1. INTRODUCTION

1.1 Purpose and Scope

The purpose of this report is to present a case study that illustrates the Nuclear Waste Management Organization's (NWMO) approach to conducting a safety assessment of a repository for used CANada Deuterium-Uranium reactor (CANDU) fuel within a hypothetical sedimentary setting in southern Ontario. This study complements a similar study completed for a used fuel deep geological repository in crystalline rock (NWMO 2012). These studies are intended to show how the safety assessment approach can be applied to both geological settings and how the approach is consistent with Canadian Nuclear Safety Commission (CNSC) Guide G-320 on Assessing the Long Term Safety of Radioactive Waste Management (CNSC 2006).

As part of this case study, a reference Adaptive Phased Management (APM) facility is described and assessed. The APM facility is a self-contained complex with a combination of surface and underground engineered structures designed to provide multiple isolation barriers and passive systems to provide long-term containment and isolation. It consists of the surface facilities and the Deep Geological Repository (DGR). The approach, methods and tools for conducting a postclosure safety assessment, which contribute to the repository safety case, are fully described. The results of the safety assessment for a hypothetical site are presented to illustrate the multi-barrier deep geological repository concept and provide evidence of how Canadian regulatory requirements can and will be met.

An actual licence application to prepare the site and to construct a used fuel repository will be supported by a site-specific safety case. A safety case is defined as the integration of arguments and evidence that describe, quantify and substantiate the safety, and the level of confidence in the safety, of the deep geological repository and associated facilities. It includes the collection of scientific and technical arguments and evidence in support of the safety of the APM facility covering the site characterization and geosynthesis, the design, construction and operation of the facility, the assessment of risk during operation and postclosure, and quality assurance of all safety-related work associated with the facility.

This definition is consistent with the CNSC Guide G-320 as well as international guidance. The International Atomic Energy Agency (IAEA) also provides guidance in SSG-23 – Safety Case and Safety Assessment for the Disposal of Radioactive Waste (IAEA 2012), where it notes that the primary objective of a safety case is to allow for informed decisions to be made that are commensurate with the lifecycle phase of the project.

The level of detail in the current study is consistent with the pre-project stage of the APM facility and is not a full safety case. It considers a hypothetical site for a deep geological repository in sedimentary rock, and therefore does not include a geosynthesis. It identifies and analyzes key scenarios, but does not assess all possible scenarios associated with the safety case for an actual site. The current study builds upon previous safety studies that were completed by Atomic Energy of Canada Limited (AECL) and Ontario Power Generation.

Site-specific information will be used in a licence application for a selected site for the APM facility. However, at this pre-project stage and in place of site-specific information, data representing a sedimentary setting are used to illustrate how the postclosure safety assessment can be carried out consistent with Canadian regulatory requirements.

A preclosure safety assessment is not included in the present report. However preclosure safety, including transportation safety, and conventional safety, will be assessed as part of a licence application for a future-selected site. A special project arrangement has been agreed to by NWMO and the CNSC that includes a CNSC review of the design concepts for the APM (CNSC and NWMO 2008). NWMO's request for a regulatory review of this pre-project report is consistent with CNSC Guide G-320 which states that:

> "*It is up to the applicant to determine an appropriate methodology for achieving the long term safety of radioactive waste based on their specific circumstances; however, applicants are encouraged to consult with CNSC staff throughout the pre-licensing period on the acceptability of their chosen methodology*."

This review is similar to other CNSC pre-project reviews conducted for new nuclear power plants.

1.2 Background and Project Overview

For decades Canadians have been using electricity generated by nuclear power reactors in Ontario, Quebec and New Brunswick. When used nuclear fuel is removed from a reactor, it is considered a waste product, is radioactive and requires careful management. Although its radioactivity decreases with time, chemical toxicity persists and the used fuel will remain a potential health risk for many hundreds of thousands of years. Canada's used nuclear fuel is now safely stored on an interim basis at licensed facilities located where it is produced.

Investigations into the long-term management of used nuclear fuel have a long history in Canada. The deep geological repository concept was identified at the start of the Canadian nuclear program. In 1977, a task force commissioned by Energy, Mines and Resources Canada recommended burial in geological formations with a preference for crystalline rock of the Canadian Shield, but noted that other rock types such as sedimentary rock and salt should also be studied (Hare et al. 1977). Also in 1978, the Porter Commission for Electricity Planning in Ontario recommended that an independent committee be established. The committee would be tasked with reporting progress on waste disposal research and demonstration, to support additional power plant capacity in Ontario. Subsequently, the governments of Canada and Ontario initiated the Canadian Nuclear Fuel Waste Management Program in 1980.

Based on this Canadian program and parallel international work, the concept for a deep geological repository was developed by AECL. The work included an underground research laboratory in Manitoba, in which approaches and materials were tested. The AECL concept was then submitted for review by a federal independent environmental assessment panel. For this review, AECL completed two case studies illustrating the deep geological repository concept in crystalline Canadian Shield settings. AECL submitted its Environmental Impact Statement to the federal review panel in 1994. In 1998, the panel made a number of recommendations and identified the following key conclusions (CEAA 1998):

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

After 1995, research on the deep geological repository concept continued under Ontario Power Generation funding. As part of this, Ontario Power Generation completed a case study identified as the "Third Case Study" in 2004, which considered a third hypothetical Canadian Shield site and used current design concepts, data and assessment methodologies (Gierszewski et al. 2004).

The NWMO was created by Canada's nuclear energy generators as a requirement of the *Nuclear Fuel Waste Act* in 2002, which largely incorporated the recommendations from the earlier federal review panel. It required the NWMO to study possible approaches, recommend an approach, and then implement the approved plan for the long-term management of Canada's used nuclear fuel.

In 2005, based on extensive discussions across Canada, the NWMO recommended the APM approach, which consists of both a technical method and a management system. Its key attributes include:

- Ultimate centralized containment and isolation of used nuclear fuel in an appropriate geological formation;
- Phased and adaptive decision-making; and
- Citizen engagement throughout all phases of implementation.

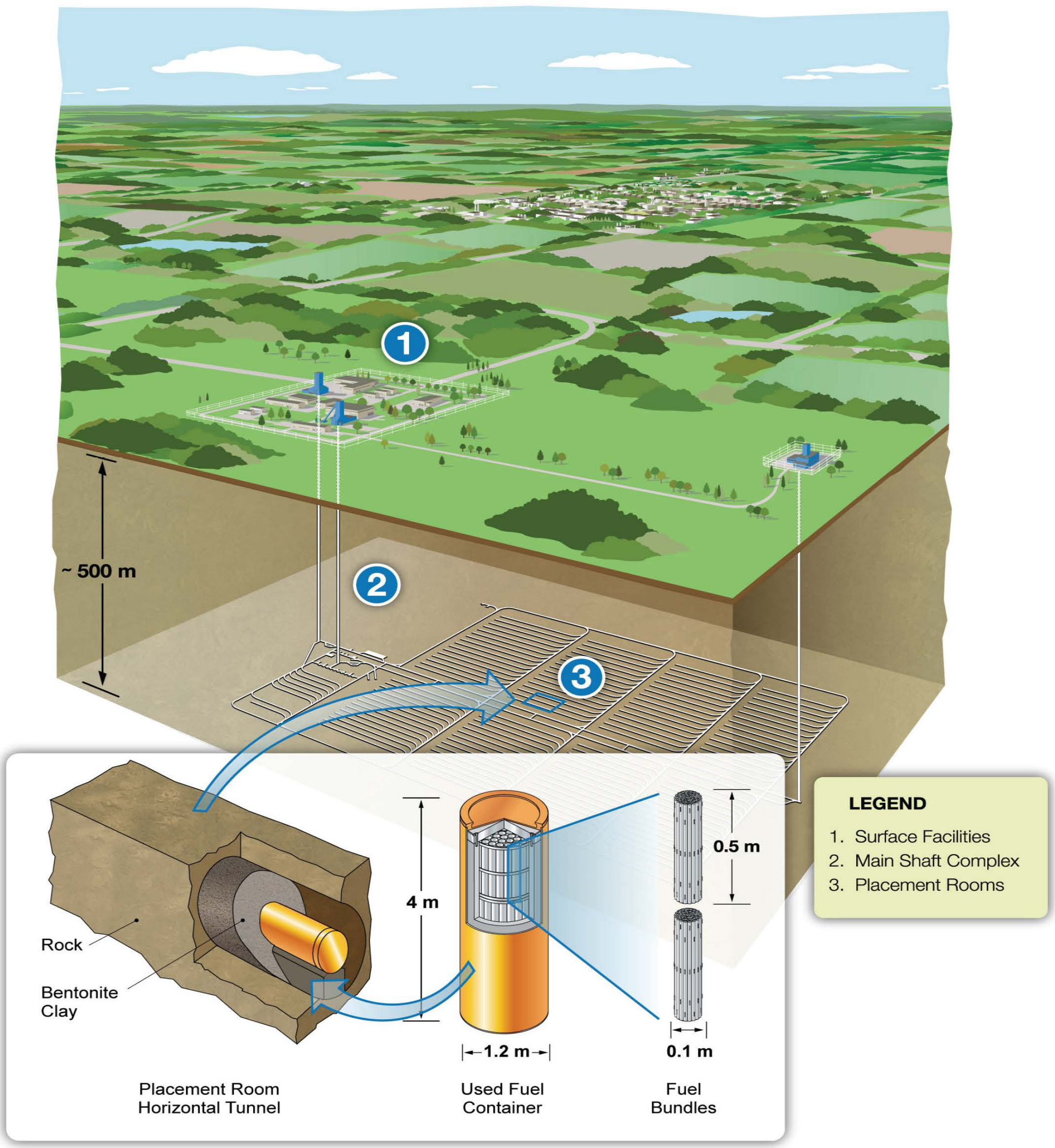
Following the 2007 decision by the Government of Canada to support the recommended approach, the NWMO collaboratively developed with Canadians an approach for the implementation of APM. The NWMO is implementing this approach that is consistent with Canadian federal government policy and with international best practice in its development of a deep geological repository.

