Session 3

Establishing Regulatory Criteria that Account for the Inherent Difficulties Associated with the Long-times Frames for Protection

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Planning for the Long Term: Perspectives of the Canadian Citizens

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To determine the best approach for long-term used fuel waste management in Canada, NWMO conducted a dialogue with Canadian citizens over a three-year period (2002-2005) under the mandate given to it by the Nuclear Fuel Waste Act.

Canadian citizens were approached through a nation-wide telephone survey involving 2 600 Canadians, through focus groups, discussion sessions, dialogue workshops, on-line forum and open houses about their views on this subject. Over the course of the study, NWMO engaged 18 000 Canadians directly in its engagement activities.

The comments Canadians made during that dialogue included those concerning the long timeframes involved in high-level waste management and how these should be addressed in the development of a management approach for Canada.

In summary, Canadians want:

- Adaptability and/or flexibility.
- Phased implementation.
- An extended timeframe for implementation.
- The ability to monitor the waste.
- The ability to retrieve the waste.

Adaptability and/or Flexibility

As part of our nation-wide survey, 92 percent said it is important that the approach be "flexible enough to adapt to new learning, and new developments in science and technology," viewed as being a fundamental requirement.

While they want the plan to have a definitive outcome, they also want flexibility in the plan for future generations to make their own decisions

Adaptability was viewed as important in that it allows for anticipating and addressing changing conditions (e.g. the potential for climate change and future societal breakdown) the significance of which is unknown to us today.

Canadians want *Phased Implementation* because it:

- Provides opportunities for continuous learning from the experiences of other countries, leading to adjustments in design details.
- Provides opportunities for future generations to be proactively engaged in the management of the used nuclear fuel.
- Allows for the emergence of new technologies and approaches that might make geological containment and isolation unnecessary.

- Allows for decisions to move as quickly or as slowly as necessary.
- Provides time for capacity building and informed decision making among youth, potential host communities and others, and avoids predetermined outcomes that might undermine community support.
- Allows future generations to decide when to decommission the above and below-ground facilities, when to close them and the nature of post-closure monitoring.

Canadians want *an extended timeframe for Implementation*.

- This was seen as a signal that a cautious and considered approach to the management of used nuclear fuel is being taken, with sufficient time for new learning and technologies.
- It was considered as "pragmatic" in that it recognises the many issues that will need to be addressed, and the difficulty in pre-judging the time needed to achieve full confidence in the approach.
- It was preferred over an approach which does not embrace design features such as flexibility, continuous learning adaptability and implementation over an extended timeframe.
- And it was seen as providing opportunities for future generations to be proactively engaged in the management of the used nuclear fuel and influence implementation of the approach to suit their values and priorities.

This takes into account the recognition that building confidence takes time, and that implementation of the selected approach needs to keep pace with the comfort level of the people.

The long time frame of implementation presents an opportunity for new learning, to take stepwise decisions as we proceed taking into account developments in science and technology, experience, and an opportunity to retain flexibility to take decisions in the future that are in the best interest of society in light of their evolving priorities and expectations.

Canadians want *the ability to monitor* for themselves and future generations.

- This was viewed as essential to ensure the long-term protection of human and ecological health, and to allow for continuous learning and well-informed decision making.
- It provides assurance to the public that the facility continues to be safe.
- It allows future generations to measure and assess their stewardship over the used nuclear fuel.

The ability to monitor was looked upon as a precondition to future retrieval of the material, regardless of the intended purpose.

Canadians also want *the ability to retrieve the waste*:

- In case monitoring indicates that safety is compromised.

Also:

- Used fuel was viewed as a potential resource for future generations; decisions and actions taken now should not foreclose future opportunities – i.e. show respect for the future generations by ensuring that the used fuel is properly cared for but remains available for possible future use.
- And future technologies could emerge to better manage the used fuel.

What Do Implementers Need in Terms of Regulatory Safety Criteria for the Post-Closure Phase?

Bruno Cahen
Andra, on behalf of IGSC, France

Background and Scope

The national experience in siting and developing conceptual designs of geological disposal is growing rapidly. It implies increasing opportunities for interactions between implementers and regulators. Many regulators have already developed a regulatory framework. The implementers need practical, transparent and deliverable regulations. These regulations should draw on experiences gained from development of geological disposal projects.

