerable patches. Over half of the ecozone's wetlands have been drained for agriculture and urbanization and little of the natural vegetation remains (as little as 3% in some places) and, that which does is highly fragmented. The Prairies contains a disproportionately high number of threatened and endangered species (close to 40) given its size and population. The native ecosystems present here are among the most endangered natural habitats in the country.

Summary

All ecozones within the illustrative economic regions have unique features and characteristics in terms of the physical and biophysical environments. All ecozones are sensitive to environmental impacts. Environmental features and characteristics at the facility level will vary across ecozones and thus across economic regions. As noted above, this assessment is not a siting study - the actual features at the facility level for any of the management approaches cannot be exactly determined within the scope of this assessment. However, it may be possible to site a management facility at a location within any of the ecozones noted above without causing significant adverse environmental effects.

9.4.3 Identify and Characterize the Project Works and Activities

The detailed environmental integrity analysis considered an extensive number of project works and activities for each management approach. Table 9.4-2 summarizes the activities considered under normal conditions and the expected type of impacts resulting from each activity.

Table 9.4-2: Project Works and Activities and Potential Type of Impacts – Normal Conditions

	Applicable to Management Approach			Type of Impact		
Project Work or Activity	**Deep Geological Disposal**	**Centralized Storage**	**Storage at Nuclear Reactor Sites**	**Physical Impact**	**Radiological Impact**	**Conventional Contaminant Impact**
Site Preparation and Containment Construction	●	●	●	●		
Access Construction	●	●	●	●		
Re-packaging for Shipment	●	●				
Transport to Storage Site	●	●				
Monitoring Activities in Near Term	●	●	●			
Passive Storage in Near Term	●	●	●		●	●
Backfill and Storage in Long Term	●			●	●	●
Active Storage in Long Term		●	●		●	●
Building Refurbishments and Repackaging		●	●	●	●	●

A number of different off-normal scenarios were also considered in the environmental integrity analysis. Five representative (bounding) accident (i.e., off-normal) scenarios are considered in this section. They are:

- **Minor Upset on Site**: Leak in the containers during passive storage at the management facility (with no damage to the ventilation or other containment systems);
- **Major Upset on Site**: DSC drop during on-site transfer or fuel handling in the process building of the management facility (i.e., 100% failure of all fuel bundles and liberation of entire free inventory of tritium and Kr^{85} immediately into the environment);
- **Major Upset on Site**: Failure in the shaft and hoisting facilities in the below-ground management facility with ventilation failure (i.e., airborne particulates will bypass the High Efficiency Particulate Air filters);
- **Minor Upset in Transit**: A road or rail accident during transport (on or off site) causing the loss of a container with the integrity of the container not being compromised (i.e., no loss of contaminant, majority of effects associated with recovery of the container); and
- **Major Upset in Transit**: A road or rail accident during transport (on or off site) causing the loss of a container and the integrity of the container being compromised (i.e., loss of contaminant, release of contents to air and water).

Table 9.4.-3 summarizes the potential types of impacts associated with each of the off-normal scenarios.

Table 9.4-3: Off-Normal Scenarios and Potential Type of Impacts

Off-Normal Scenario	Applicable to Management Approach			Type of Impact		
	Deep Geological Disposal	Centralized Storage	Storage at Nuclear Reactor Sites	Physical Impact	Radiological Impact	Conventional Contaminant Impact
Minor Upset Onsite (leak in storage container, no damage to ventilation system)	•	•	•			
Major Upset Onsite (DSC drop during onsite transfer)		•	•		•	•
Major Upset Onsite (failure in shaft and hoisting facility)	•				•	•
Minor Upset in Transit (integrity of container not compromised)	•	•		•		
Major Upset in Transit (loss of container integrity)	•	•		•	•	•

9.4.4 Identify Pathways Between the Project and the Environment

Pathways are the different means by which the stressors could enter and affect the environment. If there are no means by which a stressor can enter the environment, there is no potential for effects or risks. Under normal conditions, it was assumed that standard mitigation measures and Best Management Practices will be applied. Subsequently, the following project works and activities under normal conditions were not considered to have a pathway to the environment:

- Repackaging for shipment;
- Transport to the storage facility;
- Monitoring activities;
- Passive storage in the near term; and
- Active storage in the long term.

Additionally no pathways were identified for one off-normal scenario – Minor Upset Onsite (leak in storage container, no failure in ventilation system) – as the passive storage is self-contained with existing mitigation including air and water treatment. Therefore, leaks would not reach the external environment beyond the storage facility. The remaining normal and off-normal scenarios have pathways to the environment via surface to aquatic habitats, airborne contaminants (to aquatic and terrestrial environments and human health) and destruction of terrestrial habitat.

9.4.5 Identify Receptors Present in Defined Pathways

Potential receptors of a stressor were defined for each of the normal and off-normal activities which were determined to have a pathway to the environment. Only where there is a pathway is there a potential for a receptor to be exposed. Table 9.4-4 summarizes the potential receptors defined in the analysis of environmental integrity.

Table 9.4-4: Potential Receptors – Normal and Off-Normal Scenarios

Project Work or Activity	Applicable to Management Approach			Receptor(s) Potentially Affected
	Deep Geological Disposal	Centralized Storage	Storage at Nuclear Reactor Sites	
Normal Scenarios				
Site Preparation and Containment Construction	•	•	•	Vegetation, terrestrial biota, aquatic biota (either directly or by loss of habitat)
Access Construction	•	•	•	Vegetation, terrestrial biota, aquatic biota (either directly or by loss of habitat)
Backfill and Storage in Long Term	•			Terrestrial biota, aquatic biota (either directly or by loss of habitat)
Building Refurbishments and Repackaging		•	•	Vegetation, terrestrial biota, aquatic biota (either directly or by loss of habitat)
Off-Normal Scenarios				
Major Upset Onsite (DSC drop during onsite transfer)		•	•	All habitats and biota (through release of container contents to air and/or water)
Major Upset Onsite (failure in shaft and hoisting facility)	•			Terrestrial biota, including humans, aquatic biota, contamination of vegetation (through airborne contamination)
Minor Upset in Transit (integrity of container not compromised)	•	•		Vegetation, terrestrial biota, aquatic biota (through direct impact of containers in aquatic environment, or by impact of machinery in recovery process)
Major Upset in Transit (loss of container integrity)	•	•		Vegetation, terrestrial biota, aquatic biota (through direct impact of containers in aquatic environment, impact of machinery in recovery process or through radioactive contamination)

9.4.6 Identify and Assess Potential Effects

A detailed assessment of potential effects of the three management approaches was carried out in the detailed environmental integrity analysis. The assessment considered the activities described in Section 9.4.3 together with the major features of each ecozone as described in Section 9.4.2. The assessment was carried out using the methodology described in Section 9.3.6.

The assessment considered both normal and off-normal scenarios. Table 9.4-5 summarizes the potential effects, by activity, of the management approaches under normal conditions. The description of the significance of the effects is provided in Section 9.4.7.

Table 9.4-5: Summary of Potential Effects Under Normal Conditions

Management Approach	Activity	Ecozone	Likelihood of Occurrence	Ability to Monitor/Detect	Severity of Effect	Permanence
Deep Geological Disposal in the Cdn. Shield	All Activities	• Boreal Shield • Mixedwood Plain • Taiga Shield	Low	Good until Closure Poor after Closure	Low	Low
Storage at Nuclear Reactor Sites	All Activities	• Boreal Shield • Mixedwood Plain • Atlantic Maritime	Low	Good	Low	Low
Centralized Storage (above or below ground)	All Activities	• Boreal Shield • Mixedwood Plain • Montane Cordillera • Taiga Shield	Low	Good	Low	Low

Following closure of the Deep Geological Disposal in the Canadian Shield facility, there will not be any active environmental monitoring, as monitoring in the long term is not feasible due to the nature of the facility; however, the likelihood of an effect occurring is low.

Tables 9.4-6 to 9.4-8 summarize the potential effects, by scenario, of the management approaches under off-normal accident conditions. While all environments are sensitive to the effects of stressors, some environments are inherently more sensitive. These are often those that possess unique features, or are already under stress from other factors that have resulted in a loss of stabilizing factors that provide resiliency. In these areas, the effects of accidents could result in greater ecological damage than in areas with greater resiliency or fewer unique features.

Table 9.4-6: Summary of Potential Effects Under Accident (Off-Normal) Conditions – Deep Geological Disposal in the Canadian Shield

Accident Scenario	Ecozone	Likelihood of Occurrence	Ability to Monitor/ Detect	Severity of Effect	Permanence
Minor upset on site	• Boreal Shield (ER-2, ER-7, ER-9)	Low	Poor	Moderate	High
	• Mixedwood Plains (ER-7) • Taiga Shield (ER-2, ER-9)	Low	Poor	Severe	High
Major upset on site	• Boreal Shield (ER-2, ER-7, ER-9)	Very Low	Good	High	High
	• Mixedwood Plains (ER-7) • Taiga Shield (ER-2, ER-9)	Very Low	Good	Severe	High
Minor upset in transit	• Boreal Shield (ER-2, ER-7, ER-9)	Low	Moderate	Low	Low
	• Mixedwood Plains (ER-7)	Low	Good	Low	Low
	• Taiga Shield (ER-2, ER-9)	Low	Moderate	Moderate	Low
Major upset in transit	• Boreal Shield (ER-2, ER-7, ER-9) • Taiga Shield (ER-2, ER-9)	Very Low	Moderate	High	High
	• Mixedwood Plains (ER-7)	Very Low	Good	Severe	High

Table 9.4-7: Summary of Potential Effects Under Accident (Off-Normal) Conditions – Storage at Nuclear Reactor Sites

Accident Scenario	Ecozone	Likelihood of Occurrence	Ability to Monitor/ Detect	Severity of Effect	Permanence
Minor upset on site	• Boreal Shield (ER-3, ER-8)	Low	Good	Negligible	Low
	• Mixedwood Plains (ER-5, ER-6, ER-8, ER-10) • Atlantic Maritime (ER-10, ER-11)	Low	Good	Negligible	Moderate
Major upset on site	• Boreal Shield (ER-3, ER-8)	Very Low	Good	High	High
	• Mixedwood Plains (ER-5, ER-6, ER-8, ER-10) • Atlantic Maritime (ER-10, ER-11)	Very Low	Good	Severe	High
Minor upset in transit (onsite)	• Boreal Shield (ER-3, ER-8)	Low	Moderate	Low	Low
	• Mixedwood Plains (ER-5, ER-6, ER-8, ER-10)	Low	Good	Moderate	Low
	• Atlantic Maritime (ER-10, ER-11)	Low	Good	Low	Low
Major upset in transit (onsite)	• Boreal Shield (ER-3, ER-8)	Very Low	Moderate	High	High
	• Mixedwood Plains (ER-5, ER-6, ER-8, ER-10) • Atlantic Maritime (ER-10, ER-11)	Very Low	Good	Severe	High

Table 9.4-8: Summary of Potential Effects Under Accident (Off-Normal) Conditions – Centralized Storage (above or below ground)

Accident Scenario	Ecozone	Likelihood of Occurrence	Ability to Monitor/ Detect	Severity of Effect	Permanence
Minor upset on site	• Boreal Shield (ER-2, ER-7, ER-9) • Mixedwood Plains (ER-6, ER-7)	Low	Good	Negligible	Moderate
	• Montane Cordillera (ER-1) • Taiga Shield (ER-2, ER-9)	Low	Moderate	Negligible	Moderate
Major upset on site	• Boreal Shield (ER-2, ER-7, ER-9)	Very Low	Good	High	High
	• Mixedwood Plains (ER-6, ER-7) • Montane Cordillera (ER-1) • Taiga Shield (ER-2, ER-9)	Very Low	Good	Severe	High
Minor upset in transit	• Boreal Shield (ER-2, ER-7, ER-9)	Low	Moderate	Low	Low
	• Mixedwood Plains (ER-6, ER-7)	Low	Good	Moderate	Low
	• Montane Cordillera (ER-1) • Taiga Shield (ER-2, ER-9)	Low	Moderate	Moderate	Low
	• Prairies (ER-1)	Low	Good	Low	Low
Major upset in transit	• Boreal Shield (ER-2, ER-7, ER-9) • Montane Cordillera (ER-1) • Taiga Shield (ER-2, ER-9) • Prairies (ER-1)	Very Low	Moderate	High	High
	• Mixedwood Plains (ER-6, ER-7)	Very Low	Good	Severe	High

9.4.7 Assess the Significance of Adverse Environmental Effects

The significance of the effects of the project was assessed using the methodology outlined in Section 9.3.7. The analysis of effects indicated that all three options are safe is constructed and operated as designed (i.e., the effects are expected to result in no significant impacts to the environment).

Any anticipated minor adverse environmental effects under normal conditions are limited to physical disruption of the site, with the associated loss of vegetation and habitat, and effects of some conventional contaminants such as fuels and lubricants during construction and refurbishment works. As a result, all management approaches can be constructed and operated under normal conditions in any illustrative economic region without causing unacceptable risks to the environment.

The analysis indicates that under off-normal (accident) scenarios, particularly those that involve release of contaminants, effects could be more severe in those areas which are more susceptible to a local impact. These are generally the ecozones which have had extensive impacts due to historical anthropogenic activities, and therefore have a larger number of sensitive habitats and rare, threatened and endangered species. As containment of the effect is a major concern in any accident scenario, releases in those areas where potential for containment is low, such as releases to water, present special concerns for both the environment and humans.

The highest risk areas, under accident scenarios, are those adjacent to large bodies of water, since impacts on these water resources could be far-ranging and could potentially have international consequences. These areas include the Mixedwood Plains ecozone (which is adjacent the Great Lakes) and the Atlantic Maritime ecozone (adjacent to the Atlantic Ocean). In addition, the Montane Cordillera, the Mixedwood Plains and the Prairies contain unique habitats that in some cases are found nowhere else, and thus would be particularly more susceptible to adverse effects.

The lowest risk areas were those ecozones that are less susceptible to a local impact. Generally, these were the ecozones which have not had extensive historical human impacts and still have generally undisturbed large tracts of land. These areas are characterized by large areas of similar habitat, relatively sparse development and a greater resiliency. Additionally, water bodies in these regions tended to be smaller with less potential for far-reaching effects on water resources, though the presence of large rivers will necessitate the need for careful consideration during final siting to minimize the potential for adverse effects.

The transportation routes for Centralized Storage (above or below ground) and Deep Geological Disposal in the Canadian Shield would likely traverse multiple ecozones.

All ecozones are sensitive to environmental impacts. Environmental features and characteristics at the facility level will vary across ecozones and thus across economic regions. As noted above, this assessment is not a siting study - the significance of potential adverse effects at the facility level for any of the management approaches cannot be exactly determined within the scope of this assessment.

9.4.8 Qualitative Description of Other Factors

The following measures or indicators are discussed qualitatively below.

Related to *Number/Sensitivity of Elements of Ecosystems Potentially Impacted*

The analysis of environmental integrity was carried out at the economic region level. However, the analysis of the environment is only feasible on a site-specific scale. It was not possible to describe and assess cultural archaeology historical properties and land usage, potential usage and opportunity cost, which are site-specific measures, within the scope of this assessment.

Related to *Stresses Imposed by the Approach*

For the analysis of environmental integrity, it was assumed that all best management practices would be in place during construction and operation of the facility. Wastes produced by the approach were assumed to be managed using standard management practices. Biological stresses from the project can only be assessed on a site-specific scale – thus, it was not possible to describe and assess them within the scope of this assessment.

Related to *Off-Normal Scenarios*

Significant changes in environmental conditions include effects from climate change. Overall, while all of the management approaches are considered feasible, the existing nuclear reactor sites may not be ideal from the perspective of a facility solely intended to safely manage used nuclear fuel for hundreds of thousands of years. Glacial cycles, including for Canada, occur about one every 100,000 years[87.] Surficial storage facilities (i.e., Centralized Storage (above ground) and Storage at Nuclear Reactor Sites) would not be capable of withstanding a glacial event.

9.5 Summary of Environmental Integrity Analysis – A Comparison of Management Approaches

This objective considers the potential effects on environmental integrity of all components of the management approaches, including construction and operation of the facility, transportation of used nuclear fuel to the site and long-term management. The environmental integrity analysis focuses on measures that may allow possible differences between approaches to be highlighted, including those that may occur across illustrative economic regions. Economic regions are not homogeneous, as they contain different and varied environments and environmental conditions (e.g., wilderness areas versus urbanized areas). This analysis was completed at the level of an economic region and as such is different from a site-specific analysis. However, regardless of the particular economic region, it is assumed that all approaches are capable of being implemented without causing any significant adverse environmental effects using current best management practices, although there may be differences between approaches.

The assessment used quantitative information available in the literature or capable of being estimated within the timeframe available for the assessment and builds on the approach used by the Assessment Team and by GAL/GLL in similar studies. Information was developed for each of the approaches within each of the illustrative economic regions. Current experience with respect to environmental assessment of similar waste management projects provides a useful and appropriate basis for predicting and comparing the benefits and risks of implementing each of the

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[87] EPICA, *Eight Glacial Cycles from an Antarctic Ice Core,* EPICA Community Members, Nature Publishing Group, Nature, Vol. 29, June 10, 2004, pp. 623-628.

approaches in the near and long term at the geographic level of an economic region. A specific environmental assessment would need to be completed as part of any siting studies.

The primary considerations for the analysis included:

1. **Risk scenario:** Risks to environmental integrity are as a result of disturbances caused by the management approaches, either under normal or off-normal conditions. Disturbances may be physical disturbances, radiological releases or conventional contaminant releases.

2. **Receptors or resources potentially affected**: All ecozones within illustrative economic regions have unique features and characteristics in terms of the physical and biophysical environment. All ecozones are sensitive to environmental impacts. Environmental features and characteristics at the facility level will vary across ecozones and across economic regions. Measures or characteristics of the environment are identified to make conclusions on the differences in the number, type and sensitivity of the features and species between economic regions.

3. **Significance of effects on the impacted receptor**: The significance of environmental effects under normal and off-normal conditions is assessed qualitatively by considering the likelihood, severity, ability to monitor and permanence of an adverse effect. It is assumed that an effect that is difficult to detect, large in extent and magnitude and difficult to reverse is a potentially significant adverse effect.

A summary of the environmental integrity analysis for the three management approaches in terms of their benefits, risks and costs is presented below and is detailed in Table 9.5-1.

Benefits

All three approaches can be constructed and operated without causing significant adverse effects on the environment in the near and long term. This is achieved by implementing standard mitigation measures and best management practices. The likelihood of the occurrence of off-normal conditions for each of the approaches is low to very low. This is independent of economic region. Differences between approaches result from their implementation in different ecozones, the type of effect and the need to transport used nuclear fuel.

As there is no requirement for transportation of used nuclear fuel for Storage at Nuclear Reactor Sites, there are no associated risks to the environment due to a transportation accident, although the likelihood of occurrence of a transport accident is low to very low.

Deep Geological Disposal in the Canadian Shield offers a benefit over the other two approaches with respect to withstanding effects of significant environmental change in the long term. The nature of the facility is such that it would not be susceptible to the effects of a glacial event. Facilities constructed at or near the surface are less likely to withstand such an event.

Risks

A distinguishing factor between the approaches is the ability to monitor their environmental performance over the long term. Following closure of the Deep Geological Disposal in the Canadian Shield facility, there would not be any active environmental monitoring, as monitoring in the long term is judged not to be feasible due to the nature of the facility; however, the likelihood of an adverse effect occurring is low because of the physical and geological barriers in the underground facility.

Transportation is also a distinguishing factor between the different approaches because of the need to transport used nuclear fuel between locations in the near term. All approaches other than Storage at Nuclear Reactor Sites require off-site transportation with the associated risks. However, best environmental management practices would be used to ensure these risks are low. The transportation routes for Centralized Storage (above or below ground) and Deep Geological Disposal in the Canadian Shield would likely traverse multiple ecozones. In addition, risks associated with transportation would be lowest for illustrative economic regions that are located closest to the current reactor sites.

