Overview of DGR Radiological Safety

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Overview of DGR Radiological Safety

Purpose:
Present a high level overview of how safety is achieved and demonstrated
Focus is on radiological safety in the Preclosure and Postclosure periods

Agenda:
1. General Remarks
2. Preclosure (Operations) Phase
   • Key Features for Safety
   • Safety Assessment
3. Postclosure Phase
   • Key Features for Safety
   • Multiple Barriers
   • Geosynthesis
   • Safety Assessment
   • R&D Support
   • Natural Analogues
4. Monitoring and Oversight
5. Summary
1.0 General Remarks - Safety

‘Safety’ means protecting the public, the workers and the environment from hazards associated with facility operation.

In general, safety is achieved through a combination of:

• Robust design that complies with all applicable standards
• Engineered barriers
• Trained staff and proper equipment
• A good site
• Favourable host rock
• Durable, non-reactive wasteform
• Repository depth
• Monitoring and oversight

Safety is determined (in part) by comparing estimated effects (doses) against approved acceptance criteria.

If margins are deemed insufficient, key assumptions are examined and iteration with design and operations may occur to implement improvements.
1.0 General Remarks - Safety Case

The **Safety Case** is an integrated collection of arguments and evidence that together demonstrate the safety of the facility.

The Safety Case addresses all aspects of safety:

- Conventional Health and Safety
- Transportation Safety
- Preclosure Safety
- Postclosure Safety

The portion addressing radiological safety will include a Safety Assessment, a Geosynthesis, information on R&D support, information on Natural Analogues and more.

It will be subjected to peer review (national and international reviewers).

It will be subjected to independent review and checking by the CNSC.

Licenses will not be granted until the CNSC is satisfied that the health and safety of the public, the workers and the environment are protected.
2.0 Preclosure Phase – Key Features for Safety

During the Preclosure Phase:

• Used fuel is removed from the transport container and placed into the long-term container
• The long-term container is placed inside a shielded conveyance, taken underground and placed in an underground room

Key Features for Safety:

• All fuel handling operations take place inside specially designed rooms, with:
  • Thick concrete walls for shielding
  • Separate filtered and monitored ventilation systems
  • Internal air pressure maintained below atmospheric (for contamination control)
  • Radiation detectors and alarms
  • Redundant equipment as needed

• Also:
  • Used fuel is a solid material - not reactive, not combustible
  • Used fuel is maintained under dry conditions with low temperatures
  • Air is sufficient for cooling
  • Shielded transport vehicles and remote handling to the extent practicable
2.0 Preclosure Phase – Safety Assessment

Preclosure safety is demonstrated (in part) via a ‘safety assessment’

- A ‘safety assessment’ is an analysis which addresses:
  - Normal Operation
  - Abnormal Occurrences
  - Accidents

Idea is to show that the dose rate acceptance criteria are met for all credible occurrences
2.0 Preclosure Phase – Safety Assessment

During Normal Operations

• For Worker Safety:
  • Hazard is radiation dose due to working in close proximity to radioactive materials
  • Managed by shielding, distance and duration
  • During the design phase worker doses are estimated
  • During the operation phase worker doses are measured

• For Public Safety:
  • Potential hazard arises from contamination that may arise during handling of damaged fuel bundles
  • Releases are managed through control of room air pressure and use of ventilation system and filters
  • During the design phase public doses are estimated
  • During the operation phase, the releases are measured
  • Estimates are so low as to be almost negligible
2.0 Preclosure Phase – Safety Assessment (cont’d)

For Abnormal Occurrences and Accidents

- First Step is Event Identification:
  - Formal process for identification – Failure Modes and Effects Analysis (FMEA)
  - Identified events include such things as power failure, equipment breakdown, crane failures, dropping of bundles, dropping of container, fire
  - Also identifies external events such as earthquakes and severe storms

- Next step is the Event Consequence Assessment:
  - Potential events are categorized according to frequency
  - Analysis is performed to identify the consequences of the bounding events
  - Potential effects on workers and the public compared against acceptance criteria

Considerable Canadian and international experience in radioactive materials handling
3.0 Postclosure Phase – Key Features for Safety

Key Features for Safety:

Robust Design:
- Multiple barriers (see following slides)
- Use of materials with demonstrated long-life
- Works with the geology

Geology:
- Deep location
- Large volume of low permeability rock
- No usable mineral and water resources
- Low seismicity
- Has conditions conducive to long container life
- Seeks evidence that rocks are ancient and have survived multiple glaciations
- Seeks evidence that water in the rocks at repository level is old
3.0 Postclosure Phase – Multiple Barriers

Postclosure safety is achieved via a combination of overlapping engineered and natural barriers

Purpose of the Barriers:

- To prevent water from contacting the used fuel
- If water does contact the fuel, to inhibit and slow down the migration of contaminants to allow more time for radioactive decay

Barriers:

- Fuel pellet
- Fuel sheath
- Used fuel container
- Clay based sealing materials
- Geosphere
3.0 Postclosure Phase - Multiple Barriers