There has been a large development of international guidance in recent years (ICRP-81, ICRP-103, WSR-4, NEA publications). The wish expressed by the members of the IGSC is that international guidance capitalise on the experience gained recently in the development of safety cases presented in the framework of international fora and simplify this guidance going back to core business.

The recent evolutions at the international level show that:

- There is a general awareness that doses and risks in the future are not a measure of health detriment but are good indicators of the performance of the repository.
- Yardsticks in the different timescales may be different depending on the national context, but all countries agree on the principle that the nature of the safety assessment may not be the same in the short/medium timescales as in the far future and that this may impact compliance measure and corresponding criteria.
- Key elements of the safety strategy have already been identified: the optimisation process (BAT/ALARA), R&D, the stakeholders' role in the project, the stepwise process. Exchange on experience would be fruitful.

Safety Criteria and Very Long-time Frames

Key questions identified by the IGSC

International guidance recognises the difficulties associated with safety assessment in long time frames, and NEA work in this domain has allowed some progress but still leaves many open questions. In its programme of work, the IGSC has identified five key questions that the RF may focus on:

1. Over what time framse are wastes deemed to present a hazard?
2. Over what time frames are regulatory criteria applied and do they change over time?
3. Over what time frames are safety assessments required to be conducted?
4. How do implementers have to address uncertainties in the long time frames?
5. What happens after cut-offs: are additional analyses needed? What types of arguments are to be used?

Need for Stable, Understandable and Practical Criteria

Stable and Understandable Criteria

Criteria will be stable if they are unchallenged which means that they need to be developed on a strong scientific and societal basis.

The determination of the level of hazard presented by the waste in the long time frames is very important in this respect. It was stated until recently that this potential hazard in the future would be comparable to hazards from uranium ore. This point of view has been called into question but there is not yet a common position on the subject.

Other related issues are 1) the basis for a cut-off for the safety assessment in the long time frames, 2) the trend to move from hard criteria to soft criteria when changing of timescales or 3) the need to use additional criteria than dose and risk because of increasing uncertainties the longer the time. National regulations are evolving on these subjects. Ethical issues are coming in and stakeholders should be involved early in the process in order to better understand what is at stake. A large range of points of views has to be dealt with.

Practical Criteria

Protection objectives and criteria should have a direct application to safety options and design or organisational requirements. Regulations have a tendency to be fairly general and sometimes difficult to interpret.

Of course, a relevant regulatory framework requires a project which is mature enough and for which constructive dialogue between the regulator and the implementer has taken place. In general, safety objectives will be set by the regulator and, on this basis the implementer will define safety options that will be reviewed by the regulator to give his approval. From safety objectives and a reference design, safety requirements will be defined.

There needs to be consistency of safety options and requirements for different types of waste. Going from VLLW to LLW, ILW and HLW there is a growing need for increased performances and redundancy. In the longer time frames the emphasis would be given to robust systems, passive safety and multiple safety functions. The criteria should fit the various phases of the project (siting, designing, operating, closure and post-closure).

Safety Priorities and Requirements for High-level Waste

Experience feedback from safety cases shows that safety priorities depend very much on time frames. In the short term (100 to 1 000 years) the radioactivity of waste is high, transient thermo-hydro-mechanical processes dominate. Protection is ensured mainly by engineered containment (waste package) and to some extent also by institutional control. In the range 1 000 to 10 000 years the protection of man and environment relies on the passive safety measures put in place and thus on the performance on the individual components of the repository system. It relies also on the measures taken to reduce the effect of natural phenomena and probability of human intrusion by the depth of the disposal and its location. After 10 000 years some migration of radioactive substances may occur. The role of the repository system is to insure that consequences will remain acceptable. The geology will play a large role in this respect. In the very long term, after "time cut-off", the inventory is limited to very long-lived radionuclides whose activity level is many orders of magnitude lower than in the initial inventory. The limitation of consequences will rely on the dispersion of the waste on large volumes (no "hot spots"), the depth of the repository and the limits set on erosion rates. No need for sophisticated modeling may be required.