The analysis of off-normal scenarios, particularly those that involve release of contaminants, indicates that effects could be more severe in those economic regions with a greater number of sensitive habitats and species. These ecozones may also have been previously impacted by historical activities and may be more susceptible to further disturbance. The effects of off-normal scenarios that may be most severe are in those locations adjacent to large continuous bodies of water, as the impacts on the water resources could be far ranging and could have international consequences. The Storage at Nuclear Reactor Sites management approach has the largest number of sites adjacent to large international water bodies. Additionally, Storage at Nuclear Reactor Sites would have seven separate facilities and therefore more potential interactions with the environment.

All ecozones are sensitive to environmental impacts. Environmental features and characteristics at the facility level vary across ecozones and thus across economic regions. As noted above, this assessment is not a siting study using site-specific information and accordingly the significance of potential adverse effects at the facility level for any of the management approaches cannot be exactly determined within the scope of this assessment.

Costs

Some of the costs for environmental integrity are accounted for in the economic costs of all three approaches through facility designs and monitoring programs. However, should societal values and/or environmental risks change with time, the degree to which Canadians understand what affects the environment might change. For example, society today places a higher value on environmental integrity than 25 years ago. Therefore, mitigation measures and compensation, if required, may result in additional future costs not included in the current cost estimates.

Table 9.5-1: Summary of Environmental Integrity Analysis - A Comparison of Management Approaches: Benefits, Risks and Costs

Measure or Indicator	Benefits	Risks	Costs
Sensitivity of Receptors Potentially Affected	• There are no benefits associated with this measure.	• For off-normal scenarios, the environment effects could be more severe in those economic regions with a greater number of sensitive species and habitats. These ecozones may also have been previously impacted by historical activities and may be more susceptible to further disturbance. • All ecozones are sensitive to environmental impacts. Environmental features and characteristics at the facility level will vary across ecozones and thus across economic regions. As noted above, this assessment is not a siting study using site-specific information and accordingly the significance of potential adverse effects at the facility level for any of the management approaches cannot be exactly determined within the scope of this assessment.	• There are no costs associated with this measure.
Significance of the Effect on the Environment	• Under normal conditions, all three management approaches can be constructed and operated without causing significant adverse effects on the environment in the near and long term. This is achieved by implementing standard mitigation measures and best management practices. • There is no requirement for off-site transportation of used nuclear fuel for <u>Storage at Nuclear Reactor Sites</u>; therefore, there are no associated risks to the environment due to a transportation accident, although the likelihood of occurrence of a transport accident is low to very low. • <u>Deep Geological Disposal in the Canadian Shield</u> offers a benefit over the other two approaches with respect to withstanding effects of significant environmental change in the long term. The nature of the facility is such that it would not be susceptible to the effects of a glacial event. Facilities constructed at or near the surface are less likely to withstand such an event.	• Following closure of the <u>Deep Geological Disposal in the Canadian Shield</u> facility, there will not be any monitoring for effects, as monitoring is not feasible due to the nature of the facility; however, the likelihood of an adverse effect occurring is low because of the physical and geological barriers in the underground facility. • The effects of off-normal scenarios that may be most severe are in those locations adjacent to large continuous bodies of water, as the impacts on the water resources could be far ranging and could have international consequences. The <u>Storage at Nuclear Reactor Sites</u> management approach has the largest number of sites adjacent to large international water bodies. Additionally, Storage at Nuclear Reactor Sites will have seven separate facilities and therefore more potential interactions with the environment. • All approaches other than Storage at Nuclear Reactor Sites require off-site transportation with the associated risks. However, best environmental management practices will be used to ensure these risks are low. The transportation routes for <u>Centralized Storage</u> (above or below ground) and <u>Deep Geological Disposal in the Canadian Shield</u> would likely traverse multiple ecozones. In addition, risks associated with transportation would be lowest for illustrative economic regions that are located closest to the current reactor sites.	• Some costs for environmental integrity are accounted for in the economic costs of the management approaches through facility designs and monitoring programs. However, should societal values and/or environmental risks change with time, the degree to which Canadians understand what affects the environment might change. For example, society today places a higher value on environmental integrity than 25 years ago. Therefore, mitigation measures and compensation, if required, may result in additional future costs not included in the current cost estimates.

10.0 ANALYSIS OF ADAPTABILITY

Objective: *If something is adaptable, it means that it can 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 other objectives identified in the hierarchy can be achieved*[88].

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 4-4 (ref: Understanding the Choices) 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 they 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 degrees to which the selected approach is able to function satisfactorily in the event of unforeseen "surprises"[89].

10.1 Methods and Measures Used in the Analysis of Adaptability

The study team qualitatively evaluated how the influencing factors and measures identified by the NWMO Assessment Team were impacted by each of the management approaches, ensuring that consideration for location and time were factored in. This evaluation involved no formal ranking or scoring of factors. Rather, the study team assessed how the measures might be impacted in relation to benefits, risks and costs.

No attempt was made to develop alternative influencing factors since it was felt the NWMO Assessment Team had reasonably captured the wide range of possible factors. All influencing factors identified by the Assessment Team were considered and are listed in Table 10.1-1.

[88] Nuclear Waste Management Organization, *Understanding the Choices – The Future Management of Canada's Used Nuclear Fuel*, September 2004, page 71.
[89] ibid, page 71

Table 10.1-1: Influencing Factors Used in the Analysis of Adaptability

Influencing Factors used in Preliminary Comparative Assessment	Influencing Factors used in this Analysis	Measures used in this Analysis
Availability Of Necessary Capacity, Mechanisms And Resources For Long Term	Availability Of Necessary Capacity, Mechanisms And Resources For Long Term	• Financial viability (and surety) – cost requirements over time • Possible safety and environmental concerns and the institutional and operational framework(s) required to ensure long-term viability and monitoring
Adequacy of Institutions and Governance	Adequacy of Institutions and Governance	• Consideration of adequacy of institutions and governance models
Ability/Need to Take Corrective Actions That Address Surprises	Ability/Need to Take Corrective Actions That Address Surprises	• Approach flexibility/irretrievability • Susceptibility to "surprises" • Planning for adverse effects • Monitoring and implementation of corrective measures. • Ability to monitor performance • Opportunities for monitoring and periodic reassessment • Speed of adjustment • Repairability/reversability
Accountability	Accountability	• Opportunity for public to influence decision-making

10.2 Summary of Adaptability Analysis- A Comparison of Management Approaches

Adaptability as considered in this assessment relates to the ability of future generations to modify or change aspects of any management approach over time in response to changing societal values and/or technology. The comparative assessment of the management approaches was based the study team's judgement of how each of the three approaches relates to the influences identified by the Assessment Team. No additional criteria or impact measures for the adaptability objective were developed.

It is recognized that "adaptability" is comprised of many considerations and elements as identified by the NWMO Assessment Team. The influencing measures that this study team focused on include the following:

- Availability of necessary capacity, mechanisms and resources for long term
- Adequacy of institutions and governance

- Ability/need to take corrective actions that address surprises
- Accountability

Each of the above four measures are consistent with those considered in other studies of this nature, but more important, they are the key impact measures identified by the Assessment Team. The location of any management approach is not a significant factor in the assessment of adaptability.

A summary of the adaptability analysis for the three management approaches in terms of their benefits, risks and costs is presented below and is detailed in Table 10.2-1.

Benefits

Being able to offer a “complete” solution to the management of used nuclear fuel within the near term has unique value. Only Deep Geological Disposal minimizes the need for a long-term governance structure and supporting institutions to ensure long-term safety. This complete solution is of value because in the long term, there can be no guarantees that ensure necessary governance and supporting institutions.

However, Deep Geological Disposal is limited by not being able to adapt to new technologies or respond to alternative social values and decisions. Only the two storage approaches, Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground), have the capability to enable future generations to easily influence the long-term management of used nuclear fuel.

The process being followed by the NWMO is transparent and open to the public. When the selection process begins for a management approach and location, more stakeholder input and participation will be required to ensure public accountability. As discussed in the Community Well-Being section, it is important to recognize that public involvement will be required in the siting, design, construction, and operational phases of any preferred management approach.

Risks

The risk consideration that most affects adaptability relates to how science, technology, and social values change over time. As these change, it may be necessary or prudent to make changes to any of the three management approaches. Consider for example how science and technology has changed over the past 40 years in relation to municipal waste disposal. Specifically, municipalities managed all types of waste into "dumps" with minimal regard for how groundwater might be affected over the long term. This situation arose because there was limited science available to indicate the effects and consequences that now have to be dealt with, such as leachate seepage into groundwater and its attendant cost of remediation.

It is not possible to predict with any confidence how scientific knowledge or technology will change over time, other than it is reasonable to expect that it will change. At the same time, social dynamics and institutions that influence the mechanisms and processes for managing used nuclear fuel are also likely to change. Taken together, these changes will affect how society values risk and the trade-offs used to evaluate the management approaches. Over the long term, it is not possible to guarantee that the necessary safety and environmental concerns most relevant to Storage at Nuclear Reactor Sites or Centralized Storage (above or below ground) will continue to be monitored, appropriately. Further, no one can guarantee that the institutional and operational framework(s) required to ensure long-term monitoring and management will be in place to prevent inadvertent intrusion into the underground facilities of Deep Geological Disposal. Even if institutional controls are in place, it is possible that any one of the three approaches might require retrieving and/or mitigation measures to prevent or reverse adverse effects.

Costs

The cost of reversing or altering current decisions regarding any of the management approaches has not been factored into the Joint Waste Owners' cost estimates. This is an issue of particular importance to Deep Geological Disposal after the facility has been decommissioned and closed and the opportunity for remedial actions may be limited.

Although the risk of adverse events are very low, the costs related to reversing health or environmental effects have not been accounted for by the Joint Waste Owners' estimates;, however, it is reasonable to assume that these costs would be high based on experiences documented by the U.S. National Academy of Sciences [90].

[90] National Academy of Sciences, *A Strategic Vision for Department of Energy Environmental Quality Research and Development*, 2001.

Table 10.2-1: Summary of Adaptability Analysis - A Comparison of Management Approaches: Benefits, Risks and Costs

Measure or Indicator	Benefits	Risks	Costs
Availability Of Necessary Capacity, Mechanisms And Resources For Long Term	• Being able to offer an "immediate" solution in the near term is a benefit, since it does not impair future generations in terms of cyclical or significant costs to manage. Deep Geological Disposal in the Canadian Shield is in place by year 59, with decommissioning and closure by year 154. Because of this relatively short-term management approach, the need for adaptability in relation to financial surety is minimal in comparison to Centralized Storage (above or below ground) or Storage at Nuclear Reactor Sites, which both incur costs for thousands of years. • It is understood that all the necessary technologies, processes, financial means and other resources are in place for Deep Geological Disposal in the Canadian Shield. This is also true for the other approaches, with the exception of financial resources (see discussion in Section 7.0). • All three management approaches will require long-term monitoring as it relates to safety and environmental concerns. The institutions and management responsibilities for used nuclear fuel for all these approaches will require some form of oversight, which cannot be guaranteed in the long term. However, Deep Geological Disposal in the Canadian Shield can remain in place with no planned intervention or monitoring, whereas Centralized Storage and Storage at Nuclear Reactor Sites require active management interventions on a regular basis. This constitutes a benefit for Deep Geological Disposal in the Canadian Shield on one hand, yet this also poses a risk that it is very difficult to monitor environmental effects for this approach and to carry out corrective actions, if required. • There is no clear location benefit for any of the management approaches as it relates to adaptability.	• The risk consideration that most impacts adaptability relates to changing science, technology, and social values over time. As these change, one might be required to make changes to any of the three management approaches. Consider for example how science and technology has changed over the past 100 years in relation to municipal waste disposal. Specifically, municipalities dumped all forms of waste into "dumps" with minimal regard for how groundwater might be affected over the long term. This situation arose because a century ago, there was limited science available to indicate the effects and consequences that now have to be dealt with, such as leachate seepage into groundwater and its attendant cost of remediation. • It is not possible to predict how scientific knowledge or technology will change over time, other than it is reasonable to expect that it will change. At the same time, social dynamics and institutions that influence the mechanisms and processes for managing used nuclear fuel are also likely to change. Taken together, these changes will affect how society values risk and the trade-offs used to evaluate the management approaches. Over the long term, it is not possible to guarantee that the necessary safety and environmental concerns will be monitored, nor can one guarantee if the institutional and operational framework(s) required to ensure long-term monitoring and management will be in place. Even if these are in place, it is possible that any one of the three approaches might require retrieving and/or mitigation measures to prevent or reverse adverse effects. • In the latter case, the cost of retrieval from a closed Deep Geological Disposal in the Canadian Shield facility will likely cost less than the incremental cost to manage the other two approaches over the long term.	• Retrieval of nuclear fuel from a closed Deep Geological Disposal in the Canadian Shield facility is more difficult, costlier and more time consuming than for Centralized Storage (above or below ground) or Storage at Nuclear Reactor Sites facilities. These costs have not been included in the conceptual design cost estimates. • Costs related to reversing adverse health or environmental effects are largely unknown. However, since it is more difficult to monitor environmental effects for the Deep Geological Disposal in the Canadian Shield, it is reasonable to assume that it will take longer to discover adverse effects compared to Centralized Storage (above or below ground) or Storage at Nuclear Reactor Sites. As a result, there is greater risk and higher potential remediation cost, with Deep Geological Disposal in the Canadian Shield approach, even though the probability of adverse effects after closure are considered to be very low.

Measure or Indicator	Benefits	Risks	Costs
Adequacy of Institutions and Governance	• Over the long term, it is likely that institutions and governance will change if recent history is any indicator. Only the Deep Geological Disposal in the Canadian Shield approach minimizes the need for institutions and governance because no planned actions are required after year 154. This assumes that predicted "normal" operating conditions prevail and that there is no need for interventions (i.e., used nuclear fuel retrieval or mitigation of adverse effects).	• In comparison, Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites require numerous periodic future interventions that will be influenced by the then applicable governing laws, market forces/incentives, cultural/social values and norms, and the synthesis of continual learning. Although a benefit on one hand, (e.g., one can leverage the best science of the day to repackage used nuclear fuel), it also poses a risk. The risk is that the necessary support institutions and governance frameworks we now rely on will not be there in the long term.	• The adequacy of institutions and governance in the long term is a critical consideration. There are no other similarities found in history that one can learn from. With Centralized Storage and Storage at Nuclear Reactor Sites, the cost to future generations in ensuring the financial and institutional stability of overseeing agencies will be significant.
Ability/Need to Take Corrective Actions That Address Surprises	• As discussed in previous sections, Deep Geological Disposal in the Canadian Shield is less "susceptible" to security breeches and, if sited according to appropriate conditions, it is also environmentally safe based on current scientific knowledge. This, as the Assessment Team states, reduces the need for flexibility in relation to long-term monitoring and contingency planning. However, like the municipal waste management example cited under risks, "we do not know what we do not know", and we may think that we are more secure in theory than in fact.	• The ability to monitor and take corrective actions when required is easier and less costly for Centralized Storage and Storage at Nuclear Reactor Sites, compared to Deep Geological Disposal in the Canadian Shield. This reduces the environmental and health risks for these approaches.	
Accountability	• A critical success factor in the decision-making process for selecting an appropriate used nuclear fuel management approach is providing opportunity for public stakeholders to influence the process. This element of accountability has been discussed in the Community Well-Being Objective. It is important to add, however, that public consultation does not begin and end in selecting a preferable management approach. Rather, an open and transparent process should continue over the long term in relation to monitoring and new knowledge about how best to deal with used nuclear fuel.	• Implementation planning and corrective measures can only be accountable if the affected stakeholders have the necessary support tools, training and infrastructure to participate in the process in a meaningful and constructive way (see Section 8.0).	

11.0 ANALYSIS OF FAIRNESS

Objective*: The selected approach, among other things, should produce a fair sharing of costs, benefits, risks, and responsibilities that is regarded as being fair as possible now and in the future* [1].

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, environment, or economic costs and obligations are understood and accepted at the time of decision; and that adequate attention is given, as far as possible by the current generation, to intra-generational, inter-generational and inter-species aspects of the system selected* [2].

11.1 Context for the Analysis of Fairness

The NWMO Assessment Team discussed Fairness in the context of substantive and procedural issues. The substantive fairness measures relate to how costs and benefits associated with each of the management approaches would be distributed across people and the environment, now and over future generations. The procedural fairness measures relate to the degree to which the overall process would allow for the participation of concerned citizens in key decisions about the management approaches.

11.2 Methods and Measures Used in the Analysis of Fairness

The study team qualitatively evaluated how the influencing factors for fairness identified by the NWMO Assessment Team were impacted by each of the management approaches ensuring that consideration for location and time were factored in. This evaluation involved no formal ranking or scoring of factors. Rather, the study team assessed how the fairness measures might be impacted in relation to benefits, risks and costs.

No attempt was made to develop alternative influencing factors since it was felt the NWMO Assessment Team had reasonably captured the wide range of possible fairness factors. All influencing factors identified by the Assessment Team where considered and are listed in Table 11.2-1.

[1] Nuclear Waste Management Organization, *Understanding the Choices – The Future Management of Canada's Used Nuclear Fuel*, September 2004, page 56.
[2] Ibid, page 56.

Table 11.2-1: Influencing Factors Used in the Analysis of Fairness

<table>
<tr><th>Influencing Factors used in Preliminary Comparative Assessment</th><th>Influencing Factors used in this Analysis</th><th>Measures used in this Analysis</th></tr>
<tr><td>Intergenerational Fairness</td><td>Intergenerational Fairness</td><td>• Intergenerational distribution of costs – should future generations have to solve this generation’s problem?
• Respect for interests of future generations
• Current generation acceptance of responsibility for creating and solving used nuclear fuel issue
• Taking responsibility versus preserving flexibility for future</td></tr>
<tr><td>Interspecies Distributional Fairness</td><td>Interspecies Distributional Fairness</td><td>• Human and non-human cost and benefits over time
• Respect for life and biosphere</td></tr>
<tr><td>Distributional Fairness for Humans</td><td>Distributional Fairness</td><td>• Decision Flexibility
• Adherence to polluter pays principle
• Transportation risks and other considerations
• Distributional fairness of impacts on communities</td></tr>
<tr><td>Participation</td><td rowspan="2">Opportunity to Influence Decision Outcomes</td><td rowspan="2">• Governance model(s)
• Status of Aboriginal land claims
• Capacity for Public Engagement
• State of sustainable livelihoods capitals in each of the economic regions
• Identification of appropriate investments and mitigation measures in the five capitals</td></tr>
<tr><td>Engagement & Participatory Decision Making</td></tr>
</table>

11.3 Summary of Fairness Analysis – A Comparison of Management Approaches

Fairness is about social equity. It relates to how various stakeholders participate in the management decision-making process for used nuclear fuel now and in the future, to ensure that social values are factored into the design, construction, and operational phases. The comparative assessment of fairness was based on the study team’s judgement of how each of the approaches relate to the fairness influences identified by the Assessment Team. No additional criteria or impact measures for this objective were developed.

It was recognized that there are many influencing factors and measures for “fairness” as identified by the NWMO Assessment Team. The following four measures were selected for more detailed qualitative assessment:

- Intergenerational fairness
- Interspecies distributional fairness

- Distributional fairness
- Opportunity to influence decision outcomes & engagement in decision making

Each of the above four measures is consistent with those considered in other studies of this nature, but more important, they are the four key impact measures identified by the Assessment Team. The location of any of the management approaches does have some impact on the assessment of fairness.

A summary of the analysis of fairness for the three management approaches in terms of their benefits, risks and costs is presented below and is detailed in Table 11.3-1.

Benefits

Any management approach that limits the majority of actions, solutions and associated financial costs to the current or "near-current" generations is more preferable because it appropriately restricts procedural and financial costs (burden) to the generation that benefited from the electricity generated from the nuclear fuel. Clearly, such an approach does not put a significant financial burden on future generations who will not benefit from the processes that resulted in the used nuclear fuel and the necessity for its long-term management. Finding and implementing a solution within the current or "near current" generations shows respect for the interests of future generations from a financial perspective and it adheres more closely to the "polluter-pays" principle. Only the Deep Geological Disposal approach incurs the majority of its costs in the near term, thus limiting financial liabilities and the financial surety for the most part to the current generation, assuming that "normal" conditions prevail.

