Session 6

Human Actions

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Assessing the Effects of Human Action on the Safety of Geologic Disposal: The U.S. Regulatory Experience

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There is general agreement that geologic disposal of long-lived radioactive waste provides the greatest degree of isolation from the biosphere, and hence the greatest protection for humans, over the extended time frames during which the waste presents a hazard. Geologic disposal has an additional advantage in that it does not rely on active institutional controls to maintain and protect the facility, but is instead intended to operate passively even if all knowledge of the facility is lost. Thus, geologic disposal does not rely on the questionable assumption that governmental or other responsible institutions can be maintained in perpetuity; this, however, also raises the possibility that some future human action could be taken that disrupts the repository and compromises its ability to isolate the radioactive material. It is clear, therefore, that some evaluation of this possibility must be included in the overall safety case for the facility. The nature and extent of the analysis, as well as the relative importance it is assigned within the safety case, is less clear.

The U.S. Environmental Protection Agency (EPA) has applied two very different approaches to the analysis of human intrusion scenarios at geologic disposal facilities. For the Waste Isolation Pilot Plant (WIPP) in New Mexico, which accepts transuranic radioactive waste from government defence activities, realistic drilling and mining scenarios are analyzed as part of the safety assessment addressing the natural (undisturbed) evolution of the repository. (40 CFR 194.32 and 194.33) For the proposed repository for spent nuclear fuel and high-level radioactive waste at Yucca Mountain, Nevada, however, a specified stylised drilling scenario is analyzed separately from the safety assessment for the undisturbed evolution of the disposal system. (40 CFR 197.25)

What is the basis for these different approaches? How can they both be “right”? The answer lies in the details of the two facilities, specifically in the:

- Characteristics of the site, including historical exploitation of mineral resources.
- Design of the disposal facility.
- Legislative framework.

WIPP

WIPP is located in a salt bed in south eastern New Mexico. Although the salt has not been extensively mined, the region has historically been widely subjected to drilling for oil and gas, as well as mined for potash. Potash mines can in fact be seen adjacent to the WIPP site. EPA therefore required that deep and shallow drilling scenarios be developed that are consistent with the historical rates and types of drilling performed in the area. EPA also required that mining scenarios consistent with historical mining operations be assessed for their effect on the hydraulic conductivity of the hydro geological units affecting the WIPP.

EPA also considered the design of the disposal system, specifically the waste package. Most of the waste being disposed of at WIPP can be contact-handled because of its low gamma content. This

fact, coupled with the enveloping nature of the salt medium, means that it is not necessary for waste packages to be highly engineered for strength or shielding. In fact, the waste packages at WIPP are not considered an engineered barrier. EPA determined that the waste packages would provide little resistance to a drilling penetration, but such a penetration would represent the most likely scenario leading to releases of radionuclides to the accessible environment. As a result, the effects of drilling and mining are required to be incorporated into a probabilistic analysis along with the natural features, events and processes occurring at the site.

Yucca Mountain

By contrast, the Yucca Mountain site is in a desert location at which no mineral resources have been located. Yucca Mountain is at the top of a ridge composed of tuff, formed by volcanic activity roughly 10 to 12 million years ago. Significant ground-water resources do flow beneath Yucca Mountain; however, ground water is much closer to the surface and more accessible at distances of 18 km or more. Therefore, it is unlikely that a person would try to withdraw water from a point above the repository.

EPA was directed by the Energy Policy Act of 1992 (EnPA) to obtain advice from the National Academy of Sciences (NAS) regarding reasonable standards to protect public health and safety at Yucca Mountain. EPA's standards are to be "based upon and consistent with" the findings and recommendations of the NAS. The EnPA asked NAS two specific questions regarding the potential for human intrusion into the repository:

- Whether it is reasonable to assume that a system of post-closure oversight can be developed, based upon active institutional controls, that will prevent an unreasonable risk of breaching the repository's engineered or geologic barriers; and
- Whether it is possible to make scientifically supportable predictions of the probability that the repository's engineered or geologic barriers will be breached as a result of human intrusion.

NAS concluded that active institutional controls could not be maintained for a sufficiently long period to prevent an intrusion from occurring, nor would it be possible to make scientifically supportable predictions of the probability of such intrusions occurring, when they might occur, and for what purpose. NAS recommended, however, that a stylised intrusion scenario be evaluated to test the "resilience" of the repository. NAS suggested a scenario involving a single penetration through a waste package and into the aquifer, using water-well drilling technology employed today. NAS further recommended that this scenario be analyzed separately from the probabilistic analysis of the undisturbed (natural) evolution of the disposal system. EPA adopted these recommendations. EPA specified that the intrusion should be assumed to occur at the earliest time that a waste package would be sufficiently degraded so that such a penetration would go unnoticed by the driller. EPA included this provision because, unlike at WIPP, the waste packages for Yucca Mountain are highly engineered and robust to resist heat, physical impacts and corrosion. As designed, it is likely that they would provide significant resistance to drilling for several thousand years at least.