A siting process was developed and initiated in May 2010 to find a suitable site for a used fuel deep geological repository in a willing host community. As of December 2013, there are 17 communities engaged in exploring potential interest in hosting this national infrastructure project. These communities are located in both crystalline and sedimentary rock settings.

The NWMO is developing a deep geological repository concept for both crystalline and sedimentary rock settings, associated surface facilities and a used fuel transportation system. The repository system is a multiple-barrier concept designed to safely contain and isolate used nuclear fuel over the long term.

The current conceptual design in sedimentary rock consists of a repository constructed for a reference inventory of 4.6 million used CANDU fuel bundles at a depth of approximately 500 metres. It contains a network of placement rooms for used fuel containers (see Figure 1-1).

The actual depth of the repository will depend on geologic characteristics at the selected site, along with other design features and safety considerations.



Note: This figure is not to scale.

Figure 1-1: Illustration of Deep Geological Repository Concept

Used fuel will be loaded into licensed transport casks at the interim storage facilities at the reactor sites and transported to the deep geological repository facility where it will be repackaged in corrosion-resistant containers for placement underground. In the reference concept for sedimentary rock, the used fuel containers will be transferred underground via a shaft, placed horizontally on high density bentonite pedestals along the axis of the placement room and surrounded by clay material, with the remaining void spaces backfilled and sealed.

A similar case study was completed in 2012 for used fuel deep geological repository in crystalline rock (NWMO 2012).

1.3 APM Project Phases

The APM project is divided into phases that are linked to the major licensing activities for a nuclear facility in Canada. NWMO is committed to a step-wise decision-making process and will only proceed to the next step after careful consideration and with societal support. Assumed progress through the phases of APM is based on a number of assumptions and decisions, which may differ in terms of scope of work and timing of activities.

This section briefly describes the phases of APM, along with the milestones and the assumed timeline associated with each, providing context for the broader implementation plan. The timeline illustrating these phases is provided in Figure 1-2. The legal framework that governs these licensing activities is further described in Section 1.5.

1.3.1 Siting and Preparing for Construction

The Site Selection Process was launched by the NWMO in 2010 after a dialogue with interested Canadians. It has been designed to identify an informed and willing host community for the APM facility and to ensure that the site selected to host the facility will safely contain and isolate used nuclear fuel. The Site Selection Process is a nine-step process based on social and technical considerations. Site screening criteria have been established to ensure that documented safety criteria are defined at an early step in the siting process. These criteria will be used in the site evaluations, which include studies to confirm site suitability that could support a future licence application. Section 1.6.3 of this report highlights the evaluation factors used in the process. The timeframe associated with completing surface and subsurface investigations at a candidate site is about 5 years.

An application for a licence to prepare the site and to construct the facility will be submitted for a selected site. Licences are issued under the *Nuclear Safety and Control Act*. Licences can only be issued once an environmental assessment has been completed and a series of steps in the CNSC's licensing process have been completed. This phase of the project is expected to last five years or more and will begin by submitting a project description to the CNSC. Subsequently, a Preliminary Safety Report, an Environmental Impact Statement (EIS) and other supporting documents, will demonstrate compliance with the regulatory requirements as set out in the *Nuclear Safety and Control Act* and its associated regulations, as well as in the EIS Guidelines for the environmental assessment (EA).

Figure 1-2: Illustrative APM Implementation Schedule for Planning Purposes

1.3.2 Site Preparation and Construction

On receipt of the licence to prepare the site and construct the facility, the site will be prepared for construction by clearing, site grading, installing fencing, installing temporary construction services, and establishing a surface water management system. The first phase of construction will be to excavate the shafts and an underground demonstration facility. This phase is expected to last about five years, the time needed to sink the shafts, construct the demonstration facility, complete the detailed design and update the safety case. It is described in more detail in Chapter 4.

After the final design is completed, the construction of the full-scale underground repository and associated surface facilities can begin. The purpose of this construction phase is to excavate and erect all of the facilities necessary for the operation of the repository. This phase is expected to last about five years.

Therefore, the total site preparation and construction phase could be about 10 years.

1.3.3 Operation

The operation of the repository will only begin once a licence to operate the facility has been issued. Operation will consist of receiving used nuclear fuel transported to the site, re-packaging the used fuel into long-lived containers, placing the used fuel containers in the repository, and continued underground development. All activities will be executed in compliance with the supporting documents used to obtain the operating licence.

For a reference used fuel inventory of 4.6 million used CANDU fuel bundles, these operational activities are expected to last about 40 years. The actual duration of repository operation will depend on the total inventory of used fuel to be managed at the site and the timing of its production, transportation considerations and other operational factors.

1.3.4 Extended Monitoring

Following placement of used fuel in the repository, a period of monitoring is assumed to continue for an extended period of time. The duration of extended monitoring will be decided in collaboration with a future society. For planning purposes, the period of extended monitoring is assumed to be up to 70 years.

Towards the end of the extended monitoring period (i.e., during the last five years), a detailed decommissioning plan will be prepared, the detailed design of the shaft sealing system will be finalized, and an application to decommission the facility will be submitted to the CNSC.

1.3.5 Decommissioning

Decommissioning will only begin once a licence to decommission has been issued. It is expected that an Environmental Assessment to cover decommissioning activities will also be needed prior to the issuance of a decommissioning licence. The decommissioning of the facility will include sealing of access tunnels and shafts, and removal of surface facilities. In the case of a deep geological repository, decommissioning does not include the removal of the used fuel placed in the repository. The site will be restored to a defined end-state that will depend largely on future plans for the site (e.g., industrial, forestry, park, or wilderness). For planning purposes, the period of decommissioning is assumed to be 30 years.

A formal licence to abandon the facility could be obtained once the decommissioning and monitoring results have confirmed that it is acceptable to release the facility from CNSC regulatory control. An application for this licence will include a decommissioning end-state report and other supporting licensing documents. It is anticipated that appropriate institutional controls will be put in place at that time.

1.4 Repository Timeframes

In this safety assessment the potential impact of a repository is assessed in accordance with the CNSC Policy P-290 (CNSC 2004), which requires that, "the assessment of future impacts of radioactive waste on the health and safety of persons and the environment encompasses the period of time when the maximum impact is predicted to occur." In discussing the long-term evolution of a repository system, it is helpful to consider a sequence of timeframes during which certain events or processes dominate in the postclosure period.

1.4.1 Preclosure Period

The preclosure period is intended to cover the activities described in Sections 1.3.1 to 1.3.5 and is assumed to last up to about 160 years (see Figure 1-2).

During this time, the reference inventory of 4.6 million used nuclear fuel bundles will be transported to the APM facility, encapsulated in approximately 12,800 long-lived used fuel containers, transferred to the underground repository and surrounded by clay-based sealing materials. The total radioactivity in the repository will increase as more used fuel is placed in the repository, and then start to decrease due to radioactive decay.