All three management approaches would be constructed and would operate using best management practices. This would minimize adverse effects on humans, plant and animal species. The key to ensuring interspecies distributional fairness is being able to effectively monitor, detect and mitigate adverse consequences in a timely manner. In this regard, Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites allow for easier monitoring, detection and mitigation (if necessary) in the long term, compared to a closed Deep Geological Disposal facility.

Risks

There is no "fail-safe" solution or management approach for used nuclear fuel in the long term. All three management approaches have risks that could impact on people and the environment.

All three management approaches place some risk in the hands of future generations. There are tradeoffs and decisions must consider them carefully. For example, the two storage approaches require long-term repackaging and facility rebuilding activities which increases exposure risk to people and the environment. Alternately, Deep Geological Disposal limits choices and flexibility of future generations to adapt new technologies and social values into the management process.

Location of the management approach is important. If a Centralized Storage facility or a Deep Geological Disposal facility were to be located in a rural area, human interactions and consequences from adverse effects are less compared to the possible impact on other species, at least in the near term. Over the long term, the population, environment and other dynamics in current rural or remote areas of Canada might change for a variety of reasons, including for example, population growth and/or social preferences. This means that current decisions about location siting and possible interspecies effects will be strongly influenced by current conditions and may not accurately reflect the situation in future.

Costs

Although the risk of an adverse effect from any of the approaches in the near or long term is extremely low, the distribution of social and personal costs are not equally distributed or shared by Canadians, either over time or geographically. Adverse events may be natural (e.g. an earthquake) or human induced (e.g., terrorism). Most beneficiaries of nuclear energy today reside in urban centres throughout eastern Canada. If a future adverse event occurs at one location, then those people and sensitive environments located near the event would be most affected and would likely incur the brunt of social, environmental and economic costs related to the event, its remediation and/or quality of life degradation.

All communities affected by any of the used nuclear fuel management approaches will need to participate not just in the initial siting decisions, but in the on-going management of the facility(ies), where appropriate. In the long term, governance models and institutions will likely change. Giving local communities a role in on-going management of the used nuclear fuel is one way to ensure some degree of homogeneity of long-term management - not that their governance or social model won't change, but that they have to live with the legacy of this generation's decision regarding a preferred management approach. As such, they have the most to gain and lose, and they and their descendants will be least likely to let the long-term management approach commitments lapse.

Table 11.3-1: Summary of Fairness Analysis - A Comparison of Management Approaches: Benefits, Risks and Costs

Measure or Indicator	Benefits	Risks	Costs
Intergenerational Fairness • Intergenerational distribution of costs • Respect for interests of future generations • Current generation acceptance of responsibility • Taking responsibility versus preserving flexibility for future	• One key benefit relates to the distribution of financial costs between the current and future generations resulting from any of the three management approaches. Clearly, any management approach that limits the majority of actions, solutions and associated financial costs to the current generation is more preferable because it restricts procedural and financial costs (burden) to the generation that benefited from the electricity generated from the nuclear fuel and does not put a significant financial burden on future generations who will not benefit. In doing so, it shows respect for the interests of future generations from a financial perspective and it adheres more closely to the 'polluter-pays" principle. Only Deep Geological Disposal in the Canadian Shield incurs the majority of its costs in the near term (i.e., by year 59), thus limiting financial liabilities and the financial surety for the most part to the current generation, assuming that "normal" conditions prevail. • Both Centralized Storage and Storage at Nuclear Reactor Sites force future generations to more actively manage and finance the ongoing activities required over thousands of years, at much higher cost to future generations. However, these two management approaches offer greater flexibility to future generations in terms of making their own decision about how best to manage used nuclear fuel and to monitor human and environmental effects more effectively. It is important to note that the Deep Geological Disposal in the Canadian Shield facility (repository) is planned to remain "open" or accessible for a period of about 100 years after the used nuclear fuel is finally in place (i.e., year 59). This means that active and effective monitoring will conducted over this time period and should issues arise, corrective actions can be implemented, including retrieval and re-deployment. One option in this case might be to extend the period in which the deep geological repository remains "open". • Most of the direct costs linked to Deep Geological Disposal in the Canadian Shield have a higher degree of certainty and the amount of financial resources required to complete this approach could be obtained in a reasonable timeframe. Moreover, the short-term solution through Deep Geological Disposal in the Canadian Shield to the long-term problem of used nuclear fuel management offers a variety of other benefits related to fairness, including institutional stability – i.e., it is likely that the institutions and processes required for the completion of Deep Geological Disposal in the Canadian Shield will be sustainable in the near term. Institutional stability in the long term is likely to change and thus Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground) could be at risk.	• Deep Geological Disposal in the Canadian Shield reduces the ability of future generations to manage their own risks by making it difficult for them to monitor the facility and take corrective measures, compared to Centralized Storage and Storage at Nuclear Reactor Sites. This means that Deep Geological Disposal in the Canadian Shield shifts some of the risk from the current generation to future generations, in part because the multiple barriers might fail in the future and there is insufficient monitoring capability to measure when this happens and how extensive the effect might be. Having said that, the cost of retrieval from a closed Deep Geological Disposal in the Canadian Shield facility is likely to be significantly less than the additional costs for long-term management for either of the other two approaches. • In regards to flexibility, it is reasonable to expect that science & technology and social values will change with time. These changes might mean that future generations may decide a different management approach is warranted. Applying an alternative approach at some point in the future is easier with Centralized Storage or Storage at Nuclear Reactor Sites, given the technology of today. • Each of the three approaches places some risk in the hands of future generations. Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground) require periodic re-handling of the used nuclear fuel during repackaging events far into the future, with associated financial liabilities, worker health & safety risks, environmental risks, and security risks. Deep Geological Disposal in the Canadian Shield is intended to be a permanent solution that reduces these risks for the most part to only the next few generations, assuming that "normal" conditions prevail.	• For the Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites management approaches, costs will continue far into the future as used nuclear fuel is re-packaged and storage facilities are re-built on a periodic basis. This means future generations bear the majority of the management costs for these two approaches. • However, the costs to monitor and take corrective measures, if and when required, are easier and likely less costly for the two storage management approaches, compared to a closed Deep Geological Disposal in the Canadian Shield facility (i.e., after year 154).

Table 11.3-1: Summary of Fairness Analysis - A Comparison of Management Approaches: Benefits, Risks and Costs

Measure or Indicator	Benefits	Risks	Costs
Interspecies Distributional Fairness ♦ Human and non-human cost and benefits over time ♦ Respect for life and biosphere	• All three management approaches would be constructed and would operate using best management practices. This will minimize impact on humans, plant and animal species. The key to ensuring interspecies distributional fairness is being able to effectively monitor, detect and mitigate adverse consequences in a timely manner. In this regard, Centralized Storage and Storage at Nuclear Reactor Sites allow the ability for monitoring, detection and mitigation (if necessary) in the long term. • Such consideration and protection for people and environment leaves greater flexibility to future generations to apply their value(s) about the biosphere, plant and animal species into an alternative management approach that enhances their protection, if required. In comparison, Deep Geological Disposal in the Canadian Shield offers limited benefit in this context in the long term.	• There is no "fail-safe" solution or management approach for used nuclear fuel in the long term. All three management approaches have risks that could impact on plant and animal species and the biosphere. • Location of the management approach is important. If a Centralized Storage facility or a Deep Geological Disposal in the Canadian Shield facility were to be located in a rural or remote area, human interactions and consequences from adverse effects are less compared to the possible impact on other species, at least in the near term. Over the long term, the population, environment and other dynamics in current rural or remote areas of Canada might change for a variety of reasons, including for example, population growth and/or social preferences. This means that current decisions about location siting and possible interspecies effects will be strongly influenced by current conditions. • In this context, transportation of used nuclear fuel, which occurs in the near term, poses a risk to human, plant and animal species from a security and safety perspective. This is only applicable to the Centralized Storage (above or below ground) and Deep Geological Disposal in the Canadian Shield. There are more risks associated with transportation routes that are longer.	• How society values the environment and interspecies existence will change with time. Consider for example, how the logging industry in Canada has transformed from "clear-cutting" (with its attendant negative impact on species preservation and rare habitats) a few decades ago, to one now of less invasive "selective logging" and the establishment of forest reserves in unique habitat areas. This is exemplified in British Columbia's Upper Walburn Valley[93], where preservation of a unique coastal temperate rainforest is taking precedence over certain logging activities. The cost of losing such a habitat is not possible to estimate in conventional terms.

[93] Western Canada Wilderness Committee, *The Upper Walburn Valley –Protect It Now!*, 2004, www.wildernesscommitteevictoria.org/campaigns_walburn.php.

Table 11.3-1: Summary of Fairness Analysis - A Comparison of Management Approaches: Benefits, Risks and Costs

Measure or Indicator	Benefits	Risks	Costs
Distributional Fairness ♦ Decision Flexibility ♦ Adherence to polluter pays principle ♦ Transportation risks and other considerations ♦ Distributional fairness of impacts on communities	• Deep Geological Disposal in the Canadian Shield is a permanent solution, whereas both Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites are long-term storage approaches with greater financial liability, health & safety concerns, environmental and security risks and costs incurred by future generations. • Implementation of any of the three management approaches brings significant employment and income (wealth) benefits to the local host economic region, the host province, and to Canada as a whole (see analysis in Section 8.0). • The degree of benefit does vary considerably between the three management approaches. Deep Geological Disposal in the Canadian Shield offers a significant economic boom (i.e., $16 billion) to a host region and province, followed by a rapid decline (bust) after year 59. In comparison, Storage at Nuclear Reactor Sites offers benefits to 6 economic regions simultaneously, with the greatest benefit occurring in south-central Ontario, where the majority of used nuclear fuel is currently located. Even though such benefits are cyclical, these cycles are far enough apart (i.e., approximately 300 years) that the host region(s) can not avoid a "boom and bust" type cycle and the attendant costs. • The degree of economic benefit also varies by location. Rural and remote economic regions tend to capture less of the total economic benefits (i.e., employment, income and tax revenues) compared to the more populated urban centres. • Communities along the transportation route(s) to Deep Geological Disposal in the Canadian Shield or Centralized Storage (above or below ground) sites would incur some added risks but few, if any, benefits as transportation services and infrastructure may originate from outside these regions.	• In the near term, as noted above, transportation of used nuclear fuel in the case of Deep Geological Disposal in the Canadian Shield or Centralized Storage (above or below ground) incur some added risks, whereas Storage at Nuclear Reactor Sites has no transportation risk because no off-site transportation is required. • In the long term, social values and technology change; as these change, options for used nuclear fuel management change. It is also likely that new 'risks' related to used nuclear fuel management will be discovered for all three management approaches due to such changes. The management approach that is chosen has to be flexible (from a technology perspective), incorporate security (from a social value perspective), and consider institutional governance (long-term sustainability of government and institutions). For both Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites, social, financial, technological, and moral liabilities are placed on future generations who will have to deal with the current generation's used nuclear fuel.	• In the event of an adverse effect on people or the environment, the distribution of social and personal costs is not equally shared. Most beneficiaries of nuclear energy today reside in urban centres throughout eastern Canada. If a future adverse event occurs at one location, then those people and sensitive environments located near the event will be most affected and will likely incur the brunt of social, environmental and economic costs related to the event, its remediation and/or quality of life degradation. • In the long term, there may be no users of nuclear fuel, but future generations must continue to bear the cost and responsibility for long – term management of used nuclear fuel. It has been discussed that the management approaches differ with respect to the distribution of benefits, but the distribution of costs is highly skewed to future generations for the two storage approaches. In addition, communities in rural and remote economic regions will likely bear a higher social and financial cost, in proportion to urban centres, for added infrastructure during construction phases, and will also have to deal with the cost of the inevitable economic bust when the initial phase(s) of the chosen management approach is complete.

Table 11.3-1: Summary of Fairness Analysis - A Comparison of Management Approaches: Benefits, Risks and Costs

Measure or Indicator	Benefits	Risks	Costs
Opportunity to Influence Decision Outcomes & Engagement in Decision Making ♦ Governance model(s) ♦ Status of Aboriginal land claims ♦ Capacity for Public Engagement ♦ State of sustainable livelihoods capitals ♦ Identification of appropriate investments and mitigation measures in the five capitals	• The NWMO is committed to a process of full and open community engagement and consultation on all the issues relating to the management of used nuclear fuel. Currently, this process is independent of management approach and location. It is sensitive to issues relating to the eight objectives articulated by the NWMO Assessment Team.	• Community and stakeholder engagement is a worthwhile and valuable component to deciding on an appropriate management approach for used nuclear fuel. However, there are risks that should be considered, including for example: • New ideas and options are bound to be expressed, that if not fully accounted for in subsequent discussions, might lead to stakeholder disenchantment and disengagement with the process; and • No matter how much effort and support is put into a community engagement process, one must recognize that not all stakeholders will be happy or "buy-in" to the final decision. • These and other risks of community engagement can be minimized with a comprehensively open and easily accessible consultation and engagement process, such as the process implemented for the MacKenzie Valley Pipeline[94]. What Thomas Berger demonstrated is that it is possible to achieve an effective agreement on a specific course of action. Although not everyone might agree with that action, everyone can clearly see the process and understanding the influencing factors leading to the final decision.	• There are certain issues that need to be addressed prior to finalization of a used nuclear fuel management approach. One element clearly identified by the Assessment Team is community engagement and participation in the decision-making processes. This is not as easy as simply inviting stakeholders to meetings. Stakeholders at all levels and from many locations lack the training, education, support institutions, and financial resources to participate in a meaningful and constructive way, particularly those who reside in rural and remote regions of Canada. These need to be resolved first, and it will not likely be a process that can be done quickly. The need for community engagement and participation in the decision-making processes is independent of management approach and possible site(s) location. • Consider for example the following: • Aboriginal land claims need to be accounted for in any future discussions regarding the decision process for a preferred management approach and location. In a recent ruling by the Supreme Court of Canada (November 18 2004)[95], it was stated that no projects involving a formal environmental assessment can proceed without addressing how Aboriginal land claims will be addressed or accounted for. • Moreover, Aboriginal communities within all of the illustrative economic regions examined in this study have a relatively low adaptive capacity and will likely face far greater challenges in the basic process of engaging with NWMO than will non-aboriginal populations.

[94] Berger, Thomas R., *Northern Frontier, Northern Homeland: The Report of the Mackenzie valley Pipeline Inquiry,* Volume 1, Minister of Supply and Services Canada, 1977.
[95] According to this new ruling, governments have a legal duty to consult with First Nations to some extent about the development of disputed land. This landmark ruling will have a major impact on how governments and industry deal with First Nations before making land-use decisions. The court ruled that the amount of consultation depends on the strength and seriousness of the land claim and the effect on the land in use..

Table 11.3-1: Summary of Fairness Analysis - A Comparison of Management Approaches: Benefits, Risks and Costs

Measure or Indicator	Benefits	Risks	Costs
			• All communities affected by any of the used nuclear fuel management approaches will need to participate not just in the initial siting decisions, but in the on-going management of the facility(s), where appropriate. In the long-term, governance models and institutions will likely change. Giving local communities a role in on-going management of the used nuclear fuel is one way to ensure some degree of homogeneity of long-term management - not that their governance or social model won't change, but that they have to live with the legacy of this generation's decision regarding a preferred management approach. As such, they have the most to gain and lose, and they and their descendants will be least likely to let the long-term management approach commitments lapse. • To enable meaningful and effective community engagement will require considerable investment in many, if not all, of the sustainable livelihood capitals in these communities (refer to Section 8). Such investments in these capitals will ensure a more fair analysis and decision-making process, ultimately leading to an optimal management approach.

But Chief Justice Beverley McLachlin, who wrote the decision for the court, said aboriginal claimants must not "frustrate the Crown's reasonable good faith attempts" at consultation. "Nor should they take unreasonable positions to thwart governments from making decisions or acting in cases where, despite meaningful consultation, agreement is not reached."

12.0 SUMMARY AND CONCLUSIONS

The NWMO retained Golder Associates Ltd. (GAL) and Gartner Lee Limited (GLL) to develop a comparative assessment of the benefits, risks and costs from implementing any one of three proposed approaches for the management of used nuclear fuel in Canada. The GAL/GLL team was supplemented with expertise from Nuclear Safety Solutions Limited and Econometric Research Ltd. The study team built on and expanded the evaluation framework developed by the NWMO Assessment Team by tying its assessment to eleven "illustrative" economic regions, and grounding the assessment of impacts through a combination of quantitative and qualitative analyses.

This summary describes the salient methods, results and discussion of the comparative assessment that is detailed in the main body of this report. It concludes with the study team's observations regarding the strengths and limitations of each management approach and with the study team's suggestion for an enhanced approach.

12.1 Overall Study Objectives

Taking the study objectives into consideration, there are two overriding requirements that guided this assessment:

1. To conduct a comparative assessment of the benefits, risks and costs of three management approaches for long-term management of used nuclear fuel, taking into account the following considerations:
    a. How might benefits, risks and costs change over time?
    b. How might location of the management facility(ies) affect benefits, risks and costs?
2. To discuss issues and implications of the benefits, risks and costs for each management approach using the eight evaluation objectives.

12.2 Measuring Benefits, Risks and Costs

There are five major considerations that were used to base this assessment:

Alternative Management Approaches Must Be Considered

The *Nuclear Fuel Waste Act* identified three management approaches for detailed analysis that are the focus of this study, as follows:

- Deep Geological Disposal in the Canadian Shield;
- Storage at Nuclear Reactor Sites; and
- Centralized Storage (either above or below ground).

The specifications and defining characteristics of each approach are detailed in Section 2, along with the costs and schedule for implementing them. The assessment found that all three approaches are capable of being implemented and have many common features and effects. The focus of this assessment was on the differences between the approaches.

Time Changes Benefits, Risks and Costs

It must be recognized that the management of used nuclear fuel must consider both a near and long-term perspective. The effects of used nuclear fuel have the potential to impact people and the environment for thousands of years. As such, any assessment of benefits, risks and costs must consider influencing factors that might be sensitive to time. Two time periods were evaluated as follows:

- *Near Term* is defined as 1 to 175 years; and
- *Long Term* is defined as greater than 175 years and extending up to 10,000 years.

Economic Regions Represent Unique Location Differences

The *Nuclear Fuel Waste Act* also requires that a comparative assessment of the three management approaches measure the benefits, risks and costs from the perspective of alternative economic regions. In other words, it is important to understand how the trade-off between benefits, risks and costs for the three management approaches is sensitive to location.

It is recognized that two of the management approaches assessed in this study (i.e., Deep Geological Disposal in the Canadian Shield and Centralized Storage - either above or below ground) could be located in a number of economic regions. Storage at the seven existing nuclear reactor sites occurs in six economic regions. There are, in total, 76 economic regions in Canada, with a unique mix of ecozones, population dynamics, economies, social and environmental sensitivities.

In addition to the six economic regions that currently host nuclear reactor sites, five other economic regions were selected to represent the breadth and range of possible economic regions across Canada that illustrate differences based on: economic mix, ecozones and population dynamics.

These eleven "illustrative" economic regions can be classified into two groups (urban vs. rural) with the following characteristics:

Urban	Rural
High population density	Low population density
Mixed economy – multiple industry and retail sectors	Resource-based economy (Agriculture, forestry and/or mining)
Shorter distance from used nuclear fuel sources	Longer distance from used nuclear fuel sources

Eight Evaluation Objectives

Drawing from the NWMO's Second Discussion Document (*Understanding the Choices*), it is important to assess and compare the benefit, risk and cost tradeoffs for each of the three management approaches using the influencing factors from the following eight objectives:

- Public Health and Safety;
- Worker Health and Safety;
- Security;
- Economic Viability;
- Community Well-Being;
- Environmental Integrity;
- Adaptability; and
- Fairness.

Ethical issues and considerations are explicitly considered in all eight objectives, particularly as part of community well-being, adaptability and fairness.

Analysis Measures Are Consistent With Past Studies and Experience

Measures were developed to allow an assessment of the benefits, risks and costs of each of the three approaches for each of the eight objectives. The specific measures used in this assessment were based on availability of quantitative information drawn from literature or were capable of being estimated within the timeframe available for the assessment. Their selection and evaluation built on the approach used by GAL/GLL in similar studies and is consistent and inclusive of the measures considered by the NWMO Assessment Team.