It appears more and more important to carefully balance long-term safety and operational safety. Such issues as ventilation, radiation protection requirements during operation, timing for closure of disposal cavities may have consequences on long-term safety. The derived safety criteria for the individual components should lead to measurable, verifiable specifications.

Safety Analysis, Scenarios and Safety Criteria

The assessment of geological repository post-closure safety relies on a number of qualitative and quantitative arguments. One issue is to derive safety criteria in relation with these arguments. The assessment of the induced impact of the repository on man and the environment is one element in demonstrating safety. The corresponding criteria are usually dose or risk. An alternative criterion often proposed is the radionuclide molecular flow to the surface environment in order to alleviate uncertainties associated with the biosphere components.

Specific aspects are important in the safety assessment in order to increase the confidence in the safety case. The redundancy afforded by the existence of multiple safety functions enables the repository to be maintained in a safe condition even in degraded situations. The management of uncertainties contributes to the robustness of the repository despite known/suspected uncertainties in the knowledge and in the long-term evolution. Margins of safety are developed. The soundness of the scientific basis underpinning the initial state and evolution of waste and repository depends of the quality of data and adequate understanding of phenomena.

The safety assessment may rely either on deterministic or probabilistic approaches, each presenting advantages and drawbacks. They are actually complementary.

One fundamental element in the radiological impact assessment is the understanding of the behaviour of individual radionuclides. Different components and functions of the repository system will be brought forward depending on the type of radionuclide. At least three families may be distinguished:

- Short-lived and medium-lived elements, which decay before waste packaged are degraded. They will remain in the repository vaults in normal evolution conditions. They are controlled by containment in the waste packages.
- Long-lived elements that have a reduced mobility because of low solubility limits and/or high sorption properties. These may migrate in the geosphere because of their long decay time but their low mobility will delay their impact in the very long time frames and their low solubility limits will keep their molecular flow at a very low level. They are controlled by retention in the geosphere.
- Long-lived, highly soluble elements presenting low sorption properties. Their impact will be controlled by the concentration/molar flow reduced by diffusion/dispersion processes in the host rock. They are controlled by delay and dispersion in the geosphere.

The safety assessment should be based on the detailed understanding, description and modeling of the processes governing the migration of the different radionuclides. Scientific knowledge leads to reliable quantitative information on the repository evolution resulting in a transparent safety case. The detailed understanding of the system allows identifying intermediate safety indicators bringing confidence on the overall evolution of the system, the dose being the ultimate safety indicator. An optimisation process based on the assessment of the performance of a series of indicators linked with the properties of individual components of the repository system would certainly contribute to confidence and help uncertainty management.

Some examples of indicators associated with requirements may be the following:

- Requirement of data on the waste inventory as its chemical content and long-term evolution: the corresponding indicator is the soundness of the provided data.
- Minimum design performances required for the waste package, the EBS, the host rock for long-term safety. These minimum design performances should take also into account operational safety.
- Indicators of performance associated with each function associated with repository components and the level of redundancy corresponding to each time frame. Optimisation will be directed on these elements.
- Requirements on the safety assessment methods related to the definition of evolution scenarios, on sensitivity studies and on the hypothesis for the biosphere. The indicators will be the peak dose or the peak molecular flow of radionuclides to the geosphere, the percentage released activity per year or the time of occurrence of releases.

Scenarios Drive Criteria for Siting and Waste Characterisation (Optimisation Iterative Loop)

The confirmation of the favourable characteristics of the host rock, the location of the disposal facility with respect to site features depend very much on results from the analysis of the consequences from the normal evolution scenario and human intrusion scenarios. Many site properties come directly into play such as the favourable hydrological context, the low erosion rate, the geometry of the host rock which should be compatible with a disposal facility at a depth of at least 200 m and a thickness sufficient to delay and disperse long-lived, mobile and soluble radionuclides. The prevention from human intrusion and major disruptions is obtained by the absence, in the surroundings, of "profitable" natural resources and of natural risks connected to geodynamics.

Waste characterisation (content, chemical properties) should be driven toward radionuclides which dominate the radiological impact. It should also be driven by factors influencing THMCR processes or the interaction with repository components. Decisions on an overpack or canister to control the source term may be made on this basis.