1.4.2 Postclosure Period

The postclosure period starts at the end of decommissioning, after the shafts have been sealed and the surface facilities have been dismantled.

In the postclosure period, the site is assumed to remain under institutional controls for a period of time. Based on CNSC Guide G-320 (CNSC 2006), and IAEA Safety Series No. 111-F (IAEA 1995), institutional controls can be defined as, "the control of residual risks at a site (by a designated Institution or Authority) after it has been decommissioned." These controls can include both active measures (requiring activities on the site such as monitoring and maintenance) and passive measures (that do not require activities on the site, such as land use restrictions, as well as measures taken to support societal memory). Such measures should prevent inappropriate land use, including drilling, deep excavation, or disruption of the shaft seals.

Institutional controls and societal memory can continue indefinitely to preserve knowledge of the repository. However, it is assumed for safety assessment purposes that these institutional controls or societal memory are only effective for about 300 years. This is consistent with international practice for excluding inadvertent human intrusion during this period when assessing the risks associated with this scenario.

The postclosure period is described in four timeframes. Each of the timeframes is also described in this section. To provide context for these timeframes, Figure 1-3 highlights timescales for relevant past events and expected future events in the Earth's history.

1 - 1,000 years

At the beginning of this time, the facility is decommissioned. Distinct physical and chemical differences exist between the various components of the repository, and between the repository and the geosphere. The containers reach their peak temperature. Slow migration of groundwater into the repository occurs. Especially during the first 500 years, radioactivity and heat in the used fuel decrease significantly due to the decay of most of the fission products.

1,000 - 60,000 years

This time period represents conditions with no glaciation coverage of the site. During this period, the initial sharp physical and chemical gradients around the repository slowly diminish. Slow saturation of the repository by groundwater occurs, which is accompanied by swelling of bentonite sealing materials. The surrounding sedimentary rock reaches its peak temperature and largely cools back down to approximately ambient temperatures. Surface conditions are likely to change reflecting human activities and natural evolution, possibly in response to climate change. Although the overall climate is likely to remain temperate, climate changes could include global warming in the near term, and the advent of cooler climate in the long term.

60,000 - 1,000,000 years

Over this timescale, the main perturbations in the system cease to be repository-driven. Instead, there are regional-scale changes in the geosphere that in turn may be transmitted to the repository. In particular, during this timeframe, climate change initiated by broad changes in solar insolation patterns may occur leading to initiation of a new glaciation cycle. Based on past history, several cycles of glaciation are likely to occur over the next million years.

1,000,000 years and beyond

Beyond this timescale, the repository will be a relatively passive feature of the geosphere, in quasi-equilibrium with the surrounding rock. The dominant processes will be regional perturbations to the geosphere that in turn affect the repository. Over this longer time period, the changes will include slow-acting tectonic forces, and cumulative erosion or deposition processes.

In the safety analysis presented in this report, the discussion of the evolution of a repository focuses on the interval covered by the first three postclosure timeframes, i.e., up to one million years. It will be during this period that the differences between the natural environment and an engineered repository for used fuel are noticeable. Long before major changes will be apparent at times beyond one million years, the total amount of radioactivity in the waste will have diminished to the point that it is similar to that of a naturally occurring uranium ore body.[1] As part of the safety case prepared for an actual candidate site, geoscientific arguments and evidence supporting the long-term stability and resilience to change of a sedimentary rock environment would also be presented.

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[1] With about 90,000 Mg of uranium, it will be smaller than large ore bodies like Cigar Lake and MacArthur River in Saskatchewan.

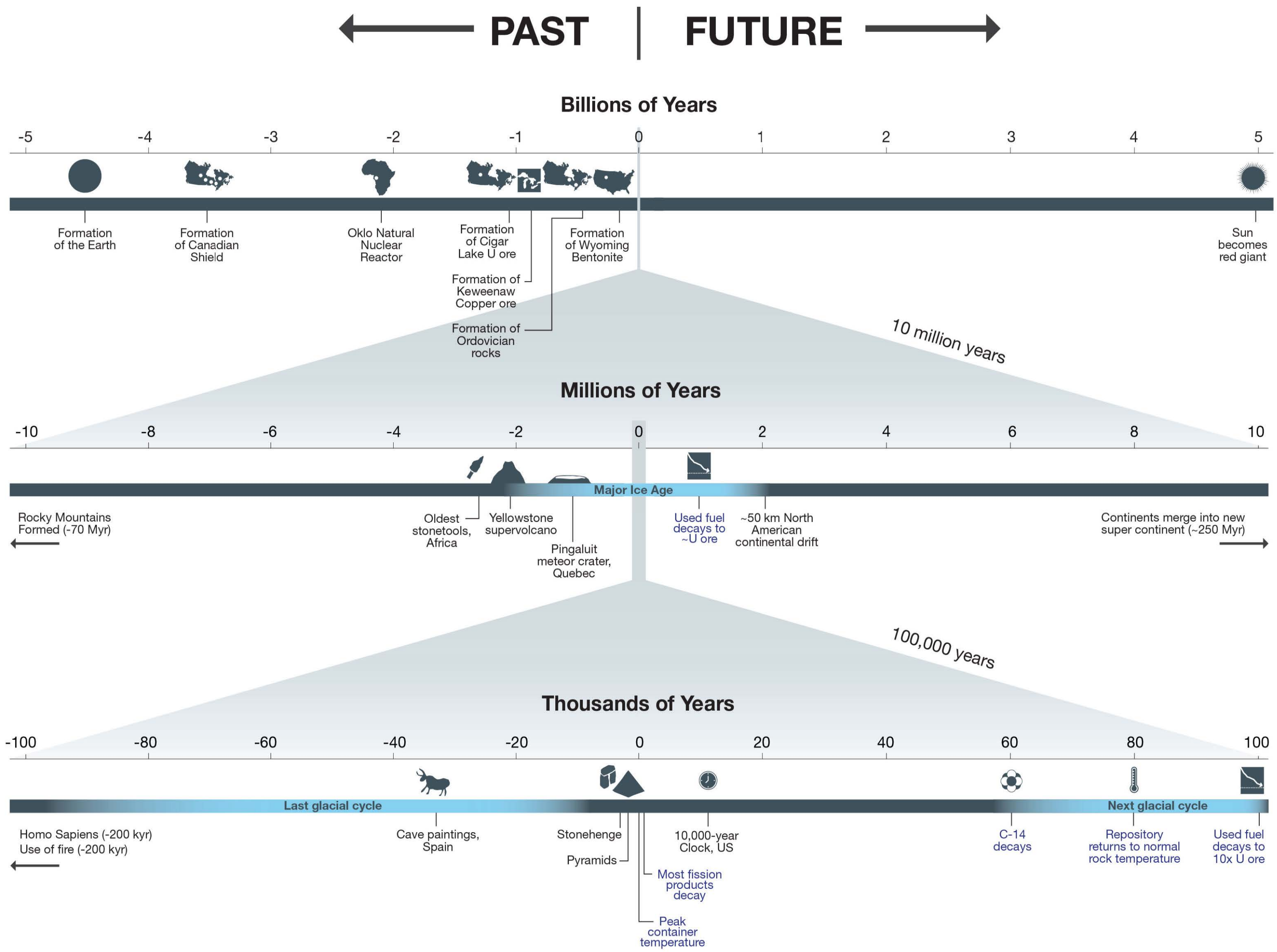

Figure 1-3: Perspective of Past Events and Expected Future Events in Earth's History Including Repository Events

1.5 Relevant Legislation

This section presents the regulatory requirements under the *Nuclear Safety and Control Act* and its associated regulations, as well as the international guidance on safety of a deep geological repository.

The intention is for the deep geological repository to meet or exceed all regulatory requirements and to be consistent with international practices during site preparation, construction, operation, and beyond.

1.5.1 CNSC Regulatory Requirements

In accordance with paragraph 2(g) of *Nuclear Safety and Control Act* and paragraph 1(e) of the Class I Nuclear Facilities Regulations, the repository is a Class 1B nuclear facility.

Paragraph 26(e) of the Act states that, “subject to the Regulations, no person shall, except in accordance with a licence…prepare a site for, construct, operate, modify, decommission or abandon a nuclear facility”. The following licences are required over the life of the repository:

- Site Preparation Licence;
- Construction Licence;
- Operating Licence;
- Decommissioning Licence; and
- Abandonment Licence.