12.3 Comparative Assessment

For each of the eight objectives considered in this assessment, a comparison of the management approaches was conducted as it relates to their benefits, risks and costs. In doing so, near and long-term time considerations were taken into account as were the effects of location by using the illustrative economic regions as examples. A summary of the analysis completed and the results of the assessment for each of the eight objectives is provided below.

Objective 1: Public Health & Safety

Public health and safety relates to the likelihood that members of the public proximate to the facility or along the transportation route might be exposed to unacceptable radiological and conventional risks as a result of implementing an approach. The management approach, 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, the public will not be subject to risks or harmful exposures, chronic or accidental, greater than those acceptable to Canadian and international authorities. Security and terrorism as a threat to public health and safety is discussed under “Security”.

The assessment used quantitative information available in the literature or capable of being estimated within the timeframe available for the assessment and builds on the approach used by the Assessment Team and GAL/GLL in similar studies. Information was developed for each of the approaches within each of the illustrative economic regions. This included the identification of the radiological and physical risks associated with each approach, including transportation of the used nuclear fuel.

The primary considerations for the analysis included:

1. **Number of people potentially exposed:** The overall risk to members of the public is a function of the size of the population potentially located proximate to the facility, including the population along the transportation route: the greater the number of people, the greater the corresponding risk. The population density, size, and number of population centres in each illustrative ER provide a good indication of the number of people potentially affected in both the near and long term.

2. **Seriousness of potential risks:** Risks to members of the public result both from potential radiation exposures and conventional safety, including both normal and off-normal exposures. The maximum radiation dose to the public (identified as the bounding case) at the facility or during transportation and the time of peak impact was assumed to provide an indication of the average radiation dose to the public as a whole. It was assumed that approaches where the maximum doses are lower will have lower typical or average doses. Conventional health and safety risks relate primarily to transportation: it was assumed that injuries and fatalities as a result of transportation accidents depend on distance travelled.

3. **Likelihood of a potential risk occurring:** The probability of a serious effect to members of the public was determined by estimating the radiation exposures for a variety of credible normal and off-normal scenarios. Whenever possible, bounding cases which have the potential to result in the largest radiological risk were identified and events with extremely low probabilities were not considered. Where the bounding cases result in negligible consequences, it was assumed that cases involving lesser risks would not result in significant negative impacts. The likelihood of conventional accidents occurring during transportation is based on current transportation accident statistics.

Benefits

All three approaches can be built and operated to meet applicable safety criteria with a considerable margin of safety under normal conditions. Under off-normal conditions, radiation exposure is well below the applicable criteria for near and long term for all approaches, with the exception of the human intrusion scenario. As long as institutional control is in place, the risk to the public from off-normal conditions is very low for all approaches.

Differences between approaches relate to the number of people that may be exposed to unacceptable risks as a result of implementing an approach and the total transportation distance involved in transporting used nuclear fuel. The nature of the risks associated with all three approaches are similar, namely radiation exposures, and injuries and fatalities as a result of traffic accidents in the case of Deep Geological Disposal and Centralized Storage (above or below ground).

Risks

All three approaches involve real and perceived risks, including risks associated with transporting used nuclear fuel for the Deep Geological Disposal and Centralized Storage (above or below ground) approaches.

During normal and off-normal conditions in the near term, all potential radiation exposures are expected during or just after placement of the fuel in the management facility. The repackaging cycles associated with Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground) may result in potential radiation exposures of members of the public through the time of maximum exposure (greater than 10,000 years into the future). Human intrusion into these two management approaches may result in an unacceptable radiation risk to the public in the long term if institutional control is not maintained.

The probability of the bounding off-normal scenarios during the near term for all approaches is very low for a long as institutional control features are in place. For Deep Geological Disposal, the probability of human intrusion in the long term is extremely low compared with the probability of intrusion for Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground).

If there is a loss of institutional control before closure (Year 154 for Deep Geological Disposal), all three approaches cannot prevent an unacceptable radiation risk to public health caused by an inadvertent human intrusion. However the risk from Deep Geological Disposal is far lower because the used nuclear fuel is managed at well below ground surface. In the long term, the risk to the public is lowest for Deep Geological Disposal because the used nuclear fuel is contained below ground in a secure facility with engineered and geological barriers. However, for some off-normal scenarios for Deep Geological Disposal, there is a perceived risk that some radioactivity may escape from the facility via the groundwater pathway at some unspecified point in future. The predicted impact of any groundwater release from Deep Geological Disposal is well below applicable standards.

Transportation activities associated with Deep Geological Disposal and Centralized Storage (above or below ground), can be designed and carried out safely and meet all applicable criteria. Risks from off-normal transportation conditions primarily relate to transportation distance.

Costs

Costs of radiation protection and public safety are accounted for in the economic costs of all approaches through facility designs and monitoring programs using today's technology and standards.

Objective 2: Worker Health & Safety

Worker health and safety relates to the conventional and radiological risks that workers may be exposed to as a result of implementing the used nuclear fuel management approaches. This includes risks associated with the transportation of used nuclear fuel and other operations associated with its long-term management. The construction, 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 greater than those acceptable to Canadian and international authorities at the time of construction.

The assessment used quantitative information available in the literature or capable of being estimated within the timeframe available for the assessment and builds on the approach used by the Assessment Team and GAL/GLL in similar studies. Information was developed for each of the approaches within each of the relevant illustrative economic regions. This included the identification of the radiological and physical risks associated with each approach, including transportation. Current experience with respect to radiation exposures and occupational health and safety in similar industrial sectors provides a useful and appropriate basis for predicting and comparing the benefits and risks of implementing each of the approaches.

The primary considerations for the analysis included:

1. **Number of workers potentially exposed:** The overall risk to workers is a function of the number of workers involved in implementing the approach, including transporting the used nuclear fuel. The number of workers estimated includes workers directly associated with the construction and operation of the facility and does not include indirect or induced employment. The size of the workforce for each management approach is

generally independent of ER. It is assumed that the greater the number of workers, the greater the corresponding risk.

2. **Seriousness of potential risks:** The radiation dose to the maximally exposed workers (identified as the bounding case) at the facility or during transportation provides an indication of the average radiation dose to the workforce as a whole. It is assumed that approaches where the maximum doses are lower will have lower typical or average doses. It is assumed the conventional occupational health and safety risks are similar to those that may be associated with resource-based industries such as mining, quarrying and aggregate production, as expressed by accident frequency and severity rates.

3. **Likelihood of a potential risk occurring:** The probability of a serious effect to workers was determined by estimating the radiation exposures for a variety of credible normal and off-normal scenarios. Whenever possible, bounding cases which have the potential to result in the largest radiological risk were identified and events with extremely low probabilities (i.e., less probable than $1x10^{-7}$ per year) were not considered. Where the bounding cases result in negligible consequences, it was assumed that cases involving lesser risks would not result in significant negative impacts. The likelihood of conventional accidents occurring is included in the predicted accident frequency and severity rates.

Benefits

All three approaches can be built and operated to meet applicable worker health and safety standards under normal and off-normal conditions. Most importantly, all of the activities required to implement the approaches involve current and proven procedures and practices, which have been demonstrated to be capable of being carried out safely without undue risk to workers.

Differences between approaches relate to the number of workers required for construction and operation, the nature of the activities and the total transportation distance involved in transporting used nuclear fuel.

The size of the workforce anticipated for Deep Geological Disposal is less than that required for Storage at Nuclear Reactor Sites and Centralized Storage. However, the workforce required for Deep Geological Disposal is only required until Year 154, whereas the other approaches require a workforce beyond Year 10,000.

In the near term, radiation doses to workers are lower for Storage at Nuclear Reactor Sites and Centralized Storage (above ground), because most of the work is conducted above-ground where work tends to be less confined and ventilation is easier and generally more effective, during normal and off-normal conditions.

The industrial accident rate (injuries and fatalities) predicted for all approaches is typically less than in non-nuclear mining and construction projects for all management approaches. This assumption is based on the current safety record of the nuclear industry, including uranium mining.

Risks

Radiation exposures to workers during operations and transportation are within acceptable Canadian standards for all management approaches under normal and off-normal conditions. Radiation exposures will be incurred throughout the entire management period for Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground). In contrast, all radiation exposures to workers will be incurred through Year 154 for Deep Geological Disposal, at which time the facility is closed (i.e., all risks to workers are incurred during the near term only). The highest radiation exposure to the greatest number of workers occurs for Deep Geological Disposal; however, risks are within acceptable standards and occur before the closure of the underground facility.

The anticipated number of industrial accidents depends on the total person-years anticipated for each management approach; therefore, over the entire analyzed time span (until year 10,000) there are more injuries predicted for Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites, which require ongoing repackaging cycles. In the near term, and particularly during placement of the used nuclear fuel, there are more injuries anticipated for Deep Geological Disposal.

Transportation activities associated with the two approaches that have off-site movement of used nuclear fuel, namely, Deep Geological Disposal and Centralized Storage (above or below ground), can be designed and carried out safely and meet all applicable criteria. Risks from off-normal transportation conditions primarily relate to transportation distance. Accordingly, risks associated with transportation would be lowest for illustrative economic regions that are located closest to the current reactor sites.

Costs

The cost of the approaches includes the total workforce costs, which incorporate reasonable and predictable costs for worker safety. These include the costs for worker radiation protection and conventional occupational health and safety programs and procedures for all management approaches through facility designs and monitoring programs.

Objective 3: Security

This objective relates to the capacity of a used nuclear fuel management approach to provide long-term security of nuclear material, facilities and infrastructure. The security analysis focuses on differences in the vulnerability of the three management approaches. For the purpose of this analysis, vulnerability is defined as a weakness that may be exploited by terrorists by causing a radiological release near a population centre or by obtaining material to construct an illicit nuclear device.

Measures were developed to allow an assessment of the benefits, risks and costs of each of the three approaches. The specific measures used in the assessment of security are based on quantitative information available in the literature or capable of being estimated within the timeframe available for the assessment. Their selection and evaluation builds on the approach used by the Assessment Team and by GAL/GLL in similar studies. The current experience and understanding with respect to security can provide only a general indication of potential threats. It is not possible or prudent to speculate on specific new types of terrorist threats that could exist in future.

Information was developed for each of the approaches within each of the relevant illustrative economic regions. This included the identification and categorization of physical and geological barriers and the number of times used nuclear fuel needs to be repackaged for each approach. The analysis draws on the published literature and the study team's own experience in this area. Transportation requirements were determined and compared by estimating the total number of trip-kilometers required for each approach.

The primary considerations for the analysis included:

1. **Fuel Accessibility:** The risk of security threats or breaches is proportional to the duration of the time period while the used nuclear fuel is accessible, either in the facility or during transportation. It is assumed that greater security risks exist while the used nuclear fuel is accessible and capable of being dispersed into the natural and human environment.

2. **Number of repackaging recycles and transportation requirements:** Each of the approaches has different requirements with respect to transportation and/or repackaging the used nuclear fuel. Some approaches require that the used nuclear fuel be repackaged numerous times and some require the used nuclear fuel to be transported to a new location. It is assumed that transportation and repackaging provide opportunities for a security breach: the more times the used nuclear fuel is repackaged or the greater the distance it is transported, the greater the risk.

3. **Robustness of physical barriers:** physical barriers, including both engineered and geological features, provide the greatest deterrent to security threats and breaches, including threats as a result of societal breakdown, regardless of the time or duration when the used nuclear fuel may be accessible. It is assumed that the greater the number of barriers, the more secure the approach.

4. **Number of large population centres in economic region and along transportation route:** It is assumed that the current number and size of population centres within an economic region and along the transportation route provide an indication of the number of people potentially at risk, both now and in the future.

Benefits

All three approaches are capable of providing a high degree of security from threats of theft despite possibilities of terrorism or war. This high level of security is achieved by restricting the accessibility of used nuclear fuel in the near and long term through the construction of engineered and geologic barriers. These barriers prevent terrorists for gaining access to the used nuclear fuel and/or causing radioactivity to be dispersed into the environment. The barriers generally are independent of illustrative economic region, although the specific nature of a particular barrier may vary from location to location.

Differences between approaches relate to the potential accessibility of used nuclear fuel and the number of people potentially at risk at the location and along the transportation route. The accessibility of used nuclear fuel is assessed by comparing the number of used nuclear fuel repackaging events required throughout the lifetime of each approach, the number and robustness of physical and geological barriers, and the total transportation distance.

In the near term, all three approaches incorporate at least four independent engineered barriers, which prevent accessibility of used nuclear fuel. Centralized Storage (above or below ground) and Deep Geological Disposal offer more barriers than does Storage at Nuclear Reactor Sites. In the long term, Deep Geologic Disposal offers additional security compared with the other approaches because of the geologic barriers and permanent closure. In the long term, Deep Geological Disposal also offers the greatest security in the event of societal breakdown since it does not rely on a continuing human presence.

Risks

Transportation is a key distinguishing factor between the different approaches and is a critical factor to be addressed in assessing further risks that might be posed to society or the environment through the movement of used nuclear fuel between locations in the near term. All approaches other than Storage at Nuclear Reactor Sites require off-site transportation with the associated risks. However, engineered and security barriers are available to ensure these risks are low. In addition, risks associated with transportation would be lowest for illustrative economic regions that are located closest to the current reactor sites or regions with fewer large population centres.

Deep Geological Disposal offers advantages compared with the other two approaches, since the number of times the used nuclear fuel needs to be repackaged is limited to one or two compared with up to 100 repackaging events for the others. Storage at the Existing Reactor Sites offers an advantage compared with the other two approaches since it does not require any transportation of used nuclear fuel.

Storage at Nuclear Reactor Sites includes long-term storage of used nuclear fuel at seven reactor sites across six ERs. The greater number of storage facilities for Storage at Nuclear Reactor Sites combined with the fact that these ERs have large population centres present a greater security risk than the other two approaches.

Storage/disposal sites that are located in economic regions with a large number of large population centres may be at greater risk in the event of a terrorist attack, as such centres present a more attractive target. As illustrative economic regions in the Canadian Shield generally have lower population densities and fewer large population centres (>50,000 inhabitants), Deep Geological Disposal could have a lower risk because of a lower number of people that would be potentially impacted from a terrorist breach. This benefit may be off-set somewhat by a requirement to transport used nuclear fuel a long distance.

Costs

Some of the costs for security are accounted for in the economic costs of all three approaches through facility designs and monitoring programs. However, recent international events indicate that security standards can be breached and additional costs may be required to address as yet unspecified risks. With the passage of time, it may be necessary to change current security standards and activities to account for changing world events. This may dramatically change future security requirements and its attendant costs. Cost uncertainty is greatest for the Storage at Nuclear Reactor Sites and Centralized Storage since both these approaches provide opportunities for the accessibility of used nuclear fuel throughout the entire lifetime.

Objective 4: Economic Viability

This objective relates to the need to ensure that adequate economic resources are available, now and in the future, to pay all the costs of the selected approach. The selected approach should provide high confidence that funding shortfalls will not occur that would threaten the assured continuation of necessary operations.

Measures were developed to allow an assessment of the benefits, risks and costs of each of the three approaches. The specific measures used in the assessment of economic viability are based on quantitative costing information developed by the Joint Waste Owners and based on quantitative information in the literature or capable of being estimated within the timeframe available for the assessment. Their selection and evaluation builds on the approach used by the Assessment Team and by GAL/GLL in similar studies. Economic benefits related to the implementation of the three approaches (i.e., employment, income, and taxes) are described under *Community Well Being,* Community Economic Health section. It is assumed that all the necessary financial resources would be available to allow implementation of any of the three approaches, although there may be differences between approaches in both the cost and funding required.

For economic viability, the primary considerations for the analysis included:

1. **Costs over time (present value and non discounted)**: It is assumed that an approach with a smaller present value cost is preferred from a financial planning perspective, all else being equal. It is also assumed that an approach with a greater portion of its costs in the near term would have a more certain cost estimate than for an approach with a greater portion of costs in the long term. Joint Waste Owners' cost estimates, by nature and necessity, are based on current technology costs and are order-of-magnitude only for costs to be incurred beyond the near term.

2. **Incremental Transportation Cost:** It is assumed that transportation of used nuclear fuel to a facility farther from the current location of the majority of the used nuclear fuel (i.e., southern Ontario) would have higher costs.

3. **Certainty of Cost Estimates:** An approach with a more certain cost estimate should provide higher confidence that a funding shortfall would not occur. Cost estimates are more uncertain the farther into the future they are projected.

The Joint Waste Owners' estimated total costs for the approaches at a conceptual design level were validated by others as "suitable for their purpose of assessing the magnitude of the costs of alternative management methods". [96] The magnitude and timing of these costs in the near term and long term as well as the present value of these costs are important considerations in the analysis of economic viability.

For Deep Geological Disposal in the Canadian Shield and for the Centralized Storage (above or below ground), incremental transportation costs (by road) were estimated based on a total distance estimate for the transport of all used nuclear fuel to each illustrative ER.

[96] ADH Technologies Inc. & Charles River Associates Inc., *Validation of Cost Estimating Process for Long-Term Management of Used Nuclear Fuel*, prepared for the Nuclear Waste Management Organization, April 2004.

Benefits

The economic benefits related to the implementation of the management approaches are discussed under *Community Well Being,* Community Economic Health section.

The cost estimates for all three management approaches are reasonable, provided the design that is implemented is similar to that costed. Differences in total cost, expenditure scheduling and cost uncertainty exist, but are within reasonable bounds at the conceptual design stage and reflect differences in philosophy. No one approach is superior in all respects. All three approaches represent well thought-out concepts for managing used nuclear fuel safely compared with cost estimates in other jurisdictions. With the exception of transportation costs, economic viability is independent of the ERs in which an approach would be implemented.

Risks

Cost estimates are more uncertain the farther into the future they are projected. Similarly, reasonable surety is more difficult to assess for dates farther ahead in time. With respect to the time-dependence of estimate certainty and the provision of surety, Deep Geological Disposal has the most certain estimates as the vast majority of costs would be incurred in the near term. It is also the easiest to develop surety for, as major activity ceases with facility close-out in year 154. The need for major rebuilding operations on a regular basis in perpetuity undermines the current generation's ability to estimate costs and provide surety with respect to Centralized Storage and Storage at Nuclear Reactor Sites.

Thus, Deep Geological Disposal should provide a higher confidence that funding shortfalls will not occur that would threaten the assured continuation of necessary operations compared with the other approaches.

Contingency allowances included in the cost estimates are comparable, as a percentage of cost estimates across the four common project stages, for the three approaches, as all approaches have been subject to similar levels of conceptual design and cost estimation.

Costs

Economic viability was assessed using non-discounted cash flows (costs) and present value costs. Using non-discounted cash flows for cost comparisons between the three approaches is helpful in outlining the timing of the future costs. Utilizing present value costs of each approach for comparison purposes is also an accepted practice and is utilized for financial planning.

The present value cost estimates for Deep Geological Disposal, Centralized Storage (above / below ground), and Storage at Nuclear Reactor Sites (new above ground technology) as per the Joint Waste Owners' estimates are $6.2 billion, $3.4 to 3.8 billion, and $4.4 billion, respectively (January 2004 dollars) - for the 3.7 million fuel bundle scenario.

Deep Geological Disposal has the lowest total single operational cycle (non-discounted) cost (approximately $16.2 billion, spanning to year 154 when the facility is closed). The Storage at Nuclear Reactor Sites approach has the highest non-discounted cost over one operational cycle ($2.42 billion, spanning between year 55 and 320 across the seven current reactor sites). However, Storage at Nuclear Reactor Sites and Centralized Storage have many operational cycles and significantly higher life cycle costs (non-discounted). For example, Deep Geological Disposal has the lowest costs over 10,000 years ($13.7 billion for non-discounted facility costs), as it is decommissioned after one operational 'cycle'. Centralized Storage and Storage at Nuclear Reactor Sites are rebuilt at regular cycles and have significantly higher costs (non-discounted) over 10,000 years.

Deep Geological Disposal and Centralized Storage approaches have transportation costs on the order of $1.2 billion (non-discounted). Site location can significantly affect this cost. Storage at Nuclear Reactor Sites does not have such a transportation component.