In the framework of a stepwise approach an overall system optimisation comes into play and all the elements of the safety case should be adequately weighted. This includes balancing long-term and operational safety. In this context, operational safety also means risk analysis, evaluation of specific [dimensioning] accidental scenarios (fire, waste package falling…).

Conclusions

With respect to the main objectives for the RF-workshops, the possible further implication of IGSC may be both in long-term safety and operational safety. Long-term safety criteria, management of extremely long timescales and safety assessment methods are major topics of interest for the IGSC and inputs from RF workshops would be of the upmost importance. The IGSC feels that international developments, following experience feedback from implementation of ICRP-81 and ICRP-103 in national regulations, should deserve a particular attention. The IGSC has an interest in the technical implications of operational safety considerations on long-term repository performance and in terms of design constraints needed to balance operational safety and long-term safety requirements. A stepwise approach to explore this issue was initiated, beginning with an IGSC Topical Session in 2008 (IGSC-10) to define the issue and gather national experience and challenges. Workshops on this subject are planned for the period 2010-2012. Inputs from RF-workshops on implementing an optimisation process would be very valuable.

Consideration of Timescales in the Finnish Safety Regulations for Spent Fuel Disposal

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Introduction

The Finnish spent fuel disposal programme is progressing towards the construction-license stage. The preparations by the regulator (STUK) for the license application review include renewal of the safety regulations. These include the Government Decree[1] on the Safety of Nuclear Waste Disposal which entered into force on 1st December 2008. The Decree will be detailed by a STUK Guide which is currently being updated. These regulations distinguish three post-closure time periods for which different safety criteria are defined; these are discussed below.

Environmentally Predictable Future

The first time period, so-called environmentally predictable future, is defined to extend up to several thousands of years. During this period, the climate type is expected to remain similar to that nowadays in Northern Europe, predictable albeit considerable environmental changes will occur at the disposal site due to the ongoing land uplift: a sea bay will turn into a lake, then into wetland and might later on be used as farmland. The geosphere is expected to remain quite stable though slight, predictable changes will occur due to the land uplift and the heat generating waste.

In this timeframe, the engineered barriers are required to provide almost complete containment of the disposed waste because of its high radioactivity. Consequently, people might be exposed to the disposed radioactive substances only due to limited early failures of engineered barriers, due to e.g. fabrication defects.

Despite the environmental changes, conservative estimates of human exposure can be done for this time period and accordingly the safety criteria are based on dose constraints. The Government Decree includes the following radiation protection criteria:

Disposal shall be so designed that as a consequence of expected evolutions

- The annual dose to the most exposed members of the public shall remain below 0.1 mSv.
- The average annual doses to other members of the public shall remain insignificantly low.

These constraints are applied to assessment periods that are adequately predictable with respect to assessments of human exposure but that shall be extended to at least several thousands of years.

1. Government Decree on the Safety of Nuclear Waste Disposal (736/2008), Finland.

In the STUK guide,[2] the radiation protection criteria are clarified as follows:

The dose constraints apply to radiation exposure of members of the public as a consequence of expected evolution scenarios and which are reasonably predictable with regard to the changes in the environment. Humans are assumed to be exposed to radioactive substances released from the repository, transported to near-surface groundwater bodies and further to watercourses above ground. At least the following potential exposure pathways shall be considered:

- *Use of contaminated water as household water, as irrigation water and for animal watering.*
- *Use of contaminated natural or agricultural products originating from terrestrial and aquatic environments.*

Changes in the environment to be considered in applying the dose constraints include at least those arising from land uplift. The climate type as well as the human habits, nutritional needs and metabolism can be assumed to be similar to the current ones.

The constraint for the most exposed individuals, effective dose of 0.1 mSv per year, applies to a self-sustaining family or small village community living in the vicinity of the disposal site, where the highest radiation exposures arise through the pathways discussed above. In the environs of the community, a small lake and shallow water-well is assumed to exist.

In addition, the assessment of safety shall address the average effective annual doses to larger groups of people, who are living at a regional lake or at a coastal site and are exposed to the radioactive substances transported into these watercourses. The acceptability of these doses depend on the number of exposed people, but they shall not be more than one hundredth – one tenth of the constraint for the most exposed individuals.