The detailed requirements to obtain a licence are described in Section 3 of the General Nuclear Safety and Control Regulations and in Sections 3, 4 and 5 of the Class I Nuclear Facilities Regulations. Other applicable regulations include the Nuclear Security Regulations, Radiation Protection Regulations, Packaging and Transport of Nuclear Substances Regulations, which apply to all nuclear facilities, and the Uranium Mines and Mills Regulations – due to similarities of some aspects of the APM facility (i.e., deep geological repository) to a mining project.

In addition to the regulations, a number of CNSC regulatory documents in the following categories are also applicable:

- Regulatory policies – describe general principles applied by the CNSC in their review;
- Regulatory documents and standards – establish regulatory standards; and
- Regulatory guides – set out regulatory expectations.

In Canada, the primary regulatory requirements and expectations for the assessment of long-term safety of radioactive waste management are given in the CNSC Policy P-290 (CNSC 2004) and CNSC Guide G-320 (CNSC 2006) and these are the focus of this pre-project report. These and other regulatory documents that will apply to the APM project in support of a future licence application are listed in Table 1-1.

Table 1-1: CNSC Regulatory Documents Applicable to the APM Project

Document Number	Title
Pre-project Report	
P-290	Managing Radioactive Waste (CNSC 2004)
G-320	Assessing the Long Term Safety of Radioactive Waste Management (CNSC 2006)
Licence Application	
P-119	Policy on Human Factors
P-211	Compliance
P-223	Protection of the Environment
P-299	Regulatory Fundamentals
P-325	Nuclear Emergency Management
R-72	Geological Considerations in Siting a Repository for Underground Disposal of High-Level Radioactive Waste
G-129 Rev.1	Keeping Radiation Exposures and Doses "As Low as Reasonably Achievable (ALARA)"
G-205	Entry to Protected and Inner Areas
G-206	Financial Guarantees for the Decommissioning of Licensed Activities
G-208	Transportation Security Plans for Category I, II or III Nuclear Material
G-219	Decommissioning Planning for Licensed Activities
G-221	A Guide to Ventilation Requirements for Uranium Mines and Mills
G-225	Emergency Planning at Class I Nuclear Facilities and Uranium Mines and Mills
G-274	Security Programs for Category I or II Nuclear Material or Certain Nuclear Facilities
G-276	Human Factors Engineering Program Plans
G-278	Human Factors Verification and Validation Plans
GD-314	Radiation Protection Programs for the Transport of Nuclear Substances
RD/GD-99.3	Public Information and Disclosure
RD-327/GD-327	Nuclear Criticality Safety
RD-336/GD-336	Accounting and Reporting of Nuclear Material
RD-353	Testing the Implementation of Emergency Measures
RD-363	Nuclear Security Officer Medical, Physical, and Psychological Fitness
RD-364	Joint Canada-United States Guide for Approval of Type B(U) and Fissile Material Transportation Packages
REGDOC- 2.9.1	Environmental Protection Policies, Programs and Procedures

Note: Current versions of the CNSC regulatory documents can be found on the CNSC website (www.cnsc-ccsn.gc.ca).

CNSC Policy P-290 (CNSC 2004) identifies the need for long-term management of radioactive waste and hazardous waste arising from licensed activities. The principles espoused by CNSC Policy P-290 that relate to long-term management are the following:

- The management of radioactive waste is commensurate with its radiological, chemical, and biological hazard to the health and safety of persons and the environment, and to national security;
- The assessment of future impacts of radioactive waste on the health and safety of persons and the environment encompasses the period of time when the maximum impact is predicted to occur; and
- The predicted impact on the health and safety of persons and the environment from the management of radioactive waste is no greater than the impact that is permissible in Canada at the time of the regulatory decision.

Key objectives for long-term management are *containment* and *isolation* of the waste, in accordance with the CNSC Guide G-320 (CNSC 2006). The guide states that:

> *"containment can be achieved through a robust design based on multiple barriers providing defence-in-depth. Isolation is achieved through proper site selection and, when necessary, institutional controls to limit access and land use".*

CNSC Guide G-320 identifies expectations for *"developing a long term safety case that includes a safety assessment complemented by various additional arguments based on:*

1. *Appropriate selection and application of assessment strategies;*
2. *Demonstration of system robustness;*
3. *The use of complementary indicators of safety; and*
4. *Any other evidence that is available to provide confidence in the long term safety of radioactive waste management."*

Guidance is also provided for defining acceptance criteria and performing long-term assessments that includes considerations for: selection of methodology, assessment context, system description, assessment timeframes, assessment scenarios, assessment models, and the interpretation of results.

A mapping that shows how the content of this report is consistent with aspects of CNSC Guide G-320 is shown in Table 1-4 and described in more detail in Chapter 12.

1.5.2 Transportation of Used Nuclear Fuel

The safe and secure transportation of used nuclear fuel is regulated through a comprehensive multi-agency framework of regulations, oversight, and inspections. The process builds on the roles of federal, provincial, and local agencies.

The regulatory oversight of safe transportation of used nuclear fuel in Canada is jointly shared by the CNSC and Transport Canada. Transport Canada's *Transportation of Dangerous Goods Regulations,* and the *Transportation of Dangerous Goods Act,* and CNSC's *Packaging and Transport of Nuclear Substances Regulations,* associated with *Nuclear Safety and Control Act,* and the *Nuclear Security Regulations* apply to all persons who handle, offer for transport, transport or receive nuclear substances.

Transport Canada and CNSC regulations follow the IAEA regulations (TS-R-1) for the safe transport of radioactive materials and cover certification of the package used to transport the used fuel, the licence to transport, the security planning, training requirements for the shipper, receiver and the transporter, emergency response planning, and communications. These are in addition to the normal commercial vehicle and rail operating regulations and are similar to those used internationally. Packages designed for the transport of used nuclear fuel require certification by the CNSC before they can be used in Canada.

The provinces are responsible for developing, maintaining, and operating the highway infrastructure and for inspecting the commercial vehicles and their drivers. Local governments provide law enforcement and emergency response to incidents. The interaction and cooperation between these agencies facilitates comprehensive regulation and oversight of all transportation of used nuclear fuel.

1.5.3 Canadian Codes and Standards

A number of Canadian codes and standards apply to a deep geological repository project. Compliance with these will be demonstrated in the future in support of a licence application. For example, requirements exist in the following areas and include the following:

- Civil structures will comply with the National Building Code of Canada and the National Fire Code of Canada;
- Electrical installations and components will be in accordance with the Canadian Electrical Code and associated Canadian Standards Association (CSA) standards;
- The management system will comply with the CSA N286 series of standards as well as International Organization for Standardization (ISO) 9001;
- The environmental management and monitoring programs will comply with the CSA N288 series of standards as well as ISO 14001; and
- The occupational health and safety management programs will comply with the CSA Z1000 standard.

Some regulatory requirements from the provincial jurisdiction will also be applicable. For example, the health and safety program will comply with provincial Occupational Health and Safety Requirements. Although there is presently no specific site and therefore no specific province identified, for purposes of this study some provincial regulations or criteria may be adopted to provide more specific context. For example, while Canadian Drinking Water Quality guidelines are generally used to assess water quality, in some cases in this study the criteria have been based on more complete provincial standards, such as the Ontario water quality objectives (MoEE 1994) and the soil, groundwater and sediment standards (MoE 2011).

1.5.4 Safeguards

Canada’s international safeguards obligations are the result of treaty commitments (IAEA 1970, IAEA 1972, and IAEA 2000). The specific legal requirements to implement these commitments come in the form of licence conditions that are included in a CNSC licence. Compliance with these requirements will be demonstrated in support of a future licence application.

1.5.5 Traditional Knowledge

NWMO respects the status and rights of First Nations and understands that interweaving of Aboriginal Traditional Knowledge in the implementation of APM helps to build relationships with Aboriginal peoples and benefits the long-term management of used nuclear fuel. Early in the project this includes recognizing the importance of water, the relationships between various aspects of the environment as well as the health, trade and spiritual needs of people. The NWMO's Site Selection Process will look to Aboriginal peoples as practitioners of Traditional Knowledge to be active participants in the process, and to share that knowledge with the NWMO to the extent they wish to in order to help guide the decisions involved in site selection and ensure safety and the long-term well-being of the community. The NWMO will seek to engage in discussions with Traditional Knowledge holders to ensure that the factors and approaches used to assess the site appropriately interweave Traditional Knowledge and western science throughout the steps in the siting process.