Objective 5: Community Well-Being

Community well-being is about how various communities might be affected from the introduction of any one of the three management approaches for used nuclear fuel. The comparison was based on a combination of quantitative and qualitative analyses. Economic impacts were measured using ***Input/Output*** models specifically developed for each of the eleven illustrative economic regions. Community capacities to adapt to the opportunities and challenges of the management approaches were measured using the ***Sustainable Livelihoods Framework***, specifically tailored to each of the eleven illustrative economic regions. Drawing on published literature and the study team's own experience in this field, qualitative discussion regarding community impacts were also provided.

The analysis for this objective was divided into three separate components as follows:

1. ***Community economic health.*** Using a customized Input/Output model for each of the eleven illustrative economic regions, the following measures were used to assess economic impacts:

    - Income;
    - Employment; and
    - Tax revenues.

    It was assumed that higher levels of employment, income and taxes are preferred by economic regions and the host provinces.

2. ***Community social quality***. The Sustainable Livelihoods Framework was used to assess the strengths of the following four "capitals", as a means to assess how well the eleven illustrative economic regions might be able to leverage the employment and income opportunities offered in their region, and cope with the challenges of adjusting to this change, for either of management approaches:

   - Human capital;
   - Social capital;
   - Financial capital; and
   - Physical capital.

3. ***Aboriginal community quality*.** The Sustainable Livelihoods Framework was again used to assess the strengths of the following "capitals", as a means to assess how well Aboriginal communities in the eleven illustrative economic regions might be able to leverage the employment and income opportunities offered in their region, and cope with the challenges of adjusting to this change, for either of management approaches:

   - Human capital;
   - Financial capital; and
   - Physical capital.

For both community social quality and Aboriginal community quality, it was assumed that higher scores for each "capital" are preferable, and that a balanced mix of capitals is also more preferable.

Benefits:

All three management approaches generate very large economic benefits in the host communities and province. These benefits include thousands of jobs, billions of dollars in new income, and taxes to all three levels of government.

Differences between approaches are evident between economic regions and time frames. In general, rural economic regions tend to capture less of the employment, income and tax benefits as compared to more urban economic regions. This is because rural economic regions tend to have a smaller and less diverse supporting economic base and infrastructure that can capture "spin-off" benefits. In this case, more jobs and income tend to "leak" out to other regions.

The Deep Geological Disposal approach provides the largest economic benefit in the near term (i.e., up to 175 years), while Centralized Storage and Storage at Nuclear Reactor Sites spread economic benefits over thousands of years. Only Storage at Nuclear Reactor Sites offers economic benefits to all six host economic regions simultaneously, although two host economic regions in southern Ontario capture the greatest share of benefits since they are also the source of most of the used nuclear fuel.

Risks:

Despite the very positive economic benefits resulting from all three management approaches, there is a variety of social and economic costs that are attendant with projects of this magnitude, particularly when sited in rural regions of Canada with smaller and less diverse local economies.

The *"Boom and Bust"* cycles linked to each of the management approaches involves thousands of workers and billions of expenditures. Below are just three examples of possible effects that need to be managed:

- Housing and land values can rapidly spike at the outset of project implementation and might crash upon project completion;

- The large influx of short-term and temporary workers might increase demand for social and physical infrastructure services, which might become oversized and inefficient upon project completion; and

- The loss of "wilderness" and other "heritage" values important to stakeholders across Canada is a possibility if the development project is not managed. These social values are at greatest risk in rural economic regions and tend to become more valuable with the passage of time.

Costs:

Along with the economic benefits, each of the alternative management approaches bring a range of social and economic costs that must be managed and accounted for. Such costs may likely include:

- Rising costs for basic services during the "peak" phases of operations;

- Labour shortages and wage rate inflation also during the peak phases of operations;

- With increased wealth and population growth, increases in crime and other social issues might rise;

- Change in the nature and character of communities in the region, particularly those that are in close proximity to either the Deep Geological Disposal or Centralized Storage management approach; and

- The impact on community character is likely to be less for Storage at Nuclear Reactor Sites since they already contain temporary used nuclear fuel handling facilities.

During the "bust" or decline period(s), social and economic costs abound which can be managed, such as:

- Loss of personal and family wealth;
- Out-migration;
- Increased financial and personal stress;
- Business closures and loss of supporting services;
- Increased crime and other social disorders; and
- Drug / alcohol abuse.

The costs are independent of management approach but tend to be greatest in rural economic regions. The various costs identified above can be managed, but this requires long-term planning and investment in some or all of the Sustainable Livelihood Framework "capitals". The analysis of all eleven economic regions shows that there are distinct differences among the regions in relation to their capacity to adapt to the positive and negative "shock(s)" that are linked to all three management approaches. It is evident that the more rural regions have the lowest relative adaptive capacity. Some rural regions have at the present time very high unemployment rates, a lower educated workforce, higher life stresses and the least opportunities for self-improvement. Thus, should either Centralized Storage or Deep Geological Disposal locate in such a region, the local population is least capable of adapting to the new employment opportunities. This might mean that employment opportunities may go to non-residents who reside in the region only for the duration of the project activity.

The Sustainable Livelihoods Framework helps one to identify possible ways to support people and communities in building their livelihoods assets in the face of incoming activities linked to all three management approaches. It also identifies ways to encourage responsive support from institutions and organizations and avenues that people and communities might choose to harness change for social and economic enhancement.

Many of the rural and remote economic regions examined in this study face significant challenges in the basic process of engaging with the NWMO even in preliminary discussions of possible siting. The analysis flags many needs for early measures to build the capacity of people within these rural and remote regions to effectively participate in discussions, dialogue and employment opportunities offered by each of the alternative management approaches.

Objective 6: Environmental Integrity

This objective considers the potential effects on environmental integrity of all components of the management approaches, including construction and operation of the facility, transportation of used nuclear fuel to the site and long-term management. The environmental integrity analysis focuses on measures that may allow possible differences between approaches to be highlighted, including those that may occur across illustrative economic regions. Economic regions are not homogeneous, as they contain different and varied environments and environmental conditions (e.g., wilderness areas versus urbanized areas). This analysis was completed at the level of an economic region and as such is different from a site-specific analysis. However, regardless of the particular economic region, it is assumed that all approaches are capable of being implemented without causing any significant adverse environmental effects using current best management practices, although there may be differences between approaches.

The assessment used quantitative information available in the literature or capable of being estimated within the timeframe available for the assessment, and builds on the approach used by the Assessment Team and by GAL/GLL in similar studies. Information was developed for each of the approaches within each of the illustrative economic regions. Current experience with respect to environmental assessment of similar waste management projects provides a useful and appropriate basis for predicting and comparing the benefits and risks of implementing each of the approaches in the near and long term at the geographic level of an economic region. A specific environmental assessment would need to be completed as part of any siting studies.

The primary considerations for the analysis included:

1. **Risk scenario:** Risks to environmental integrity are as a result of disturbances caused by the management approaches, either under normal or off-normal conditions. Disturbances may be physical disturbances, radiological releases or conventional contaminant releases.

2. **Receptors or resources potentially affected**: All ecozones within illustrative economic regions have unique features and characteristics in terms of the physical and biophysical environment. All ecozones are sensitive to environmental impacts. Environmental features and characteristics at the facility level will vary across ecozones and across economic regions. Measures or characteristics of the environment are identified to make conclusions on the differences in the number, type and sensitivity of the features and species between economic regions.

3. **Significance of effects on the impacted receptor**: The significance of environmental effects under normal and off-normal conditions is assessed qualitatively by considering the likelihood, severity, ability to monitor and permanence of an adverse effect. It is assumed that an effect that is difficult to detect, large in extent and magnitude, and difficult to reverse is a potentially significant adverse effect.

Benefits

All three approaches can be constructed and operated without causing significant adverse effects on the environment in the near and long term. This is achieved by implementing standard mitigation measures and best management practices. The likelihood of the occurrence of off-normal conditions for each of the approaches is low to very low. This is independent of economic region. Differences between approaches result from their implementation in different ecozones, the type of effect and the need to transport used nuclear fuel.

As there is no requirement for transportation of used nuclear fuel for Storage at Nuclear Reactor Sites, there are no associated risks to the environment due to a transportation accident, although the likelihood of occurrence of a transport accident is low to very low.

Deep Geological Disposal in the Canadian Shield offers a benefit over the other two approaches with respect to withstanding effects of significant environmental change in the long term. The nature of the facility is such that it would not be susceptible to the effects of a glacial event. Facilities constructed at or near the surface are less likely to withstand such an event.

Risks

A distinguishing factor between the approaches is the ability to monitor their environmental performance over the long term. Following closure of the Deep Geological Disposal in the Canadian Shield facility, there would not be any active environmental monitoring, as monitoring in the long term is judged not to be feasible due to the nature of the facility; however, the likelihood of an adverse effect occurring is low because of the physical and geological barriers in the underground facility.

Transportation is also a distinguishing factor between the different approaches because of the need to transport used nuclear fuel between locations in the near term. All approaches other than Storage at Nuclear Reactor Sites require off-site transportation with the associated risks. However, best environmental management practices would be used to ensure these risks are low. The transportation routes for Centralized Storage (above or below ground) and Deep Geological Disposal in the Canadian Shield would likely traverse multiple ecozones. In addition, risks associated with transportation would be lowest for illustrative economic regions that are located closest to the current reactor sites.

The analysis of off-normal scenarios, particularly those that involve release of contaminants, indicates that effects could be more severe in those economic regions with a greater number of sensitive habitats and species. These ecozones may also have been previously impacted by historical activities and may be more susceptible to further disturbance. The effects of off-normal scenarios that may be most severe are in those locations adjacent to large continuous bodies of water, as the impacts on the water resources could be far ranging and could have international consequences. The Storage at Nuclear Reactor Sites management approach has the largest number of sites adjacent to large international water bodies. Additionally, Storage at Nuclear Reactor Sites would have seven separate facilities and therefore more potential interactions with the environment.

All ecozones are sensitive to environmental impacts. Environmental features and characteristics at the facility level vary across ecozones and thus across economic regions. As noted above, this assessment is not a siting study using site-specific information and accordingly the significance of potential adverse effects at the facility level for any of the management approaches cannot be exactly determined within the scope of this assessment.

Costs

Some of the costs for environmental integrity are accounted for in the economic costs of all three approaches through facility designs and monitoring programs. However, should societal values and/or environmental risks change with time, the degree to which Canadians understand what affects the environment might change. For example, society today places a higher value on environmental integrity than 25 years ago. Therefore, mitigation measures and compensation, if required, may result in additional future costs not included in the current cost estimates.

Objective 7: Adaptability

Adaptability as considered in this assessment relates to the ability of future generations to modify or change aspects of any management approach over time in response to changing societal values and/or technology. The comparative assessment of the management approaches was based the study team's judgement of how each of the three approaches relates to the influences identified by the Assessment Team. No additional criteria or impact measures for the adaptability objective were developed.

It is recognized that "adaptability" is comprised of many considerations and elements as identified by the NWMO Assessment Team. The influencing measures that this study team focused on include the following:

- Availability of necessary capacity, mechanisms and resources for long term
- Adequacy of institutions and governance
- Ability/need to take corrective actions that address surprises
- Accountability

Each of the above four measures are consistent with those considered in other studies of this nature, but more important, they are the key impact measures identified by the Assessment Team.

The location of any management approach is not a significant factor in the assessment of adaptability.

Benefits

Being able to offer a “complete” solution to the management of used nuclear fuel within the near term has unique value. Only Deep Geological Disposal minimizes the need for a long-term governance structure and supporting institutions to ensure long-term safety. This complete solution is of value because in the long term, there can be no guarantees that ensure necessary governance and supporting institutions.

However, Deep Geological Disposal is limited by not being able to adapt to new technologies or respond to alternative social values and decisions. Only the two storage approaches, Storage at Nuclear Reactor Sites and Centralized Storage (above or below ground), have the capability to enable future generations to easily influence the long-term management of used nuclear fuel.

The process being followed by the NWMO is transparent and open to the public. When the selection process begins for a management approach and location, more stakeholder input and participation will be required to ensure public accountability. As discussed in the Community Well-being section, it is important to recognize that public involvement will be required in the siting, design, construction, and operational phases of any preferred management approach. This has implications for communities that lack the capacity to effectively participate in discussions and negotiations, and points to the need for early measures to build this capacity.

Risks

The risk consideration that most affects adaptability relates to how science, technology, and social values change over time. As these change, it may be necessary or prudent to make changes to any of the three management approaches. Consider for example how science and technology has changed over the past 40 years in relation to municipal waste disposal. Specifically, municipalities managed all types of waste into "dumps" with minimal regard for how groundwater might be affected over the long term. This situation arose because there was limited science available to indicate the effects and consequences that now have to be dealt with, such as leachate seepage into groundwater and its attendant cost of remediation.

It is not possible to predict with any confidence how scientific knowledge or technology will change over time, other than it is reasonable to expect that it will change. At the same time, social dynamics and institutions that influence the mechanisms and processes for managing used nuclear fuel are also likely to change. Taken together, these changes will affect how society values risk and the trade-offs used to evaluate the management approaches. Over the long term, it is not possible to guarantee that the necessary safety and environmental concerns most relevant to

Storage at Nuclear Reactor Sites or Centralized Storage (above or below ground) will continue to be monitored effectively. Further, no one can guarantee that the institutional and operational framework(s) required to ensure long-term monitoring and management will be in place to prevent inadvertent intrusion into the underground facilities of Deep Geological Disposal. Even if institutional controls are in place, it is possible that any one of the three approaches might require retrieving and/or mitigation measures to prevent or reverse adverse effects.

Costs

The cost of reversing or altering current decisions regarding any of the management approaches has not been factored into the Joint Waste Owners' cost estimates. This is an issue of particular importance to Deep Geological Disposal after the facility has been decommissioned and closed and the opportunity for remedial actions may be limited.

Although the risk of adverse events is very low, the costs related to reversing health or environmental effects have not been accounted for by the Joint Waste Owners' estimates; however, it is reasonable to assume that these costs would be high based on experiences documented by the U.S. National Academy of Sciences[97].

Objective 8: Fairness

Fairness is about social equity. It relates to how various stakeholders participate in the management decision-making process for used nuclear fuel now in the future, to ensure that social values are factored into the design, construction, and operational phases. The comparative assessment of fairness was based the study team's judgement of how each of the approaches relate to the fairness influences identified by the Assessment Team. No additional criteria or impact measures for this objective were developed.

It was recognized that there are many influencing factors and measures for "fairness" as identified by the NWMO Assessment Team. The following four measures were selected for more detailed qualitative assessment:

- Intergenerational fairness
- Interspecies distributional fairness
- Distributional fairness
- Opportunity to influence decision outcomes and engagement in decision-making

[97] National Academy of Sciences, *A Strategic Vision for Department of Energy Environmental Quality Research and Development*, 2001.

Each of the above four measures is consistent with those considered in other studies of this nature, but more important, they are the four key impact measures identified by the Assessment Team. The location of any of the management approaches does have some impact on the assessment of fairness.

Benefits

Any management approach that limits the majority of actions, solutions and associated financial costs to the current or "near-current" generations is more preferable because it appropriately restricts procedural and financial costs (burden) to the generation that benefited from the electricity generated from the nuclear fuel. Clearly, such an approach does not put a significant financial burden on future generations who will not benefit from the processes that resulted in the used nuclear fuel and the necessity for its long-term management. Finding and implementing a solution within the current or "near-current" generations shows respect for the interests of future generations from a financial perspective and it adheres more closely to the 'polluter-pays" principle. Only the Deep Geological Disposal approach incurs the majority of its costs in the near term thus limiting financial liabilities and the financial surety for the most part to the current generation, assuming that "normal" conditions prevail.

All three management approaches would be constructed and would operate using best management practices. This would minimize adverse effects on humans, plant and animal species. The key to ensuring interspecies distributional fairness is being able to effectively monitor, detect and mitigate adverse consequences in a timely manner. In this regard, Centralized Storage (above or below ground) and Storage at Nuclear Reactor Sites allow for easier monitoring, detection and mitigation (if necessary) in the long term, compared to a closed Deep Geological Disposal facility.

Risks

There is no "fail-safe" solution or management approach for used nuclear fuel in the long term. All three management approaches have risks that could impact on people and the environment.

All three management approaches place some risk in the hands of future generations. There are tradeoffs and decisions that must be considered carefully. For example, the two storage approaches require long-term repackaging and facility rebuilding activities which increases exposure risk to people and the environment. Alternately, Deep Geological Disposal limits choices and flexibility of future generations to adapt new technologies and social values into the management process.

Location of the management approach is important. If a Centralized Storage facility or a Deep Geological Disposal facility were to be located in a rural area, human interactions and consequences from adverse effects are less compared to the possible impact on other species, at least in the near term. Over the long term, the population, environment and other dynamics in current rural or remote areas of Canada might change for a variety of reasons, including for example, population growth and/or social preferences. This means that current decisions about location siting and possible interspecies effects will be strongly influenced by current conditions and may not accurately reflect the situation in future.

Costs

Although the risk of an adverse effect from any of the approaches in the near or long term is extremely low, the distribution of social and personal costs are not equally distributed or shared by Canadians, either over time or geographically. Adverse events may be natural (e.g., an earthquake) or human induced (e.g., terrorism). Most beneficiaries of nuclear energy today reside in urban centres throughout eastern Canada. If a future adverse event occurs at one location, then those people and sensitive environments located near the event would be most affected and would likely incur the brunt of social, environmental and economic costs related to the event, its remediation and/or quality of life degradation.

All communities affected by any of the used nuclear fuel management approaches will need to participate not just in the initial siting decisions, but in the on-going management of the facility(ies), where appropriate. In the long term, governance models and institutions will likely change. Giving local communities a role in on-going management of the used nuclear fuel is one way to ensure some degree of homogeneity of long-term management - not that their governance or social model won't change, but that they have to live with the legacy of this generation's decision regarding a preferred management approach. As such, they have the most to gain and lose, and they and their descendants will be least likely to let the long-term management approach commitments lapse.

12.4 COMPARING THE STRENGTHS AND LIMITATIONS OF ALTERNATIVE MANAGEMENT APPROACHES

12.4.1 Deep Geological Disposal in the Canadian Shield

The assessment has found that this approach could be safely and securely implemented without adverse effects on people and the environment while providing significant economic benefit at all locations studied. The following subsections identify the strengths and limitations of Deep Geological Disposal in the Canadian Shield in comparison with the other approaches.

Strengths

This solution for used nuclear fuel management is virtually completed within one generation, limiting the cost and liability to future generations. This is fair and reasonable from the principle that current users and generators of nuclear energy will deal with and pay for the long-term management of used nuclear fuel. The facility-related costs are relatively well understood and processes are in place to ensure that required the financial resources will be in place when needed.

In the near term, Deep Geological Disposal in the Canadian Shield creates the largest economic benefits by a factor of two over Centralized Storage and by a factor of eight over Storage at Nuclear Reactor Sites. Although the economic benefits to all host provinces and regions are expected to be very significant in terms of employment, income (wealth) creation and tax revenues, not all regions capture the same degree of benefit. Generally speaking, economic regions with a higher population density and a mixed industrial/commercial base stand to capture a greater portion of these economic benefits for residents within their region, compared to rural and remote regions. However, there are many measures that can be implemented to enhance the benefits to rural and remote areas. These measures have been outlined in a separate report.[98]

Deep Geological Disposal in the Canadian Shield provides the most secure environment for the long-term management of used nuclear fuel. The number and robustness of physical and geological barriers make threats of terrorism very low. Radiation exposure to workers and members of the public are limited to the near term, unlike other approaches where potential exposures continue over 10,000 years and beyond. However, during construction and placement of used nuclear fuel, this management approach creates some increased degree of worker exposure compared to the two storage approaches.

Limitations

Once closed, a Deep Geological Disposal in the Canadian Shield facility is difficult to monitor for potential adverse effects, although such effects appear very unlikely. This might mean that impact to people and the environment could go undetected for a longer period of time compared to the other approaches. Equally important, it may prove to be more difficult and costly to undertake remedial actions should an environmental breech be detected sometime in the future.

This option is the least flexible in terms of adapting to changing technologies and social values. Once in place, it is technically feasible, but not easy to retrieve the used nuclear fuel.