Era of Extreme Climate Changes

Beyond about 10 000 years, great climatic changes, such as permafrost and glaciation, will occur. The range of potential environmental conditions will be very wide and assessments of potential human exposures arising in that time period would involve huge uncertainties. With conservative approach, the safety case should be based on extreme bio-scenarios and on overly pessimistic assumptions.

Though the climatic changes affect significantly also the conditions in the geosphere, their ranges are estimable. In this time period, substantial degradation of the engineered barriers cannot be ruled out, though they were planned to withstand the climate-induced disturbances in bedrock. Radionuclide release and transport in the repository and geosphere can be assessed with reasonable assurance and consequently, it is prudent to base the radiation protection criteria on constraints for release rates of radionuclides from geosphere to biosphere (geo-bio flux constraints).

The Government Decree includes the following the radiation protection criteria for the era of extreme climate changes:

Beyond the assessment period referred to above, the average quantities of radioactive substances over long time periods, released from the disposed waste and migrated to the environment, shall remain below the nuclide specific constraints defined by the Radiation and Nuclear Safety Authority. These constraints shall be defined so that:

- *At their maximum, the radiation impacts arising from disposal can be comparable to those arising from natural radioactive substances in the earth's crust.*

2. STUK (2001), *Long-term Safety of Disposal of Spent Nuclear Fuel*, STUK Guide YVL 8.4 (2001), STUK, Helsinki.

- *On a large scale, the radiation impacts remain insignificantly low.*

In the STUK guide, these criteria are specified as follows:

The nuclide specific constraints for the activity releases to the environment are:

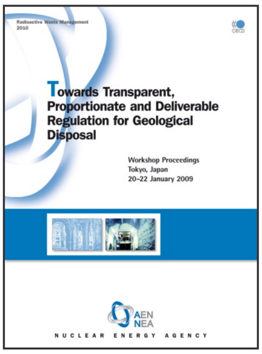
- *0.03 GBq/a for the long-lived, alpha emitting radium, thorium, protactinium, plutonium, americium and curium isotopes.*
- *0.1 GBq/a for the nuclides ^{79}Se, ^{129}I and ^{237}Np.*
- *0.3 GBq/a for the nuclides ^{14}C, ^{36}Cl and ^{135}Cs and for the long-lived uranium isotopes.*
- *1 GBq/a for ^{94}Nb and ^{126}Sn.*
- *3 GBq/a for the nuclide ^{99}Tc.*
- *10 GBq/a for the nuclide ^{93}Zr.*
- *30 GBq/a for the nuclide ^{59}Ni.*
- *100 GBq/a for the nuclides ^{107}Pd and ^{151}Sm.*

These constraints apply to activity releases which arise from the expected evolution scenarios and which may enter the environment not until after several thousands of years. These activity releases can be averaged over 1 000 years at the most. The sum of the ratios between the nuclide specific activity releases and the respective constraints shall be less than one.

The selected approach means that the regulator has taken upon him the consideration of the impacts in biosphere from the releases of disposed radionuclides, and the implementer need not to consider the bio-scenarios when preparing its safety case for the time period discussed. The approach also means that more weight is put on the overall impact and less on peak impacts arising from the waste disposal. The given constraints are primarily derived on the basis of reference biosphere calculations. Besides that, some comparisons with fluxes of natural radionuclides in various scales were made in order to check the validity of the constraints and to have a more diverse standpoint on the issue.

The Farthest Future

In a time period of about 250 000 years, the activity in spent nuclear fuel becomes equal to that in the natural uranium from which the fuel was fabricated. In that time frame, the hazard posed by a spent fuel repository will be comparable to that of a medium sized natural uranium deposit and the repository might be regarded as being part of the nature. Also, the peak impact from disposal is expected to arise within the time period up to one million years, because in that time frame the containment provided by engineered barriers is assumed to be lost and there are no factors which would give rise to substantial increases in radiation exposure. Accordingly, beyond about one million years, the regulations do not require any rigorous quantitative safety assessments, but the judgement of safety can be based on more qualitative considerations, such as bounding analyses with simplified methods, comparisons with natural analogues and observations of the geological history of the site.



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