As these examples show, the appropriate analysis of human intrusion in the safety case for geologic disposal may be derived from situation-specific details regarding the site, the facility design and the legislative framework, as well as other aspects not addressed here. In this sense, a "one size fits all" approach to future human action may not actually fit the specific situation. The examples discussed above both incorporate the fundamental assumption that technologies used in a future intrusion will be the same as those employed today or historically. This assumption may not be universally accepted and should be considered along with assumptions regarding the predictability of future human lifestyles and locations, as well as potential advances in medical and other technologies.

IGSC Perspective on Human Intrusion

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Background and Concept

The Integration Group for the Safety Case (IGSC) is the technical advisory body to the Radioactive Waste Management Committee (RWMC) of the Nuclear Energy Agency (NEA). The IGSC updated its Programme of Work in 2007 (NEA, 2007). The process raised a number of issues that IGSC recommended RWMC-RF to consider for further discussion. These include issues related to human intrusion**.**

The NEA previously addressed the issue of safety assessment of human intrusion during several projects in the 1980s and 1990s (NEA, 1989, 1993, 1995). This issue was also examined in more recent publications, including that from the INTESC (International Experiences in Safety Cases) Initiative (NEA, 2009a, 2009b). Since the start of these projects, there have been no significant developments in the methodologies to address human intrusion in safety cases.

As described in the next sections, these projects show that there is **agreement at a conceptual level** on the treatment of human intrusion in safety cases. However, no single approach to deal with human intrusion in a safety case is widely accepted (i.e. it is not possible to say that the issue is "closed"). The approach adopted in a given national programme is based mainly on policy considerations and does not depend heavily on scientific determinations or information (see e.g. NAS, 1995). The requirements and constraints for considering human intrusion, therefore, are **largely specified in regulations and in many national programmes**, relatively few, or no, aspects are left to the discretion of the implementer.

Furthermore, human intrusion is a sensitive issue for many programmes. It can be an issue of high interest to stakeholders, and decisions on approaches are normally undertaken with considerable consultation – those who have taken such decisions are generally satisfied with the approaches and would not support work that might undermine or re-open the issue. Thus, a detailed re-examination of safety assessment of human intrusion and of the conclusions that have been reached previously is not a priority. Nevertheless, there remain open questions and details to be addressed regarding the treatment of human intrusion in safety cases and the specification of key parameters. Depending on the extent to which human intrusion is addressed in regulations, the responsibility for addressing such questions may rest with either the regulatory agency or the implementer. These implementation issues are of interest to IGSC and could benefit from international discussion and information sharing.

Conceptual Agreement and Approaches for Safety Assessment

A geological repository is designed, in principle, to minimise the risk of human intrusion (i.e. the concept itself, which isolates waste far underground). The process of optimisation allows the application of measures to address human intrusion in terms of the probability or the consequences.

Examples of such processes include siting criteria to avoid natural resources, design features and institutional controls or markers. Nevertheless, the possibility of human intrusion can never be completely excluded: it is an unavoidable consequence of applying the "concentrate and confine" principle and must be considered.

In safety assessment, most regulators accept a treatment of future human action separate from the base case. Furthermore, regulators generally accept stylised approaches for assessing future human actions. Because the requirements and constraints for considering human intrusion are largely stylised, many aspects may be specified in regulations; in many national programmes, relatively few (or no) aspects are left to the discretion of the implementer.

However, the extent of stylisation varies, as does the degree to which the scenarios and parameters as well as consequence assessment and evaluation are specified in regulation. In terms of the scenarios, most national programmes exclude consideration of deliberate or "advertent" intrusion and focus on inadvertent intrusion.

Aspects Relevant to IGSC

Consensus on the conceptual approach to human intrusion has changed little over the succeeding decades since NEA examined the issue in detail, and there have been no significant changes or advances in the general methodologies to address or model human intrusion in safety cases. However, programmes continue to grapple with this issue in setting regulations for long-term safety of geological disposal. For programmes seeking to implement requirements, there remain open questions and details to be addressed regarding the treatment of human intrusion in safety cases and the specification of key parameters. Furthermore, there is ongoing discussion of what practical measures can be taken to reduce the chances or consequences of human intrusion, and how these are treated in safety assessment and in the broader safety case. The IGSC identified some key aspects of interest in this regard:

- Accounting for human intrusion aspects when designing the layout of the repository and other engineering and architectural aspects (which has some relation to the concepts of optimisation and "best available techniques" as applied in many programmes) :
  - What potential counter-measures may be considered (e.g. increased repository depth, more robust engineered barriers, intrusion shields, artificial underground markers (acoustic, magnetic, radioactive...), etc.)?
  - How are these seen to relate to the concepts of "optimisation" and "BAT (best available techniques)", as applied in many programmes?
  - An issue is "retrievable" concepts or post-closure monitoring measures that may introduce potential intrusion pathways.
- The design of long-term institutional controls and markers. This could include technological advances in materials that might be used in markers, as well as emerging ideas regarding memory/record preservation:
  - What technological advances have been made in materials that might be used in markers?
  - What are emerging ideas regarding memory/record preservation?
  - What credit should be given in safety assessment in terms of reducing or eliminating the chances of human intrusion, or changing the mechanisms of intrusion considered in safety assessments?
  - Could markers actually increase the risk of intrusion if knowledge preservation fails?
- How safety cases take account of institutional controls (if at all) in terms of reducing or eliminating the chances of human intrusion, or changing the mechanisms of intrusion considered in safety assessments.