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[98] *Report on A Review of Possible Measures to Avoid or Minimize Significant Socio-Economic Effects on a Communty's Way of Life*, Draft version 4, April 28, 2005.

If this approach was located in a rural region of Canada, local communities may be less equipped to participate in a meaningful and effective consultation and decision-making process, compared to more urban regions. Also, rural or remote regions are typically not prepared in relation to developing a skilled labour force; having adequate community infrastructure; or planning capability to take full advantage of the employment and income benefits that are associated with such projects. More important, these communities will require even greater assistance in coping with the eventual down-turn ("bust") in the local economy when the site is decommissioned and closed.

12.4.2 Storage at Nuclear Reactor Sites

The assessment has found that this approach could be safely and securely implemented without adverse effects on people and the environment while providing significant economic benefit at all locations studied. The following subsections identify the strengths and limitations of Storage at Nuclear Reactor Sites in comparison with the other approaches.

Strengths

Economic benefits, in terms of employment, income and taxes, are generated for a variety of communities in six economic regions simultaneously. Although the total economic impact of this approach is smaller compared to Deep Geological Disposal in the Canadian Shield, longer-term benefits are sustained in each community from ongoing monitoring, maintenance operations, and periodic facility rebuilds.

The current reactor site communities have a good working relationship with their nuclear facility owners and have established many measures to offset or limit adverse consequences of large construction activities. As well, programs are in place to promote local community involvement in industry activities and decision-making, as well as promotion of local supply businesses.

No off-site transportation of used nuclear fuel is required, thus eliminating one source of risk to people and the environment.

Storage at Nuclear Reactor Sites offers the greatest degree of flexibility of all three approaches. It is likely that technologies and social values will change with time. As such, future generations will be better able to apply new knowledge and ideas in developing an alternative approach that best matches social values at that time. Also, it is relatively easy to conduct monitoring and to react to adverse events should they arise.

Limitations

This approach has the highest estimated long-term cost expressed as total cash cost. The majority of the costs and responsibility for used nuclear fuel management is deferred to future generations. Moreover, there is no guarantee that the necessary financial resources or the management institutions required to maintain the facilities will be in place in the long term to ensure that the used nuclear fuel continues to be managed as required.

This approach is the least secure of all three management approaches examined. Oversight and maintenance of a single facility is preferable to the current seven sites for the following reasons: some of the current reactor sites are located in seismically active areas; most of the sites are located in ecozones adjacent to or near water bodies; and most of the sites are located in populated areas where exposure is greatest in the event of an accident.

12.4.3 Centralized Storage (Above or Below Ground)

The assessment has found that this approach could be safely and securely implemented without adverse effects on people and the environment while providing significant economic benefit at all locations studied. The following subsections identify the strengths and limitations of Centralized Storage (Above or Below Ground) in comparison with the other approaches.

Strengths

This management approach embodies some of the strengths of both Deep Geological Disposal in the Canadian Shield and Storage at Nuclear Reactor Sites. It is a central facility that can be located in a region that is environmentally and geologically appropriate.

Although it is less secure than a closed Deep Geological Disposal in the Canadian Shield facility, this approach can be situated and engineered, without space limitations, to be secure. This is particularly true for the below ground option. While at the same time being flexible, this approach can be easily adapted to take advantage of future innovations and discoveries in science and technology, as well as respond to changing social values.

Centralized Storage (above or below ground) offers very large economic benefits (albeit less than Geological Disposal in the Canadian Shield) to the host province and economic region, both in the near term and long term, as this approach requires active maintenance and facility rebuilding periodically for thousands of years.

Limitations

Like Storage at Nuclear Reactor Sites, this approach does not provide a long-term solution that is fully managed and paid for by the current users of nuclear energy and the generators of used nuclear fuel. It shifts a large portion of the risk and cost for used nuclear fuel management to future generations. As stated earlier, there is no guarantee that the necessary financial resources or the management institutions required to maintain the facilities will be in place in the long term to ensure that the used nuclear fuel is managed properly.

In addition, this approach must rely on transportation of used nuclear fuel, possibly over long distances, with its inherent risks. Risk from hostile interventions or accidents are always present with attendant risks and costs to workers, the public and the environment.

12.4.4 Issues Common to All Management Approaches

There are number of other issues common to each of the management approaches that were identified in the comparative assessment. First, all three approaches impose a dramatic legacy on communities that can have both significant benefits and costs. It is recognized that, although the NWMO has embarked on a comprehensive program of stakeholder consultations, many communities and stakeholders (particularly in rural and remote regions) lack many of the basic skills and support mechanisms to contribute to this discussion in a meaningful and effective manner. This means that further investment is required to enhance the capabilities of these communities to participate in the decision-making process.

Second, if a preferred management approach were to be located in a rural or remote region, few communities would be capable of supporting such a large project undertaking, under current conditions. Many lack the physical infrastructure capacity (e.g., roads, water and wastewater treatment, schools, health services, etc.) required to serve the very large workforce expected. Both financial and managerial assistance would be required to meet this challenge. This does not mean that urban communities do not need similar assistance.

Third, if either Deep Geological Disposal or Centralized Storage (above or below ground) were to be selected, once their facilities are closed or are between periodic rebuilds, the host region and communities would then experience significant social and economic dislocation with rapid population out-migration and business losses typical of single-resource communities. Considerable planning and investment would be required to offset these and other consequences.

12.5 Suggestions for an Enhanced Approach

The comparative assessment has found that all approaches have strengths and limitations in comparison with each other.

After some period of reflection, the study team has concluded the following attributes of the approaches would be valuable to incorporate into an enhanced management approach - one that leverages the strengths of all three current approaches, yet minimizes risk.

Based on this assessment:

1. The study team has concluded that a centralized management approach such as by Deep Geological Disposal or Centralized Storage (above or below ground), offers significant advantages compared to a decentralized approach such as Storage at Nuclear Reactor Sites for the following reasons:

    - It is more secure – limits access to fewer people;
    - A location can be selected for optimum performance and minimal risk; and
    - Although requiring transportation of fuel, the risks and costs are not significant.

2. The study team has concluded that a single solution implemented within the current or near-current generations offers significant benefits compared to one that requires long-term active management of repackaging and facility rebuilding for the following reasons:

    - The cost estimates are more robust and can be known with relative certainty;
    - There is greater financial surety for funding a near-term solution;
    - It is fair that the current generation that has enjoyed the benefits of nuclear energy also take full responsibility for the cost of its long-term management; and
    - It is more secure because there is less handling of used nuclear fuel, and because it is effectively isolated deep underground within several physical and geological barriers.

3. The study team has concluded that Deep Geological Disposal (isolation) offers advantages compared with surface or near-surface facility storage for the following reasons:

    - It is more secure – there are more physical barriers to entry and degradation; and
    - The technology for Deep Geological Disposal is available now and appears capable of ensuring the degree of isolation from people and the environment well into the future.

4. Finally, the study team has concluded that an implementation strategy that provides time for all stakeholders to participate in the decision-making process offers many advantages, as well as providing extended time for "proof-of-concept" and adoption of new technologies. The reasons for this conclusion are as follows:

    - It is fair to "near-future" generations that they participate in the decision-making process;
    - It is fair that communities most affected by the siting and implementation of a solution be given enough time to effectively participate in the employment and income opportunities, as well as plan for how to adjust socially to the new reality of a used nuclear fuel management facility in their midst; and
    - It is fair to "prove-out" that all issues of concern are being managed in an equitable fashion.

Accordingly, the study team has concluded that there is considerable merit in developing and assessing another approach. The additional approach should be designed to incorporate the favourable characteristics of Deep Geological Disposal while addressing the limitations of:

- Proof of concept at selected locations;
- Opportunity for monitoring following close-out;
- Time for current and near-current generations to participate in selection and design of a long-term approach before it is fully implemented; and
- Taking advantage of potential technical enhancements in the near term.

APPENDIX A

ADDITIONAL TABLES AND FIGURES

TABLE 2.1-1
Conceptual Design and Cost Estimate Reports for
Long-Term Management of Used Nuclear Fuel

Overview Reports

Joint Waste Owners (JWO), May 2004. *Overview of Joint Waste Owners' Conceptual Design Work Related to Nuclear Fuel Waste Act, May 2004*. Based on a presentation given to the NWMO Assessment Team, January 21, 2004, by Frank King, Director, Nuclear Waste Engineering and Technology, Ontario Power Generation.

Joint Waste Owners (JWO), March 2004. *Costs of Alternative Approaches for the Long-Term Management of Canada's Nuclear Fuel Waste, Deep Geologic Disposal Approach*. A Submission to the Nuclear Waste Management Office by Ontario Power Generation, Hydro-Quebec, New Brunswick Power and Atomic Energy of Canada Limited. Rev 01.

Joint Waste Owners (JWO), March 2004. *Costs of Alternative Approaches for the Long-Term Management of Canada's Nuclear Fuel Waste, Centralized Extended Storage Approach*. A Submission to the Nuclear Waste Management Office by Ontario Power Generation, Hydro-Quebec, New Brunswick Power and Atomic Energy of Canada Limited. Rev 02.

Joint Waste Owners (JWO), January 2004. *Costs of Alternative Approaches for the Long-Term Management of Canada's Nuclear Fuel Waste, Reactor-Site Extended Storage Approach*. A Submission to the Nuclear Waste Management Office by Ontario Power Generation, Hydro-Quebec, New Brunswick Power and Atomic Energy of Canada Limited. Rev 00.

Conceptual Design Reports – Management Facilities

CTECH Radioactive Materials Management (CTECH), December 2002. *Conceptual Design for a Deep Geologic Repository for Used Nuclear Fuel*. Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro Quebec and Atomic Energy of Canada Limited. 1106/MD18085/REP/01.

CTECH Radioactive Materials Management (CTECH), April 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 Quebec and Atomic Energy of Canada Limited. 1105/MD18084/REP/08.

CTECH Radioactive Materials Management (CTECH), April 2003. *Conceptual Designs for Reactor-site Extended Storage Facility Alternatives for Used Nuclear Fuel, Alternatives for the Pickering, Bruce and Darlington Reactor Sites*. Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro Quebec and Atomic Energy of Canada Limited. 1105/MD18084/REP/12.

CTECH Radioactive Materials Management (CTECH), April 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 Quebec and Atomic Energy of Canada Limited. 1105/MD18084/REP/14.

CTECH Radioactive Materials Management (CTECH), April 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 Quebec and Atomic Energy of Canada Limited. 1105/MD18084/REP/13.

CTECH Radioactive Materials Management (CTECH), April 2003. Conceptual Designs for Reactor-site Extended Storage Facility Alternatives for Used Nuclear Fuel, Alternatives for Atomic Energy of Canada Limited's Chalk River and Whiteshell Reactor Sites. Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro Quebec and Atomic Energy of Canada Limited. 1105/MD18084/REP/15.

Conceptual Cost Estimates – Management Facilities

CTECH Radioactive Materials Management (CTECH), September 2003. *Cost Estimate for a Deep Geologic Repository for Used Nuclear Fuel.* Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro Quebec and Atomic Energy of Canada Limited. 1106/MD18085/REP/02.

CTECH Radioactive Materials Management (CTECH), May 2003. *Cost Estimates 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 Quebec and Atomic Energy of Canada Limited. 1105/MD18084/REP/11.

CTECH Radioactive Materials Management (CTECH), December 2003. *Cost Estimates for Reactor-site Extended Storage Facility Alternatives for Used Nuclear Fuel, Alternatives for Pickering, Bruce and Darlington Reactor Sites.* Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro Quebec and Atomic Energy of Canada Limited. 1105/MD18084/REP/16.

CTECH Radioactive Materials Management (CTECH), December 2003. *Cost Estimates 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 Quebec and Atomic Energy of Canada Limited. 1105/MD18084/REP/18.

CTECH Radioactive Materials Management (CTECH), December 2003. *Cost Estimates 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 Quebec and Atomic Energy of Canada Limited. 1105/MD18084/REP/17.

CTECH Radioactive Materials Management (CTECH), December 2003. *Cost Estimates for Reactor-site Extended Storage Facility Alternatives for Used Nuclear Fuel, Alternatives for AECL's Chalk River and Whiteshell Reactor Sites.* Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro Quebec and Atomic Energy of Canada Limited. 1105/MD18084/REP/19.

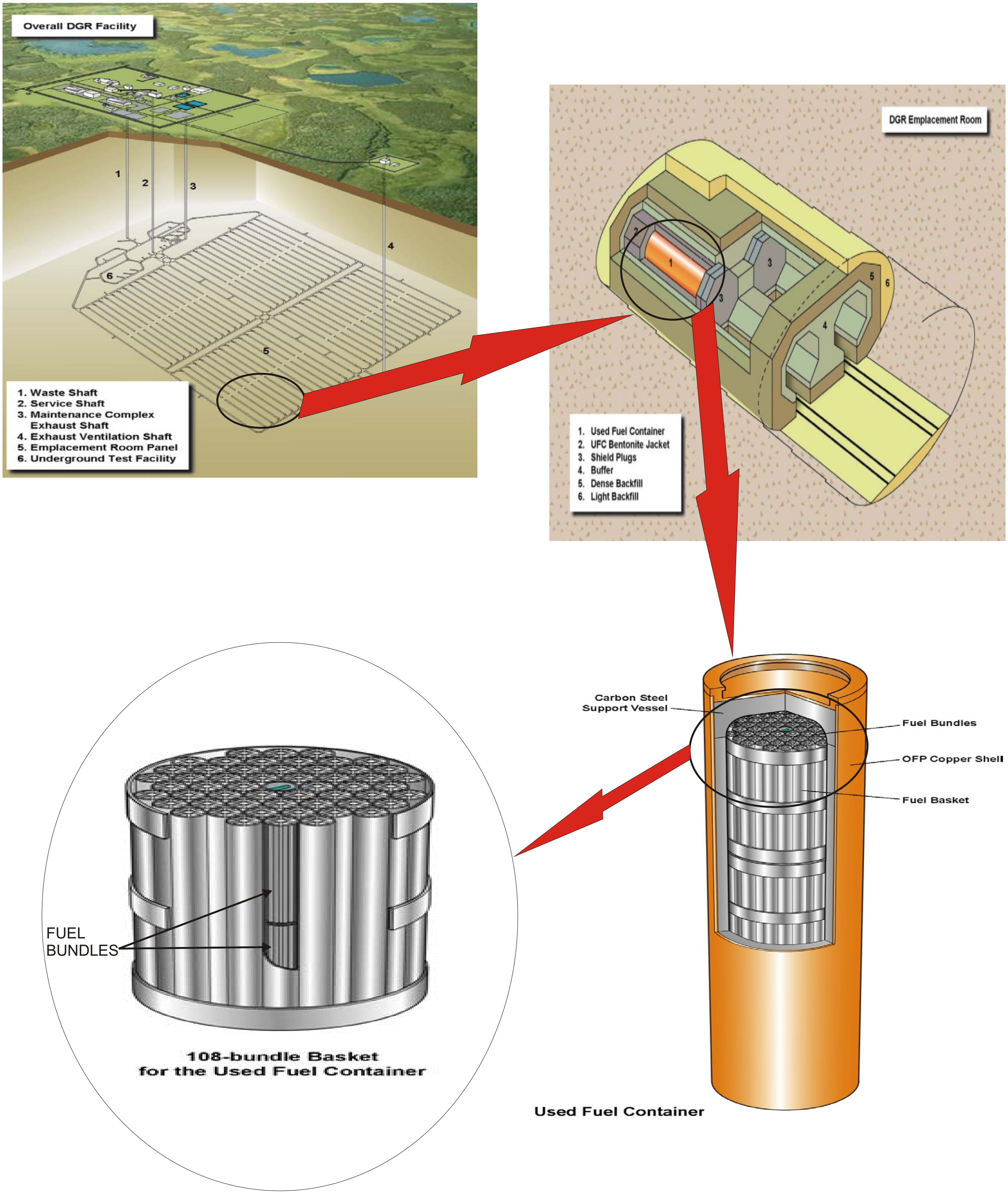
Transportation Studies

COGEMA LOGISTICS (COGEMA), May 2003. *Conceptual Designs for Transportation of Used Nuclear Fuel to a Centralised Facility.* Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro Quebec and Atomic Energy of Canada Limited. Ref. 500276-B-005. Rev. 00.

COGEMA LOGISTICS (COGEMA), September 2003. *Cost Estimate for Transportation of Used Fuel to a Centralised Facility*. Report of a Study carried out for Ontario Power Generation, New Brunswick Power, Hydro Quebec and Atomic Energy of Canada Limited. Ref. 500276-B-010 Rev. 00

DEEP GEOLOGICAL DISPOSAL IN CANADIAN SHIELD
DEEP GEOLOGIC REPOSITORY (DGR)

FIGURE 2.2-1



Source: CTECH Radioactive Materials Management

Date: FEBRUARY 2005

Project: 05-1112-002

Golder Associates

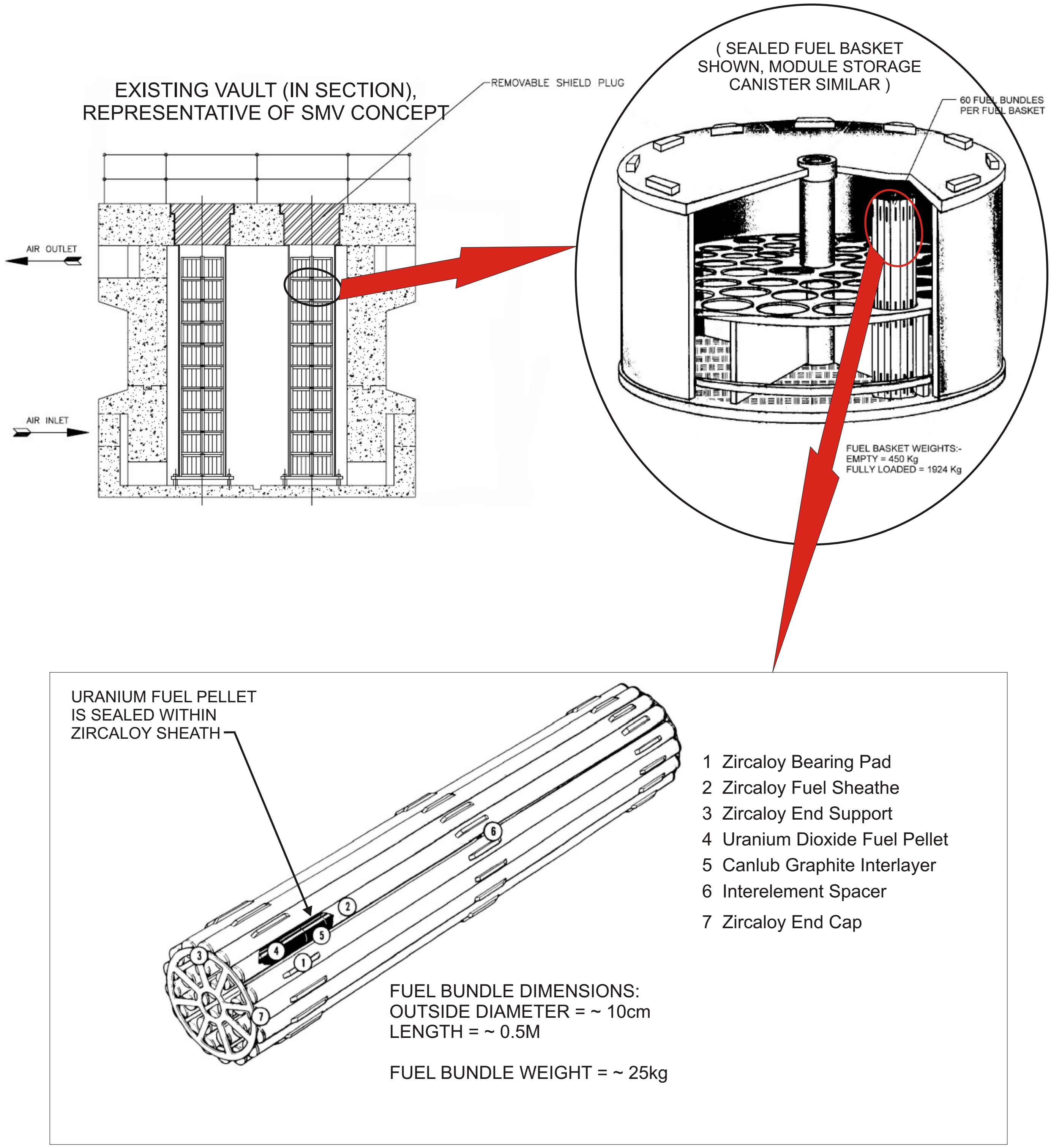
Drawn: RJ

Chkd: CJPS

05112002221.cdr

STORAGE AT NUCLEAR REACTOR SITES
SURFACE MODULAR VAULT (SMV)