Multiple Barrier System

Barrier 1: Ceramic UO₂ Fuel Pellet
Barrier 2: Fuel Sheath
Barrier 3: Used Fuel Container
Barrier 4: Clay Seals
Barrier 5: Geosphere (host rock)
Barrier 1: The Fuel Pellet

- High density durable ceramic
- Most radionuclides are trapped where they are formed in the uranium oxide fuel material
- Fuel takes millions of years to dissolve when submerged in the water that exists at repository depth
- Because they are trapped, and because the fuel dissolves very slowly, many radionuclides decay in-situ
- Ongoing research indicates that the fuel may take even longer to dissolve
3.0 Postclosure Phase - Multiple Barriers (cont’d)

Barrier 2: The Zircaloy Fuel Sheath

- Used fuel pellets are arranged inside sealed tubes made of Zircaloy
- Zircaloy is a strong, corrosion-resistant metal that provides a barrier to water contacting the fuel pellet
- No credit taken for this barrier in the safety assessment

Bundle is roughly the size of a fireplace log
3.0 Postclosure Phase - Multiple Barriers (cont’d)

Barrier 3: Used Fuel Container

- Robust and long-lived
- Steel inner shell
- Copper coating
- Steel inner shell provides strength to resist the local pressure underground, the bentonite swelling pressure and the pressure from future glaciations
- Copper coating provides corrosion protection of the inner shell
- Water cannot contact the fuel if the container remains intact
- Copper is very stable in the conditions that exist deep underground (see Natural Analogue section)
3.0 Postclosure Phase - Multiple Barriers (cont’d)

Barrier 4: Bentonite Clay Based Sealing Materials

• Bentonite Clay:
  • Naturally occurring mineral formed from volcanic ash 100 million years ago
  • Can swell up to 16x its initial volume upon contact with water - becomes essentially impermeable (see Natural Analogue section)
  • Self-healing
  • If, for some reason, water contacts the fuel and radionuclides begin to migrate, bentonite has chemical properties that make it difficult for many radionuclides to pass through

• Used fuel containers will be surrounded by bentonite clay in a ‘buffer box’
• Underground rooms will be backfilled with bentonite-based materials
3.0 Postclosure Phase - Multiple Barriers (cont’d)

Barrier 5: The Geosphere

- Host rock forms a natural barrier
- Protects the repository from natural surface events and human activities
- Has conditions deep underground that promote long container life
- If, for some reason, radionuclides are migrating through the bentonite barrier, the geosphere has chemical properties that make it difficult for some radionuclides to travel, greatly slowing their release rate to the biosphere
- See Natural Analogue section
3.0 Postclosure Phase - Geosynthesis

Geosynthesis

• Detailed study of the geosphere to:
  • Understand its past history, its current state and its future evolution
  • Provide evidence on key processes

• Examples of study areas:
  • Rock strength and stability
  • Age of water at various depths, including repository level
  • Mapping and understanding fractures
  • Seismicity and glaciation
  • Rock properties

• Provides information to support long-term safety
• Provides data for use in the safety assessment
3.0 Postclosure Phase – Safety Assessment

Postclosure safety is demonstrated (in part) via a ‘safety assessment’

Safety Assessment provides a quantitative estimate of the ability of the repository to isolate and contain radioactivity in the used fuel in the long term. Uses computer models of the repository, the surrounding host rock and the biosphere. Follows guidance in CNSC G-320 ‘Assessing the Long Term Safety of Radioactive Waste Management’.

Considers:

- The effects on people due to radiological and non-radiological hazards
- The effects on the environment due to radiological and non-radiological hazards

Diagram of ecological system with various species and processes.
3.0 Postclosure Phase - Safety Assessment (cont’d)

Safety Assessment Timescale:

Considers a 1 million year timeframe because this period covers key processes, including:

- The initial large decrease in used fuel radioactivity within the first 1000 years
- The subsequent slow decrease in used fuel radioactivity to the level of that in an equivalent amount of natural uranium
- Future glaciation, assuming first glacial cycle in about 60,000 years
- The potential for container failure, and
- Is sufficient to determine the maximum impact
Safety Assessment Status:

• Currently, no assessments have been performed for specific Canadian sites
• Preliminary assessments have been done for different conceptual designs at different hypothetical sites:

  Crystalline Rock:
  • AECL EIS and Second Case Study (1992 and 1994)
  • OPG Third Case Study (2004)
  • NWMO Fourth Case Study (2012)
  • NWMO Sixth Case Study (underway)

  Sedimentary Rock:
  • NWMO Fifth Case Study (2013)
  • NWMO Seventh Case Study (for 2016)

• These preliminary assessments allow us to enhance our learning, identify important features for long-term safety, and provide information for discussions with the CNSC, the public and other interested parties
3.0 Postclosure Phase - Safety Assessment (cont’d)

Scope:
Safety assessment does not try to predict the future, but considers the consequences of a range of scenarios
As per G-320:

Normal Evolution Scenario:
- Most likely evolution of site, repository and containers
- Includes earthquakes and glaciation
- Assumes a small number of containers are placed in the repository with undetected defects

Disruptive Event Scenarios:
- Unlikely and “What If” events
- These scenarios check the robustness of the specific site and repository design
- Range of situations where container may be compromised (e.g. all containers fail, degraded seals, undetected fault, poorly sealed borehole)
- As per G-320, also considers Inadvertent Human Intrusion
3.0 Postclosure Phase - Safety Assessment (cont’d)

Some Key Assumptions:

• People in the future are similar to people of today
• Should protect future people to the same degree that we protect ourselves
• People in the future behave plausibly, with characteristics that maximize exposure
• A self-sufficient farm family unknowingly lives on top of the repository and:
  • Grows all their food on top of the repository
  • Obtains all their drinking water from a deep well
  • Well is in the location that maximizes the uptake of repository contaminants
• If it can be shown that this hypothetical family is safe, then real families would be safer
3.0 Postclosure Phase - Safety Assessment (cont’d)

Some Modelling Illustrations:

Surface and Subsurface Model around Hypothetical Repository
3.0 Postclosure Phase - Safety Assessment (cont’d)

Sample Results – Normal Evolution (Crystalline Rock)

- Reference Case
- Fuel dissolution increased by 10
- Container defect area increased by 10
- Fuel instant release fraction increased to 10%
- Rock conductivity increased by 10 (case 1)
- Rock conductivity decreased by 10 (case 2)
- Rock conductivity decreased by 100 (case 3)
- Location of fracture decreased to 10 m
- Conductivity of EDZ increased by 10
- Sorption decreased and solubility increased
- Sorption in geosphere ignored
- Sorption in near-field ignored
- Solubility limits ignored

![Bar chart showing estimated dose consequence (mSv/yr)](chart)

- **Acceptance Criterion for Normal Evolution**
- **Natural Background**
3.0 Postclosure Phase – R&D Support

Design and safety is supported by an extensive R&D Program

- For optimization and proof testing
- To enhance scientific understanding of processes that may influence safety
- To maintain awareness of technology advancements

Achieved by:

- Tests and experiments performed in Canada over many years at a number of universities and private companies
- International collaborations with a number of countries (e.g., Sweden, Belgium, Switzerland, Germany) to share costs and knowledge
- International meetings to share experiences and knowledge
- Conferences and workshops
3.0 Postclosure Phase – Natural Analogues

Postclosure Safety is Supported by Natural Analogues:

• These are natural features that exist under conditions or processes occurring over long periods of time that are similar to those expected in some part of a deep geological repository
• They build confidence that the system will perform as expected
• Analogues exist for all repository components
3.0 Postclosure Phase – Natural Analogues (cont’d)

Example - Natural Analogue for the Repository

Cigar Lake (Canada)

- 1.3 billion year old uranium ore deposit surrounded by clay at a depth of 430 m
- No evidence at surface of the ore body
- Speaks to the effectiveness of clay and the geosphere in isolating and containing radioactive contaminants
Example - Natural Analogue for the Geosphere

Oklo (Gabon)

- Naturally occurring fission reactions took place in uranium ore body about 2 billion years ago
- Active over a period of one million years
- Studies show most of the fission product and actinide material has remained in the vicinity of the ‘reactor’
- Speaks to the effectiveness of the geosphere in inhibiting contaminant migration
Example – Natural Analogue for Copper Robustness

**England**

- Natural copper plates
- Quartz/clay matrix
- Reducing conditions
- ~1 mm corrosion
- ~200 million years old

- Speaks to the effectiveness of copper as a barrier to corrosion for the long-term container
5.0 Postclosure Safety – Natural Analogues (cont’d)

**Bentonite Clay Natural Analogue**

- Sequoia-like trees in Dunarobba forest (Italy) buried in clay for 1½ million years
- They are still made of wood and have not decomposed
- Speaks to the effectiveness of clay in isolating the container from flowing water
4.0 Monitoring and Oversight

License not granted until the CNSC is satisfied with the Safety Case

Project would be monitored continuously from before construction, through operations, and after closure:

- Monitoring by NWMO to demonstrate compliance with licence conditions
- Ongoing independent verification by CNSC staff

- The CNSC would require regular formal updates on facility performance
- Periodic relicensing would be required by the CNSC throughout the lengthy operating period
5.0 Summary

‘Safety’ means protecting the public, the workers and the environment from hazards associated with facility operation.

In general, safety is achieved through a combination of:

- Robust design that complies with all applicable standards
- Engineered barriers
- Trained staff and proper equipment
- A good site
- Favourable host rock
- Durable, non-reactive wasteform
- Repository depth
- Monitoring and oversight

The Safety Case is an integrated collection of arguments and evidence that together demonstrate the safety of the facility.

The CNSC must be convinced that the safety case is acceptable before a license to proceed would be granted.