1.5.6 International Guidance

The development and safety of deep geological repositories has been the subject of international attention by the IAEA and the Nuclear Energy Agency for many years.

A number of technical documents are available that provide guidance on best international practices with respect both to achieving safety, and on the demonstration of safety. Particular international documents relevant to development and safety for a repository are listed in Table 1-2.

Table 1-2: International Guidance Applicable to the APM Project

Document Number	Title
IAEA SSR-5	Disposal of Radioactive Waste
IAEA SSG-23	The Safety Case and Safety Assessment for Radioactive Waste Disposal
ICRP 103	The 2007 Recommendations of the International Commission on Radiological Protection
ICRP 122	Radiological Protection in Geological Disposal of Long-lived Solid Radioactive Waste
Case Study	European Pilot Study on the Regulatory Review of the Safety Case for Geological Disposal of Radioactive Waste – Case Study: Uncertainties and their Management (Vigfusson et. al 2007)

Note: The latest version of international guidance can be found on the associated agency's website (www.iaea.org, www.icrp.org).

1.6 Safety Case

CNSC Guide G-320 states "*Demonstrating long term safety consists of providing reasonable assurance that waste management will be conducted in a manner that protects human health and the environment. This is achieved through the development of a safety case, which includes a safety assessment complemented by various additional arguments*".

The safety case has been defined in Section 1.1 as: the integration of arguments and evidence that describe, quantify and substantiate the safety, and the level of confidence in the safety, of the deep geological repository and associated facilities. It includes the collection of scientific and technical arguments and evidence in support of the safety of the repository covering the site characterization and geosynthesis, the design, construction and operation of the repository, the assessment of risk during operation and postclosure, and quality assurance of all safety-related work associated with the repository.

This report documents components of a safety case, but not a full safety case, as discussed later, representing information at a very early stage before a site has been selected. The report contains a description of these various components, and in some cases, an illustration of how the design of the repository will meet Canadian regulatory requirements and will be consistent with international practice.

CNSC Guide G-320 (CNSC 2006) recommends following a structured approach for preparing a safety case and safety assessment. The safety assessment is defined as: the process of systematically analyzing the hazards associated with the facility, and the ability of the site and design to provide the safety functions and meet technical requirements.

The most recent international guidance is included in the IAEA's SSG-23 (IAEA 2012). This guidance is used to present the safety case components for this study. The guidance also acknowledges applying the concept of defence in depth to disposal facilities by stating that: *"the host environment shall be selected, the engineered barriers of the disposal facility shall be designed… to ensure that safety is provided by means of multiple safety functions. Containment and isolation of the waste shall be provided by means of a number of physical barriers of the disposal system. The performance of these physical barriers shall be achieved by means of diverse physical and chemical processes…The capability of the individual barriers…shall be demonstrated. The overall performance of the disposal system shall not be unduly dependent on a single safety function."* It further recommends that the number and extent of required barriers depends on the type of waste and should be commensurate with the hazard potential of the waste, in accordance with the graded approach.

The components of a postclosure safety case are illustrated in Figure 1-4 and are largely consistent with IAEA (2012). This figure is used to illustrate the current phase and to identify the future work that will be included as part of a project at the final selected site. The discussion of each of these components is included in this section.

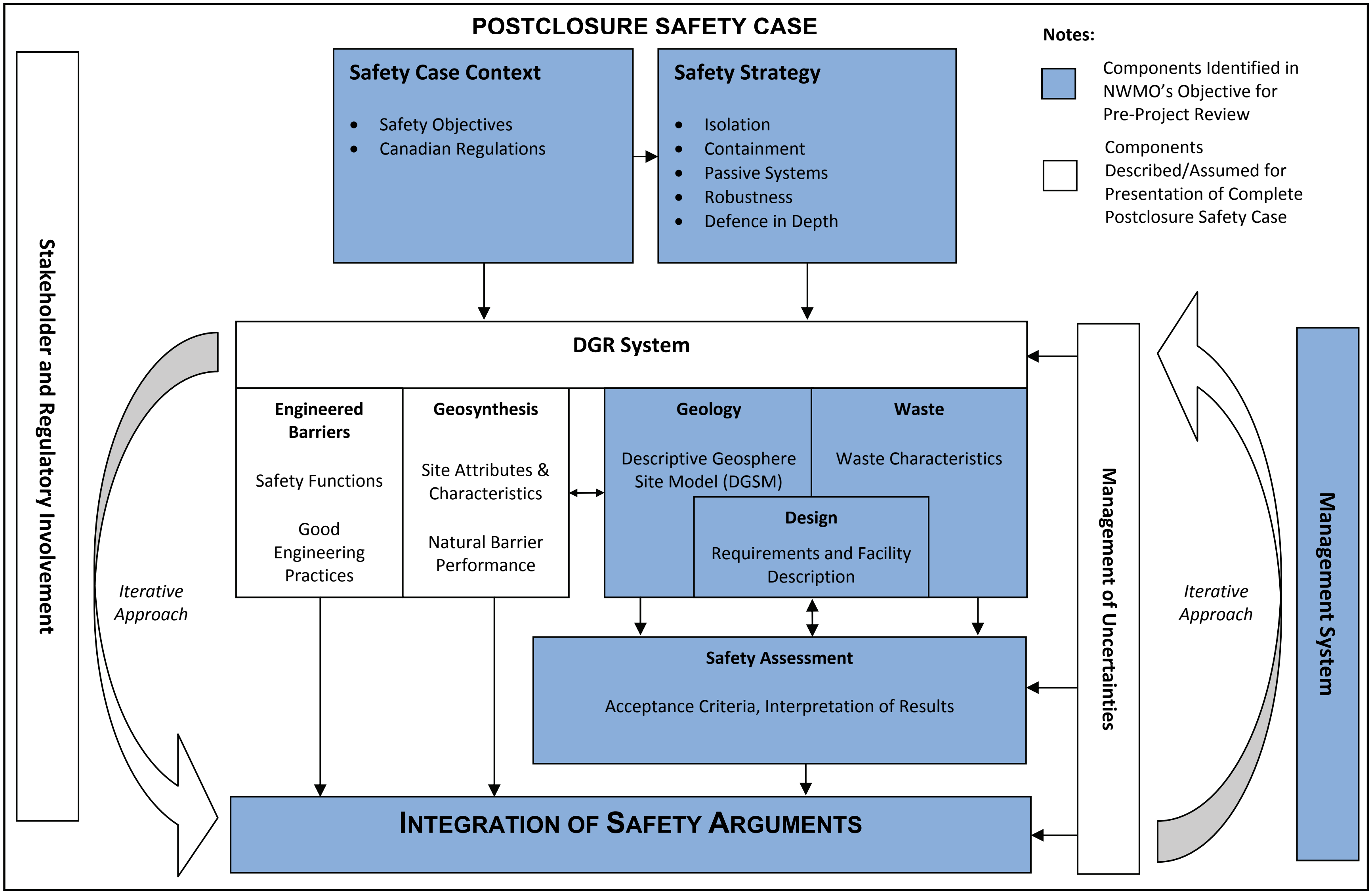

Figure 1-4: Components of the Safety Case

1.6.1 Safety Case Context

The Canadian regulatory framework presented in Section 1.5 provides the regulatory context for a deep geological repository safety case.

The primary *safety objective* of the deep geological repository is:

> to provide safe long-term management of used fuel without posing unreasonable risk to the environment or health and safety of humans.

This objective is consistent with the *Nuclear Safety and Control Act* (subparagraph 9(a) (i)) and IAEA guidance (IAEA 2011), which notes that the geological disposal of radioactive waste is aimed at:

- Containing the waste until most of the radioactivity, and especially that associated with shorter-lived radionuclides, has decayed;
- Isolating the waste from the biosphere and substantially reducing the likelihood of inadvertent human intrusion into the waste;
- Delaying any significant migration of radionuclides to the biosphere until a time in the far future when much of the radioactivity will have decayed; and
- Ensuring that any levels of radionuclides eventually reaching the biosphere are such that possible radiological impacts in the future are acceptably low.

As described in Section 1.1, this study presents a conceptual design and illustrative safety assessment for a deep geological repository at a hypothetical site. The level of detail is consistent with the pre-project stage, i.e., before a final site has been selected, and sufficient to support a CNSC review with respect to the approach and methodology. It is not a full safety case. It considers a hypothetical site, and therefore does not include a geosynthesis. It identifies and analyzes key scenarios, but does not assess all relevant scenarios.