FIGURE 2.2-2



Source: CTECH Radioactive Materials Management

Date: FEBRUARY 2005

Project: 05-1112-002

Golder Associates

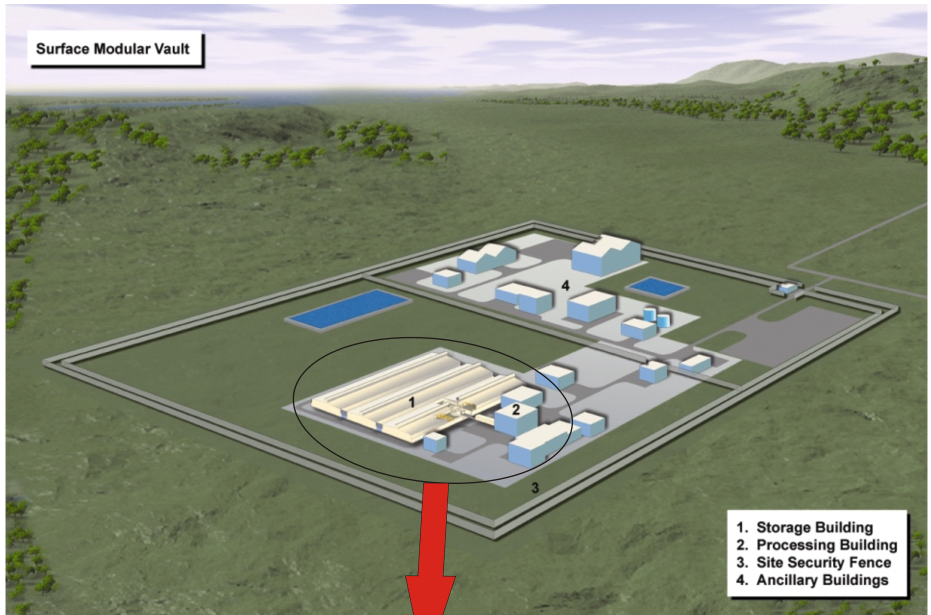
Drawn: RJ

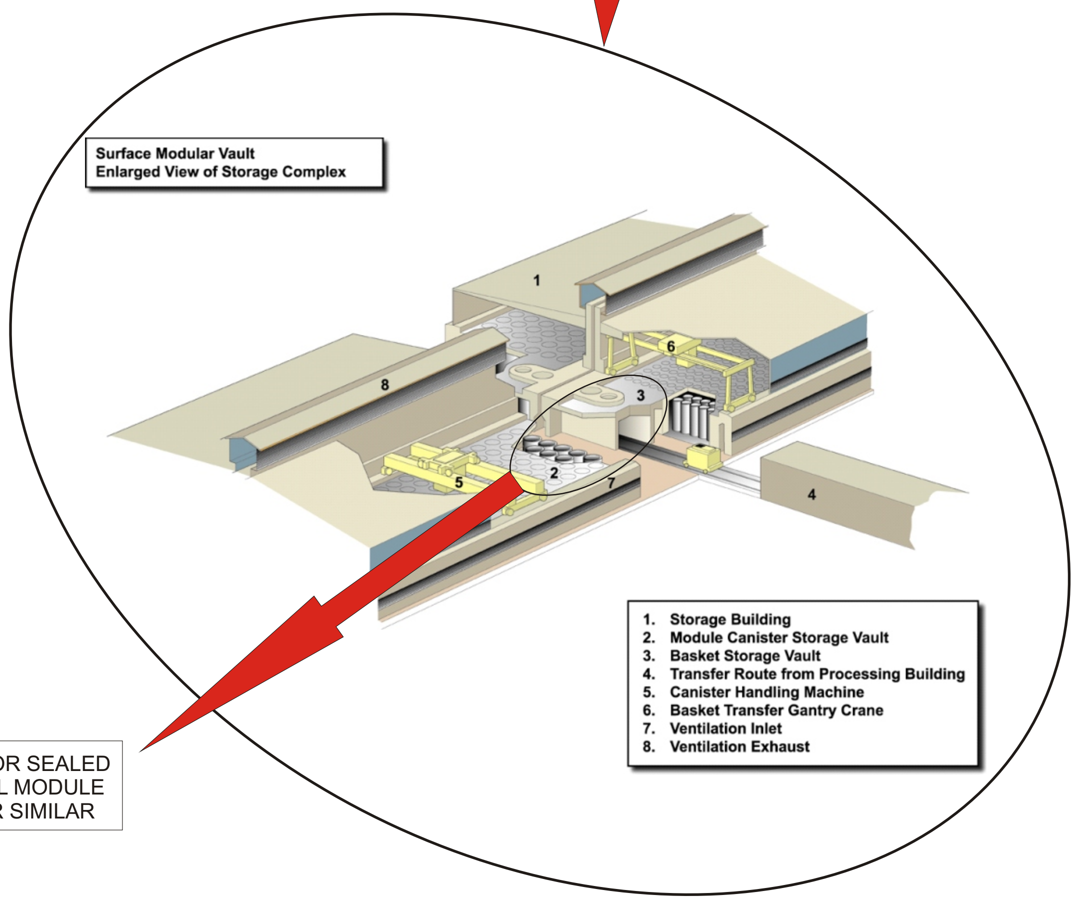
Chkd: CJPS

051112002222.cdr

CENTRALIZED STORAGE (ABOVE GROUND)
SURFACE MODULAR VAULT (SMV)

FIGURE 2.2-3





SEE FIGURE 2.2-2 FOR SEALED FUEL BASKET DETAIL MODULE STORAGE CANISTER SIMILAR

Source: CTECH Radioactive Materials Management

Date: FEBRUARY 2005

Project: 05-1112-002

Golder Associates

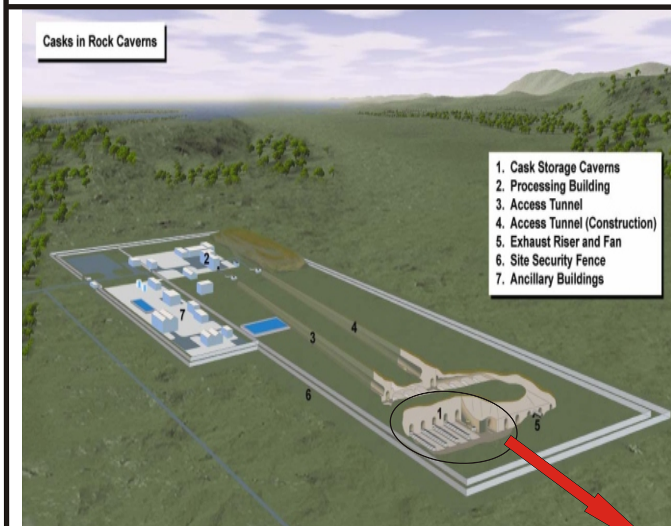
Drawn: RJ

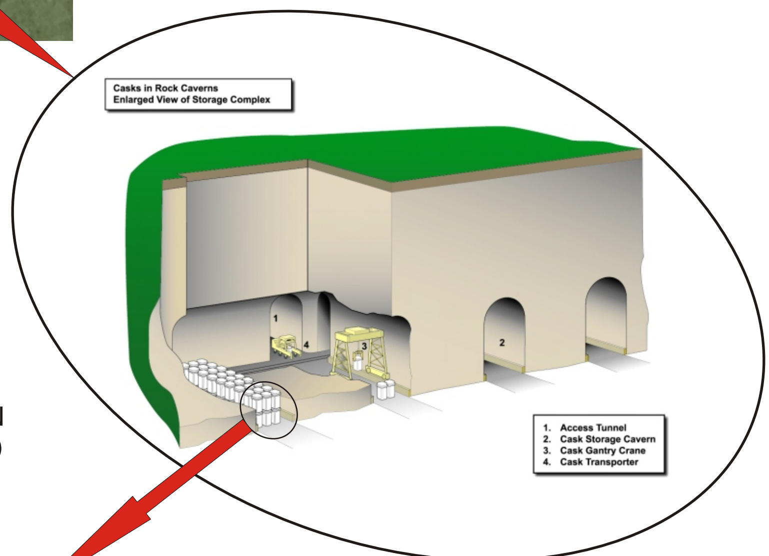
Chkd: CJPS

051112002223.cdr

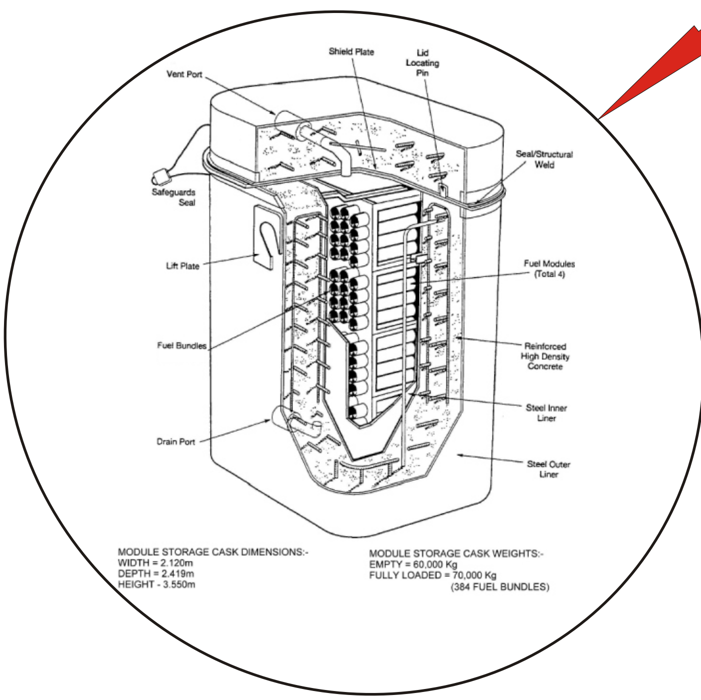
CENTRALIZED STORAGE (BELOW GROUND)
CASKS IN ROCK CAVERNS (CRC)

FIGURE 2.2-4





CASK
(MODULE STORAGE CASK SHOWN
BASKET STORAGE CASK SIMILAR)



Source: CTECH Radioactive Materials Management

Date: FEBRUARY 2005

Project: 05-1112-002

Golder Associates

Drawn: RJ

Chkd: CJPS

05112002224.cdr

Thompson - Okanagan
5930
Northern
4760
Southeast
4610
AECL - Whiteshell
Nord-du-Québec
2490
Northeast
3590
Kingston - Pembroke
3515
AECL - Chalk River
AECL - Gentilly 1
Gentilly 2
Centre-du-Quebec
2433
Point Lepreau
Saint John - St. Stephen
1330
Muskoka - Kawarthas
3520
Stratford - Bruce Peninsula
3580
Bruce A and B
Douglas Point
Pickering
Darlington
Toronto
3530
Legend
Economic Region Centroid
Nuclear Facility
Economic Region
Illustrative Economic Regions
Surficial Material
Till Blanket
Stable Soils
Figure 2.4-1
Assessment of Benefits, Risks and Costs of
Management Approaches by Economic Region
Project 40820, February 2005
Gartner Lee
Golder Associates
N
W
E
S
0
50
100
200
300
Km
REFERENCE: Geological Survey of Canada

Actively Seismic Areas | Figure 2.4-2

Assessment of Benefits, Risks and Costs of Management Approaches by Economic Region

Project 40820, February 2005

REFERENCE: National Building Code (1990)

Permafrost Regions | Figure 2.4-3

Assessment of Benefits, Risks and Costs of Management Approaches by Economic Region

Project 40820, February 2005

Gartner Lee

Golder Associates

REFERENCE: National Atlas of Canada

Canadian Shield | Figure 2.4-4

Assessment of Benefits, Risks and Costs of Management Approaches by Economic Region

Project 40820, February 2005

Illustrative Economic Regions Figure 3.2-1

Assessment of Benefits, Risks and Costs of Management Approaches by Economic Region

Project 40820, February 2005

From Point Lepreau to:	Distance (km)
Northern (4760)	4728
Nord-du-Quebec (2490)	2567
Muskoka-Kawarthas (3520)	1428
Northeast (3590)	2026
Toronto (3530)	1494
Thompson-Okanagan (5930)	5153

Distances were calculated to the centroid of the Economic Regions, using the Trans-Canada Highway and other major routes. Where no major road exists, straight line distances were calculated. Routes are intended to be illustrative only.

Travel from Point Lepreau Figure 6.3-5

Assessment of Benefits, Risks and Costs of Management Approaches by Economic Region

Project 40820, February 2005

Gartner Lee Golder Associates

From Gentilly to:	Distance (km)
Northern (4760)	3947
Nord-du-Quebec (2490)	1786
Muskoka-Kawarthas (3520)	647
Northeast (3590)	1245
Toronto (3530)	713
Thompson-Okanagan (5930)	4372

Distances were calculated to the centroid of the Economic Regions, using the Trans-Canada Highway and other major routes. Where no major road exists, straight line distances were calculated. Routes are intended to be illustrative only.

Travel from Gentilly | Figure 6.3-6

Assessment of Benefits, Risks and Costs of Management Approaches by Economic Region

Project 40820, February 2005

From Chalk River to:	Distance (km)
Northern (4760)	3429
Nord-du-Quebec (2490)	1628
Muskoka-Kawarthas (3520)	308
Northeast (3590)	728
Toronto (3530)	479
Thompson-Okanagan (5930)	3854

Distances were calculated to the centroid of the Economic Regions, using the Trans-Canada Highway and other major routes. Where no major road exists, straight line distances were calculated. Routes are intended to be illustrative only.

Travel from Chalk River — Figure 6.3-7

Assessment of Benefits, Risks and Costs of Management Approaches by Economic Region

Project 40820, February 2005

Gartner Lee

Golder Associates

From Darlington to:	Distance (km)
Northern (4760)	3556
Nord-du-Quebec (2490)	1829
Muskoka-Kawarthas (3520)	125
Northeast (3590)	853
Toronto (3530)	74
Thompson-Okanagan (5930)	4023

Distances were calculated to the centroid of the Economic Regions, using the Trans-Canada Highway and other major routes. Where no major road exists, straight line distances were calculated. Routes are intended to be illustrative only.

Travel from Darlington | Figure 6.3-8

Assessment of Benefits, Risks and Costs of Management Approaches by Economic Region

Project 40820, February 2005

From Pickering to:	Distance (km)
Northern (4760)	3527
Nord-du-Quebec (2490)	1856
Muskoka-Kawarthas (3520)	154
Northeast (3590)	825
Toronto (3530)	45
Thompson-Okanagan (5930)	3953

Distances were calculated to the centroid of the Economic Regions, using the Trans-Canada Highway and other major routes. Where no major road exists, straight line distances were calculated. Routes are intended to be illustrative only.

Travel from Pickering — Figure 6.3-9

Assessment of Benefits, Risks and Costs of Management Approaches by Economic Region

Project 40820, February 2005

Gartner Lee
Golder Associates

From Bruce to:	Distance (km)
Northern (4760)	3575
Nord-du-Quebec (2490)	2035
Muskoka-Kawarthas (3520)	298
Northeast (3590)	874
Toronto (3530)	241
Thompson-Okanagan (5930)	4002

Distances were calculated to the centroid of the Economic Regions, using the Trans-Canada Highway and other major routes. Where no major road exists, straight line distances were calculated. Routes are intended to be illustrative only.

Travel from Bruce Figure 6.3-10

Assessment of Benefits, Risks and Costs of Management Approaches by Economic Region

Project 40820, February 2005

Gartner Lee
Golder Associates

From Whiteshell to:	Distance (km)
Northern (4760)	1586
Nord-du-Quebec (2490)	2850
Muskoka-Kawarthas (3520)	1986
Northeast (3590)	1409
Toronto (3530)	1993
Thompson-Okanagan (5930)	2018

Distances were calculated to the centroid of the Economic Regions, using the Trans-Canada Highway and other major routes. Where no major road exists, straight line distances were calculated. Routes are intended to be illustrative only.

Travel from Whiteshell Figure 6.3-11

Assessment of Benefits, Risks and Costs of Management Approaches by Economic Region

Project 40820, February 2005

Gartner Lee Golder Associates

Figure 7.4-1 Total Cash Flow - Deep Geological Disposal in the Canadian Shield (Not including Interim Storage, Retrieval and Transportation)

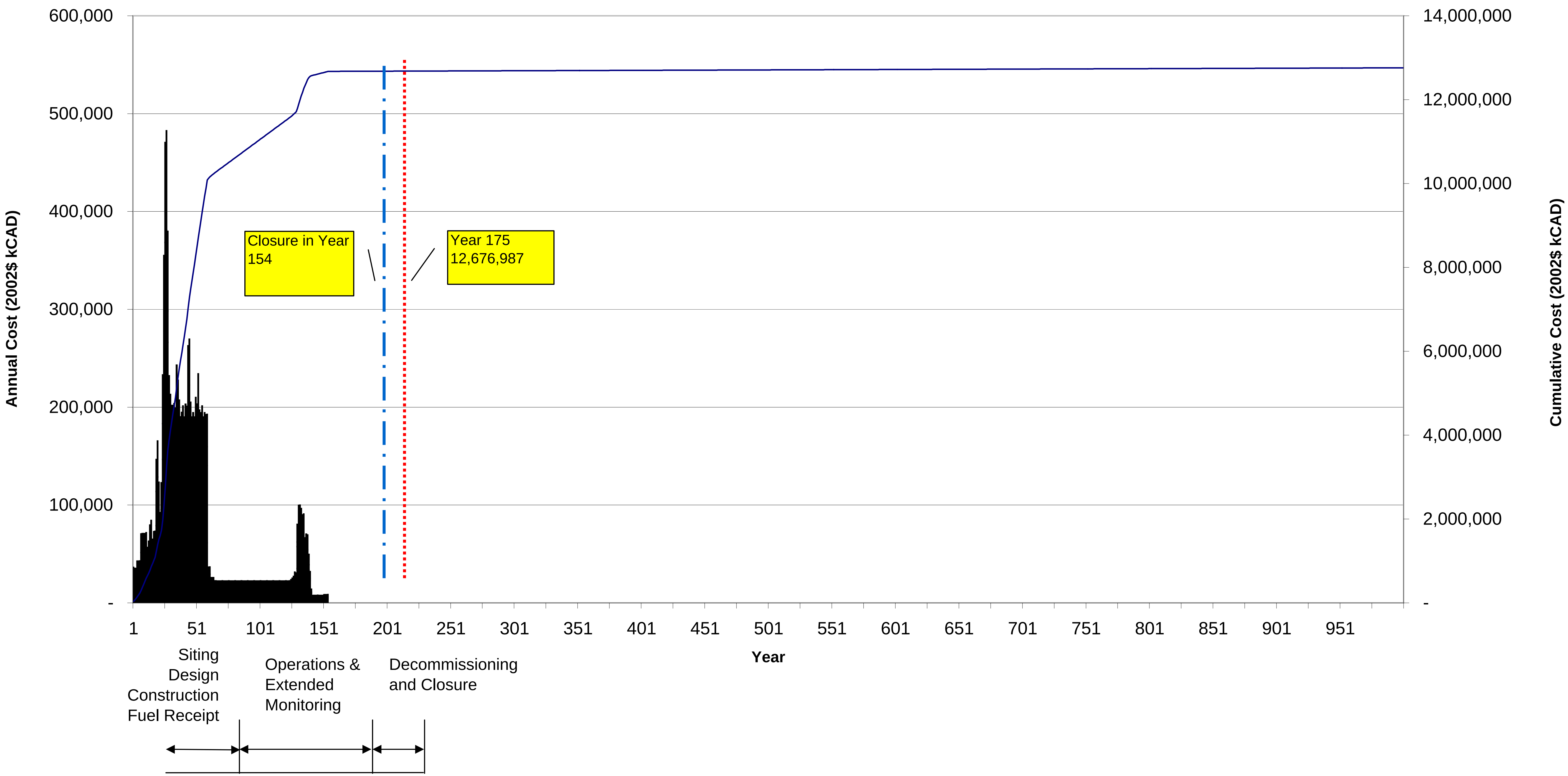


Figure 7.4-2 Total Cash Flow - Centralized Storage (Above Ground) (Not including Interim Storage, Retrieval and Transportation)