1.6.2 Safety Strategy

The safety strategy is to provide long-term containment and isolation of used nuclear fuel through the use of multiple barriers and passive systems, including in particular a stable and robust geosphere. The geosphere has characteristics that will also delay significant migration of radionuclides to ensure that the impacts of any releases in the future are acceptably low.

In this study, a set of safety relevant features are assumed to be present at a hypothetical site. The geological features will need to be affirmed at any future candidate site as part of the Site Selection Process (NWMO 2010). The design concept includes engineered barriers that have properties that also allow a set of safety functions to be fulfilled.

The geological characteristics and the engineered barrier's safety functions identified in this report are consistent with the concept of defence in depth and are further described in the following section on the deep geological repository system.

1.6.3 Deep Geological Repository System

The DGR system includes the DGR facility, its geological setting, and the surrounding surface environment. The system includes the engineered and the natural barriers that provide containment and isolation of the waste. The repository system includes the waste, containers, sealing systems and the near-field geosphere around the repository.

Figure 1-4 represents the system across three main areas for which safety arguments are presented: 1) the geology, 2) the waste characteristics, and 3) the design. This section includes a summary of the assumptions that are made and the type of information that needs to be considered in a safety case.

In this study for a hypothetical site, no specific description of communities is considered, although that will be important for any candidate site.

1.6.3.1 Geology

The information that describes the geological setting of the repository is used to guide the design of the DGR facility and as an input into the safety assessment. The geoscience program for a future candidate site will be designed to support the safety case and to produce:

- A Descriptive Geosphere Site Model (DGSM) that will describe, assess and interpret geoscientific data as it relates to site-specific geologic, geochemical, hydrogeologic and geomechanical characteristics and attributes; and
- A Geosynthesis that will provide a geoscientific explanation of the overall understanding of site characteristics, attributes and evolution as they relate to demonstrating long-term performance and safety.

The DGSM is defined as: a description of the present day three-dimensional physical and chemical characteristics of a specific site as they relate to implementation of the repository concept. For the purpose of the pre-project report and for conducting the illustrative safety assessment, this type of information is presented in Chapter 2.

The safety strategy identified that long-term containment and isolation is provided through the use of multiple barriers and passive systems, including in particular a stable and robust geosphere. The evidence to support the safety case arguments will be presented in the Geosynthesis for a candidate site that examines the past, present, and future evolution of the site. The Geosynthesis is defined as: the assembly of all the geologically-based evidence relevant to the repository safety case; the integration of multi-disciplinary geoscientific data relevant to the development of a descriptive conceptual geosphere model; and explanation of a site-specific descriptive geosphere model within a systematic and structured framework.

The NWMO's siting process (NWMO 2010) includes technical evaluations of a candidate site. The factors (listed in Section 1.6.8) in this process include the following key geological considerations.

- The depth of the host rock formation should be sufficient for isolating the repository from surface disturbances and changes caused by human activities and natural events.
- The volume of available competent rock at repository depth should be sufficient to host the repository and provide sufficient distance from active geological features such as zones of deformation or faults and unfavourable heterogeneities.

- The mineralogy of the rock, the geochemical composition of the groundwater and rock porewater at repository depth should not adversely impact the expected performance of the repository multi-barrier system.
- The hydrogeological regime within the host rock should exhibit low groundwater velocities.
- The mineralogy of the host rock, the geochemical composition of the groundwater and rock porewater should be favourable to retarding radionuclide movement.
- The host rock should be capable of withstanding mechanical and thermal stresses induced by the repository without significant structural deformation or fracturing that could compromise the containment and isolation functions of the repository.
- Current and future seismic activity at the repository site should not adversely impact the integrity of the repository system during operation and in the very long term.
- The expected rates of land uplift, subsidence and erosion at the repository site should not adversely impact the containment and isolation functions of the repository.
- The repository should not be located within rock formations containing economically exploitable natural resources such as minerals and other valuable commodities as known today.
- The repository is not located within geological formations containing groundwater resources at repository depth that could be used for drinking, agriculture or industrial uses.

It is noted that site characterization activities for an actual site in sedimentary rock would include a thorough and systematic assessment of such features as, for example, major fractures and natural resource potential in the proximity of the repository. The assessment findings would be documented in the DGSM and in the Geosynthesis prepared for a candidate site, described above. For the purpose of the pre-project report, the key attributes assumed for the hypothetical site in southern Ontario are:

- The repository is located at a depth of 500 m;
- There is sufficient volume of rock at the site and depth to host the repository;
- Groundwater and porewater at the repository horizon is saline;
- Groundwater at repository depth provides a chemically reducing environment and a low concentration of potentially corrosive agents;
- No large-scale transmissive fractures in close proximity to the repository site;
- The host rock is capable of withstanding mechanical and thermal stresses;
- Seismic activity is low, consistent with general Michigan Basin conditions;
- Rates of land uplift, subsidence and erosion at the site are low enough that they will not adversely impact the isolation of the repository; and
- The host rock formations do not contain groundwater or economically exploitable natural resources at repository depth.

1.6.3.2 Waste Characteristics

The waste characteristics are an input to the safety assessment and guide the design of the DGR facility. In addition, the waste has safety features that are identified in the safety case as follows:

- The used nuclear fuel is a durable uranium oxide (UO_2); it will dissolve very slowly under the chemical conditions within a failed container.
- Most of the initial radioactivity is held within the UO_2 grains, where it can only be released as the used fuel dissolves.

The waste characteristics are further described in Chapter 3.

1.6.3.3 Design

The design is largely guided by the geological characteristics and features of a candidate site and also by the characteristics of the waste that will be placed in the repository. For the pre-project report, a hypothetical sedimentary site in southern Ontario is considered. Representative characteristics of the sedimentary site are used to guide specific repository design requirements which include engineered barriers to fulfill specific safety functions. Design requirements are used as an input to the safety assessment.

The safety strategy acknowledges that properties of the engineered barriers will allow safety functions to be fulfilled. This includes the following design characteristics:

- The used fuel container has a design life of at least 100,000 years under the geomechanical and chemical repository conditions expected to exist within the repository; and
- The container is surrounded by a layer (approximately 60 cm) of dense bentonite-based clay that inhibits groundwater movement, has self-sealing capability, inhibits microbial activity near the container, and retards contaminant transport.

The repository design is described in Chapter 4 at a conceptual level of detail. The description focuses on the underground portions relevant to postclosure safety.

The purpose of the design concept presented here is to provide information to support the postclosure safety assessment. This design concept is expected to be further refined once a site has been selected and site specific information becomes available.

1.6.3.4 Institutional Controls

Institutional controls have been described in Section 1.4.2 where it is stated that institutional controls are assumed for a period of time. The safety feature associated with this assumption includes: institutional controls will limit the potential for human encounter with the repository in the near term after closure.

1.6.3.5 Long-Term Evolution of Repository

And finally, Chapter 5 discusses the evolution of the deep geological repository system, including how the different components of the system will interact with each other and the environment in the long term, consistent with CNSC Guide G-320 (CNSC 2006).

1.6.4 Safety Assessment

The safety assessment has been defined as: the process of systematically analyzing the hazards associated with the facility, and the ability of the site and design to provide the safety functions and meet technical requirements. As noted in the scope of this report, it focuses on the illustrative postclosure safety assessment, which is discussed in detail in Chapters 6, 7 and 8. The scenarios, assessment tools and methods and assessment results are presented. Both radiological and non-radiological impacts are assessed and the safety assessment results are compared against interim acceptance criteria.

1.6.5 Management of Uncertainties

The report describes the assessment of uncertainties associated with numerical analyses at a level that is reasonable for a conceptual design at a hypothetical site. The discussion is consistent with the CNSC guidance for analyzing uncertainties and addresses such things as: degree of conservatism, conceptual model uncertainty, parameter value uncertainty, and scenario uncertainty. The illustrative safety assessment provides examples of approaches used to assess and understand the relevance of uncertainties in scientific knowledge, data or analysis that support statements of reliability in calculated repository performance.

As described throughout Section 1.6.3, a number of assumptions have been made for the purpose of illustrating the safety assessment approach at this early stage of implementing APM. These assumptions are often characterized in the assessment process as “realistic” or “conservative”.

Realism is defined as: the representation of an element of the system (scenario, model or data), made in light of the current state of system knowledge and associated uncertainties, such that the safety assessment incorporates all that is known about the element under consideration and leads to an estimate of the expected performance of the system attributable to that element (IAEA 2006).

Conservatism is defined as: the conscious decision, made in light of the current state of system knowledge and associated uncertainties, to represent an element of the system (scenario, model or data) such that it provides an under-estimate of system performance attributable to that element and thereby an over-estimate of the associated radiological impact (i.e., dose or risk) (IAEA 2006).

As noted in Section 1.6.3.1, the geoscience program for a future candidate site will be designed to support the safety case and to produce a Descriptive Geosphere Site Model and a Geosynthesis.

The site model and geosynthesis will be developed in the phased site characterization work program. The work program will allow for the iterative development, testing and refinement of a site-specific model that will contribute to managing uncertainties in scientific understanding, data or models. The design is also expected to be further refined once a site has been selected and site specific information becomes available.

The iterative approach described below also highlights how the assessment of uncertainties will be incorporated in the process of developing a safety case for a future candidate site.

1.6.6 Iterative Approach

Consistent with international guidance, the NWMO plans to use an iterative approach in the strategies for management, site characterization, design and assessments of a candidate site. The documentation process to support this iterative approach is included in Figure 1-5. On the left hand side of this figure, two key documents that will support licence applications and that will document the safety case are identified as the Preliminary Safety Report and Final Safety Report.

As noted in Section 1.6.3.3, the design concept presented is illustrative and intended for the safety assessment methodology to be demonstrated. The actual design is expected to be refined once a specific site has been selected, site-specific information becomes available, and design optimization is implemented.

Furthermore, once a site has been selected, Figure 1-5 assumes that the characterization and engineered design programs will go through iterations based on increased knowledge of site characteristics and safety assessment input during detailed site investigations. A few iterations are expected during the phase of detailed investigations.

Some of the key activities in this approach include:

- National and international peer reviews;
- Using site characterization results as an input to repository design and safety assessment, and in building the safety case;
- Conducting complementary geoscience analogue studies to assist with the explanation of geoscience phenomena related to, and to enhance confidence in, the understanding of long-term repository safety;
- Using proven technology in the design;
- Using the results of safety assessment, in particular the preclosure safety assessment and occupational radiation dose ALARA[2] assessment and conventional safety considerations in the design;
- Continuing to make use of a range of safety and performance indicators in safety analyses; and
- Assessing associated uncertainties and identification of any significant deficiencies in scientific understanding, data or analysis that might affect the analysis results that are presented.

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[2] ALARA: As low as reasonably achievable, social and economical factors taken into account.

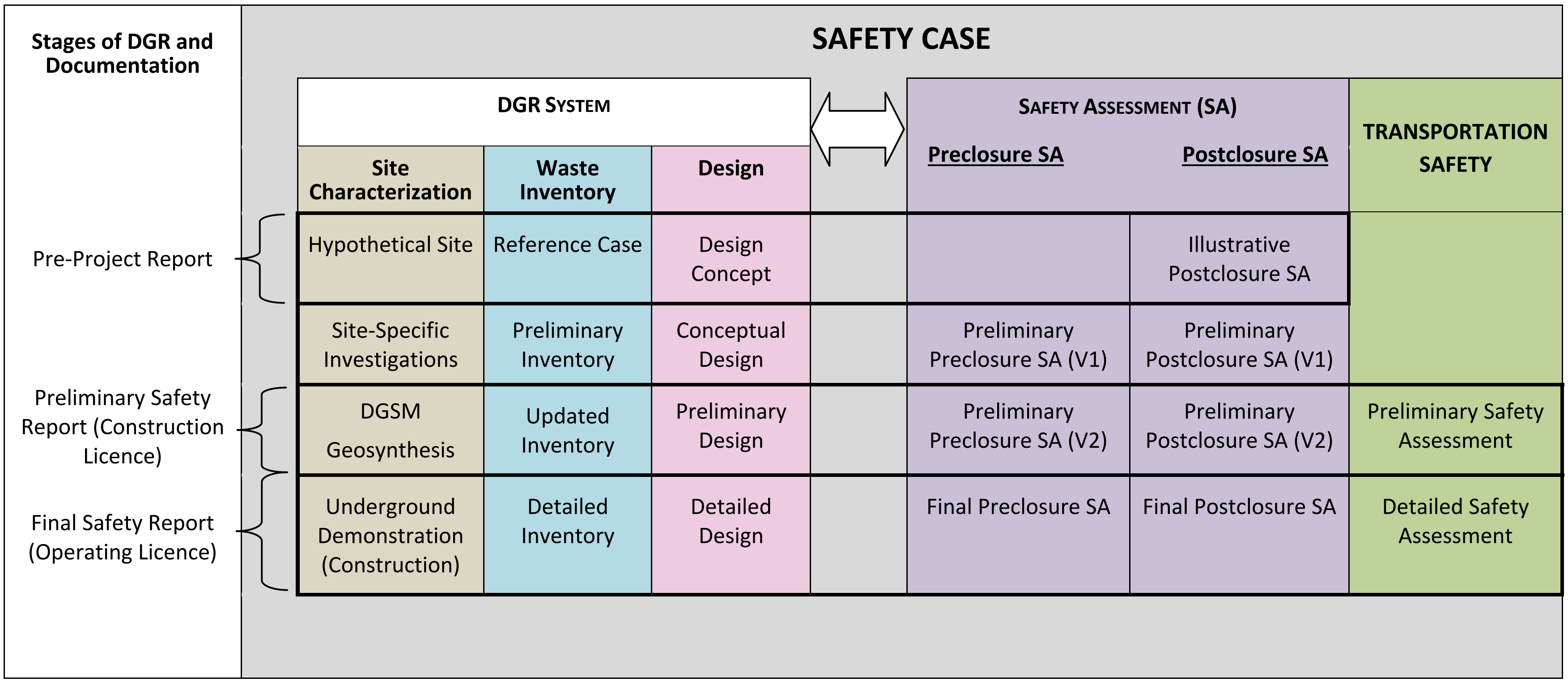

Figure 1-5: Iterative Process for Developing the Safety Case

1.6.7 Integration of Safety Arguments

The safety arguments will be integrated as part of a complete safety case. These arguments will be supported by evidence and multiple lines of reasoning gathered in the site characterization work program and documented in a Geosynthesis for a candidate site.

For the purpose of this report and to present the illustrative safety assessment, a number of assumptions are identified in Section 1.6.3. These assumptions are made to show how site characteristics or attributes and safety functions are used to illustrate the robustness of a multi-barrier system.

The assessment results presented in Chapters 7 and 8 will be used to support safety arguments resulting from the postclosure assessment.

1.6.8 Stakeholder and Regulatory Involvement

As noted in Section 1.1, the purpose of this report is to present a case study involving an illustrative safety assessment of a deep geological repository in a representative sedimentary setting for a pre-project regulatory review. This is being conducted under a special project arrangement between the CNSC and the NWMO (CNSC and NWMO 2008).

This report considers a hypothetical site, so there are no direct stakeholders. However, it will be available to the public and may be of interest to communities as part of the site selection process.

This report and illustrative safety assessment have been conducted in parallel with activities in the NWMO APM site selection process. This section shows how both of these activities are consistent and also confirms that technical evaluation stages are built into the process to select a candidate site.

As noted in the project overview, a site selection process was designed to identify an informed and willing host community for a deep geological repository for the long-term management of Canada's used nuclear fuel. It is a nine-step process developed to reflect the values, concerns and priorities expressed by Canadians, which are detailed by the NWMO (2010). The guiding principles that are embedded in the site selection process include:

- Focusing decision-making on safety;
- Meeting or exceeding regulatory requirements;
- Finding an informed and willing host community;
- Focusing siting on the provinces directly involved in the nuclear fuel cycle; and
- Acknowledging the right for a community to withdraw from the process.

Furthermore, it identifies site evaluation factors with which the suitability of a candidate site to host an APM repository will be assessed (see Figure 1-6). These factors include the list of geoscientific attributes identified in Section 1.6.3.1 and the following attributes:

- The containment and isolation characteristics (e.g., geological, hydrogeological, chemical, and mechanical) of the host rock;

- The long-term stability of the site to ensure that containment and isolation of the repository will not be unacceptably affected by future geological processes and climate changes including earthquakes and glacial cycles;
- Surface and underground characteristics of the site are favourable for the repository's construction, operation, closure, and long-term performance;
- Future human activities are not likely to disrupt containment and isolation of the repository;
- The characteristics of the site should be amenable to site characterization and site data interpretation activities; and
- The site should have a route that exists or is amenable to being created that enables the safe and secure transportation of used fuel from storage sites to the repository site.