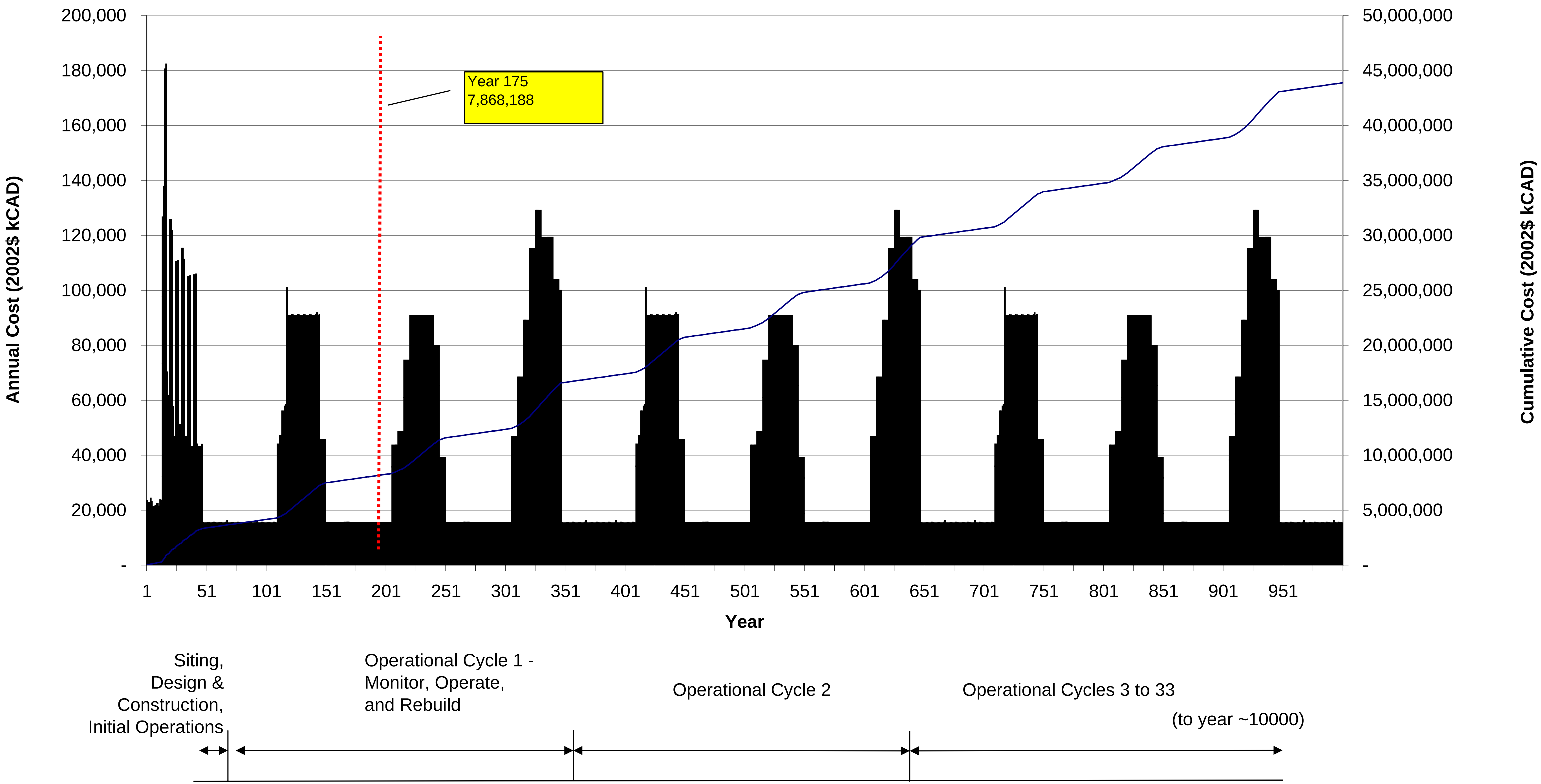


Figure 7.4-3 Total Cash Flow - Centralized Storage (Below Ground) (Not including Interim Storage, Retrieval and Transportation)

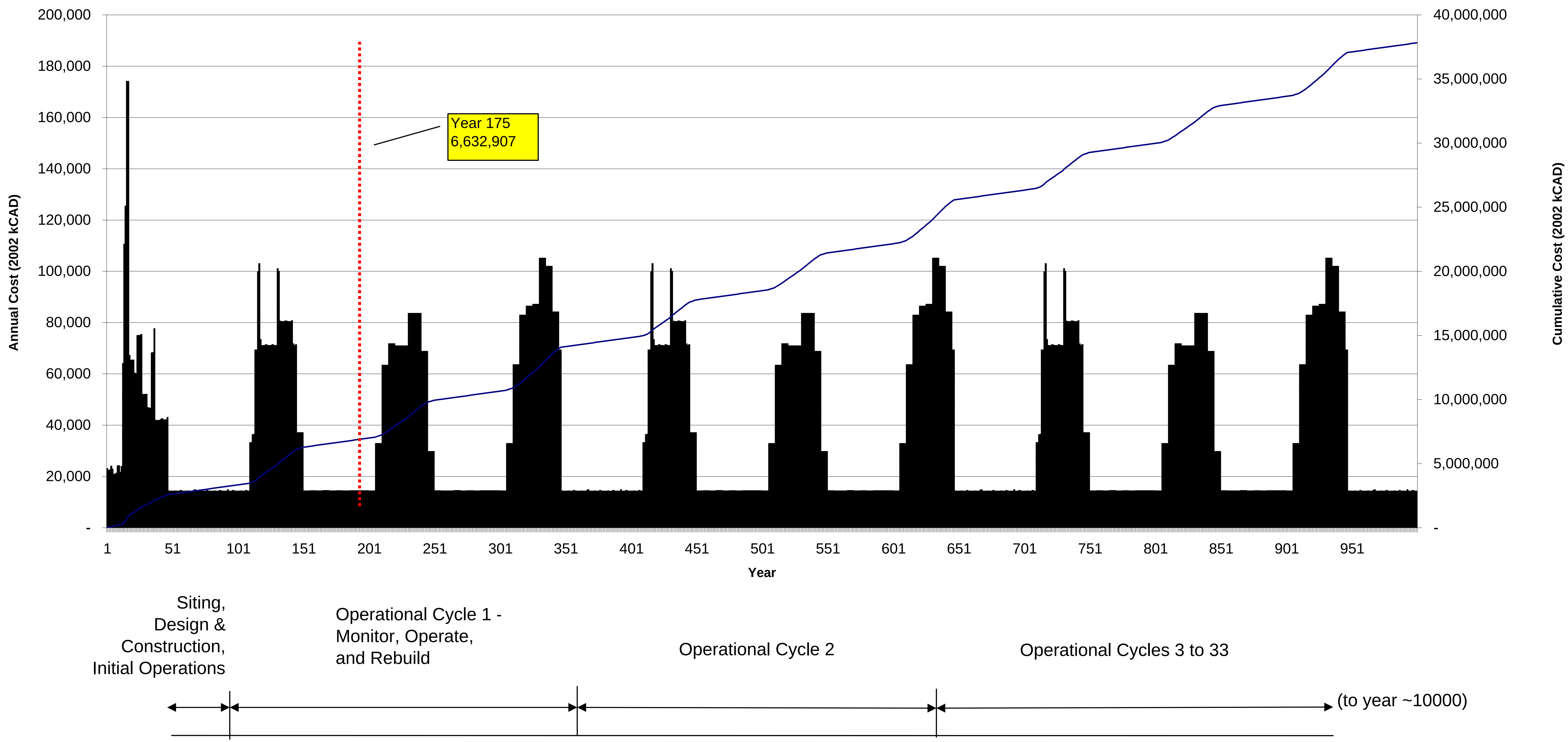
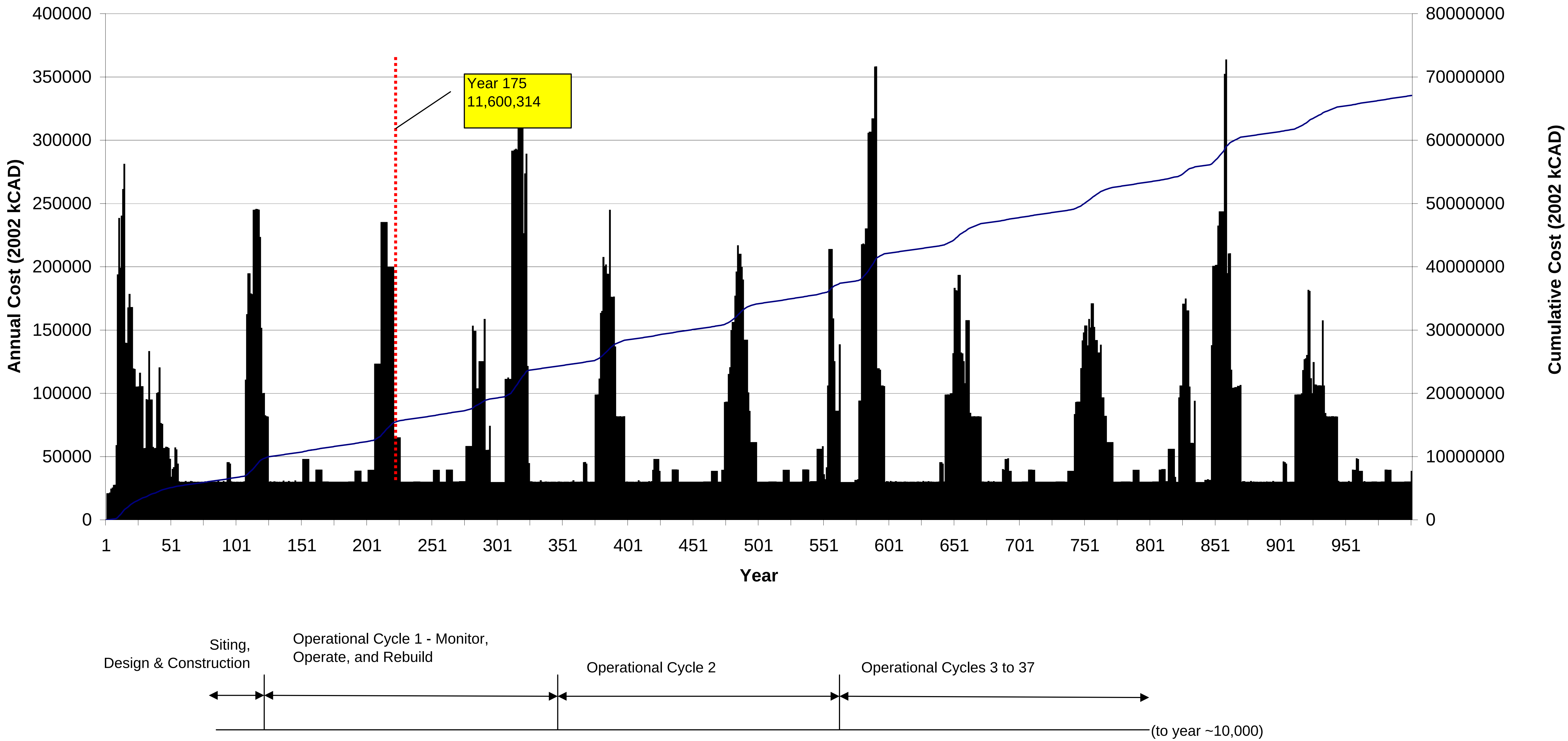
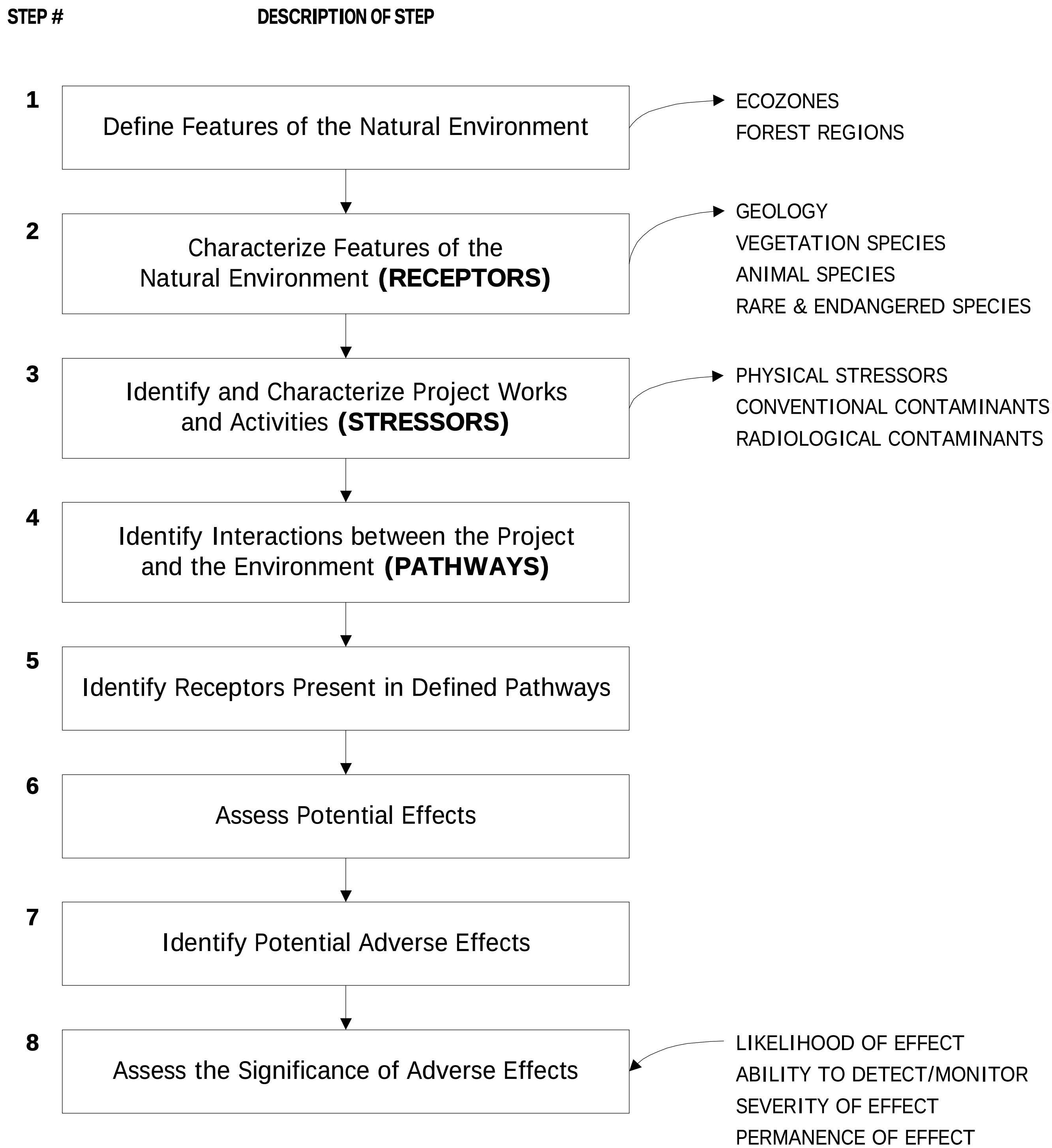


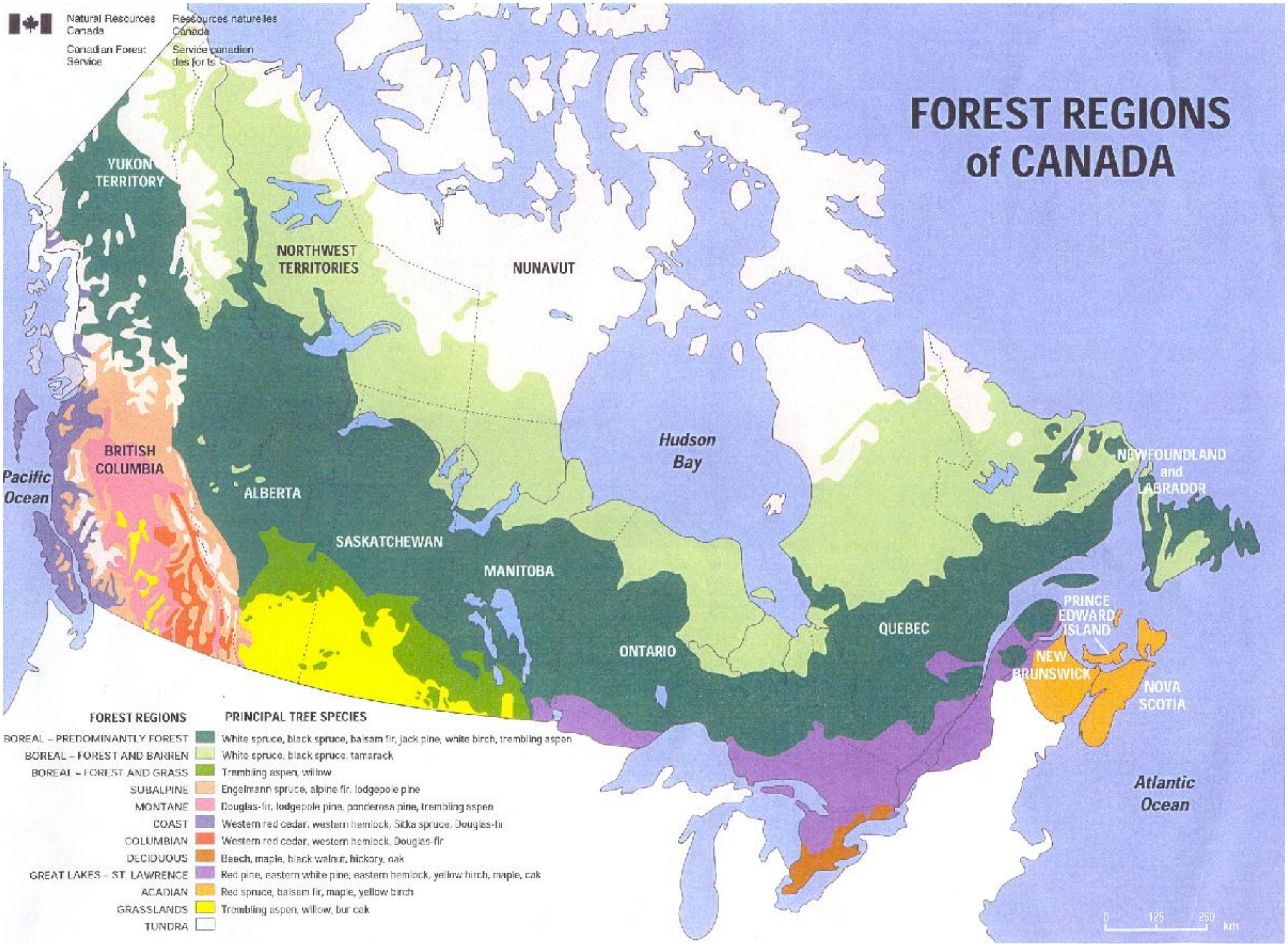
Figure 7.4-4 Total Cash Flow – Storage at Nuclear Reactor Sites



ENVIRONMENTAL EFFECTS ASSESSMENT PROCEDURE

FIGURE 9.3-1





N W E S

REFERENCE:

NATURAL RESOURCES CANADA, CANADIAN FOREST SERVICE.

SCALE	AS SHOWN
DATE	FEB. 2005
DESIGN	
CAD	KD
CHECK	CJPS
REVIEW	
FILE No.	051112002AA942.dwg
PROJECT No.	05-1112-002
REV.	A

TITLE

FOREST REGIONS

NUCLEAR WASTE MANAGEMENT ORGANIZATION

FIGURE **9.4-2**