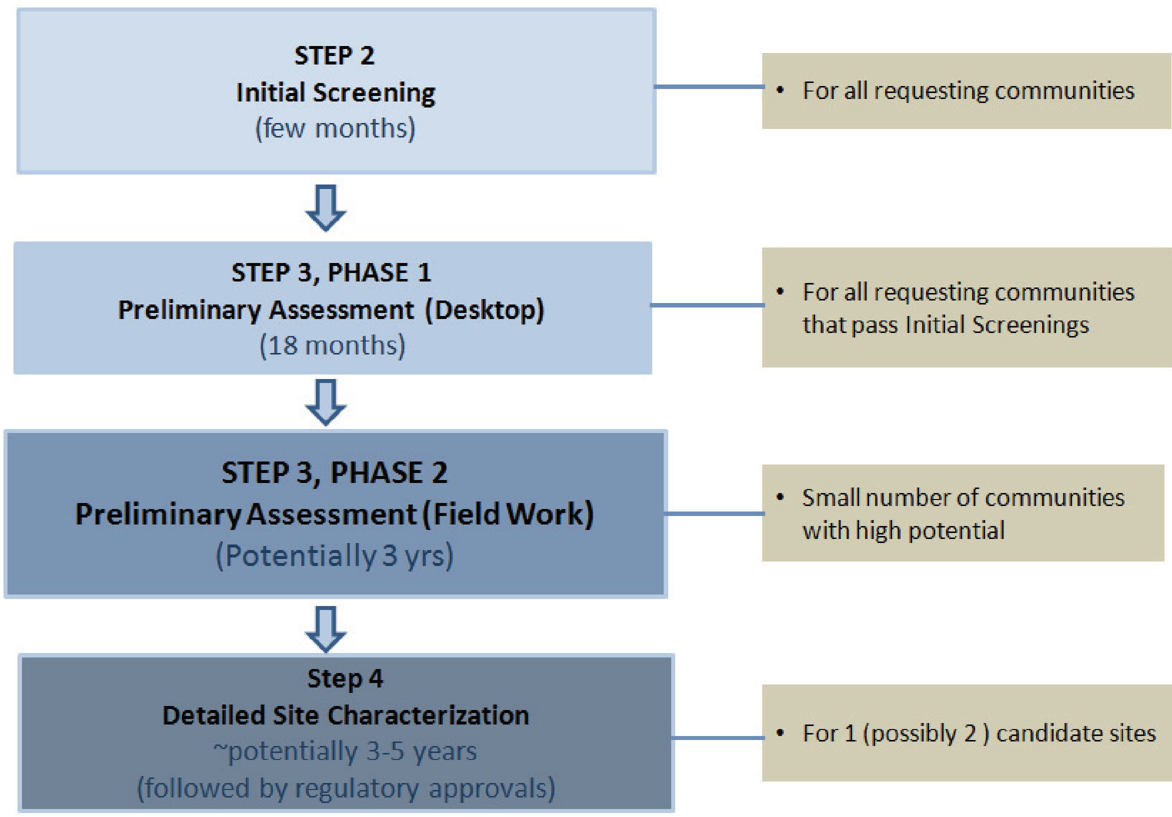

Figure 1-6: Site Evaluation Process

The stakeholder and regulatory involvement activities associated with the siting process were initiated in 2010 and are ongoing.

1.6.9 Management System

The management system includes a project quality plan under which the APM safety assessment has been executed. The project quality plan was developed specifically for this phase of the work. The plan includes the following elements:

- The project organization and responsibilities;
- NWMO and project-specific governance;
- Quality requirements;
- Verification requirements;
- Requirements for consultant or contractor quality management system;
- Records requirements;
- Program's periodic assessment activities; and
- Annual assessment activities.

Chapter 11 describes the elements of the project quality plan in more detail.

1.7 Development of National Deep Geological Repositories

The concept of using a deep geological repository for long-term management of used fuel is consistent with other national plans for high-level waste as summarized in Table 1-3.

Table 1-3: Status of National Plans for High-Level Waste

Country	National Plan for High-Level Waste	Potential Rock Type	Repository Status
Finland	Geological Repository	Crystalline Rock	- Willing host community selected - Underground demonstration facility operating at repository site
Sweden	Geological Repository	Crystalline Rock	- Willing host community selected - Underground demonstration facility operating at generic site
France	Geological Repository	Sedimentary Rock	- General geological region identified - Underground demonstration facility operating at generic site
UK	Geological Repository	To be decided	- Siting process underway
Germany	Geological Repository	Salt, Crystalline, and Sedimentary Rock	- Plans under development
Japan	Geological Repository	Crystalline and Sedimentary Rock	- Siting process underway - Generic underground research facilities under construction
Switzerland	Geological Repository	Sedimentary Rock	- Siting process underway - Underground demonstration facility operating at generic site
USA	Geological Repository	To be decided	- Blue Ribbon Panel recommendations issued
China	Geological Repository	Crystalline Rock	- Siting process underway

1.8 Report Structure and Content

The structure of this pre-project review report is as follows:

Chapter 1 Introduction: An overview of the APM project and the context for the report.

Chapter 2 Description of a Hypothetical Site: Information related to a hypothetical site is presented.

Chapter 3 Used Fuel Characteristics: Information on the reference fuel bundle adopted in the postclosure safety assessment is presented.

Chapter 4 Repository Facility – Conceptual Design: Description of conceptual design for a deep geological repository.

Chapter 5 Long-Term Evolution of the Multiple Barrier System: Description of the deep geological repository system, including the interaction of different components of the system.

Chapter 6 Scenario Identification and Description: Description of the systematic scenario identification process used to identify Normal Evolution and Disruptive Event Scenarios.

Chapter 7 Postclosure Safety Assessment – Contaminant Transport: Provides an evaluation of potential impacts during Normal Evolution and Disruptive Event Scenarios for water-borne transport.

Chapter 8 Postclosure Safety Assessment – Gas Generation and Transport: Provides an evaluation of potential impacts during the Disruptive Event Scenario for gas-borne transport.

Chapter 9 Treatment of Uncertainties: Description of scenario, model and data uncertainties.

Chapter 10 Natural Analogues: Description of natural analogues that illustrate material integrity and identification of the role of site-specific analogues.

Chapter 11 Quality Assurance: Description of the APM quality assurance plan.

Chapter 12 Summary and Conclusions: Summary of information presented in the pre-project report and overall conclusion on meeting the pre-project report objective.

Chapter 13 Special Terms: Includes units, abbreviations and acronyms.

Appendix A Design Optimization: Description of observations on sedimentary rock considerations for a used fuel repository in other countries.

The IAEA's structured approach presented in the recent guidance on the Safety Case and Safety Assessment for the Disposal of Radioactive Waste (IAEA 2012) was used to describe the components of a safety case in Section 1.6. This guidance is complimentary to the CNSC Guide G-320 and its structure is used to present the information in this report. To illustrate how the content of G-320 is captured in this report, a mapping of the pre-project report sections to the content in G-320 is included in Table 1-4.

Table 1-4: Pre-Project Report Content Mapped to CNSC Guide G-320

G-320 Content	Relevant Section(s) in Report
Developing a Long-Term Safety Case	
Safety Assessment	Chapters 7 and 8
Use of Different Assessment Strategies	Sections 7.2 and 8.2
Robustness and Natural Analogues	Chapters 7, 8 and 10
Use of Complementary Indicators to Safety	Section 7.11.1
Defining Acceptance Criteria	
Overview	Section 7.1
Criteria for Protection of Persons and the Environment	Section 7.1
Performing Long-Term Assessments	
Selection of Appropriate Methodology	Section 7.4, 8.4
Assessment Context	Section 7.2, 8.2
System Description	Chapters 2, 3, 4, and 5
Assessment Time Frames	Section 1.4
Assessment Scenarios	Chapter 6
Developing and Using Assessment Models	Sections 7.5-7.9, 8.5-8.7
Interpretation of Results	
Comparing Assessment Results with Acceptance Criteria	Section 7.12, 8.7, 8.8
Analyzing Uncertainties	Chapter 9

1.9 References for Chapter 1

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