- Factors considered in stylised scenarios:
  - What types or methods of intrusion are considered?
    - What methods and data are used to establish parameters to allow quantification of the intrusion scenario(s)?
    - To what degree are these specified in regulation or left to the implementer?
  - When is intrusion considered to be possible?
    - What factors are considered in this regard (i.e. institutional controls, package integrity, etc.)?
- Deliberate human intrusion:
  - Should not be addressed as scenarios in safety assessment, but possibly need for some discussion at general level.
  - Closely related to safeguards and retrievability for some wastes / repository concepts.
- Consideration of consequences:
  - What consequences are considered?
    - Are doses to the intruder considered?
    - Are doses to the public considered? From direct exposures of the intrusion, or from consequence of the intrusion process on containment capability?
    - Are there other aspects of performance considered?
  - What regulatory criteria are used to judge acceptability?
    - Any regulatory policy should be defended by philosophical and ethical arguments.

Summary

Human intrusion remains an issue of high interest in safety cases, especially in terms of implementation in safety assessment. The aspects noted above may benefit from international discussion. Some issues might deserve further attention in regulations and would benefit, in particular, from discussion among regulators (such as at the Regulators' Forum). Based on the IGSC observations and discussions, the following key questions can be raised to investigate whether there is still consensus on the areas of agreement and to understand how thinking has evolved:

- Should regulations require measures to reduce the likelihood or consequences of human intrusion? What "credit" can be taken for such measures? Is there new thinking or methods in terms of memory and markers?
- What types of stylised human intrusion should be considered in a safety case? What are the roles of the regulator and implementer in doing so?
- What consequences should be considered? What are the protection criteria against which to assess human intrusion scenarios?
- Are the answers to any of these questions site-, culture-, concept- or waste-specific?

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German Viewpoints on the Integration of Human Intrusion Scenarios in Safety Cases

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Introduction

There is a broad consensus that site selection, repository design, construction and closure should require measures aiming at a reduction of both the likelihood and consequences of human intrusion. Documentation of the repository position and its radiologic potential, the application of markers, the depth of the geological formation as well as keeping a distance to resources that could be of potential interest for future generations are typically regarded as appropriate measures. Because of the differing disposal concepts, site conditions and regulatory frameworks in several countries, safety requirements for dealing with human intrusion differ substantially across countries and internationally.

In Germany, two documents apply primarily concerning the treatment of human intrusion scenarios in a safety case:

- BMU Draft Guideline: "*Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste*" [1].
- Working Group on "Scenario Development":[1] "*Position of the Working Group on 'Scenario Development': Handling of human intrusion into a repository for radioactive waste in deep geological formations*," [2].

As to the first: The BMU presented this draft to the public in November 2008. It represents a proposed update of the regulatory "Safety Criteria" for the disposal of radioactive wastes in geological formations that were issued in 1983. At present, the draft is being revised by the German "Entsorgungskommmission" (Commission on Final Management), an advisory body of the BMU. In this draft regulation, the treatment of human intrusion is described in several chapters, particularly in connection with the fulfilment of safety goals within the framework of the safety case. The associated requirements are stated below.

As to the second: The Working Group on "Scenario Development" has elaborated a common position for the treatment of human intrusion which focuses on essential aspects of the topic and provides recommendations. This position paper deals with the question of how the possibility of human intrusion into a repository after its closure can be considered in a safety case.

The BMU Draft Guideline

Regarding human intrusion, the following three main requirements are addressed in the guideline.

Reduction of Likelihood of Human Intrusion

It is to be ensured that in the first 500 years after closure of the repository, information about its situation and existence should be maintained in a way that competent authorities are able to bring the

1. Members from BfS, BGR, GRS, DBE-TEC, FZK-INE and IELF TU Clausthal.

knowledge to attention. Thus all activities/measures are to be prevented for this period that could endanger the permanent isolation and containment of the radioactive wastes in the repository. Beyond that it is to be ensured that the knowledge about the presence of the repository remains permanently available, if possible.

It has to be demonstrated by the applicant to what extent possibilities of reducing the likelihood of unintentional human intrusion into the isolating rock zone has been taken into account during the site selection and the design, and development of the repository. These measures must not impair long-term safety.

- …"*The applicant shall also outline the extent to which the site designation and design of the final repository take advantage of all currently foreseeable opportunities for reducing the likelihood of unintentional human intrusion into the isolating rock zone of the final repository and the effects thereof, as well as confirming that this design does not impair the long-term safety of the repository system as long as it remains undisturbed by human intrusion*." [6.3]
- "*It has to be taken into account, that suspected use of the site as a raw material source or any form of use could increase the likelihood of human activity (drilling, driving, flooring of caverns)*." [Comments to 8.7]

Specification of reference scenarios

The draft guideline of the BMU requires that *reference scenarios*[2] for human intrusion and optimisation requirements to reduce the associated risk should be drawn.

- "*The radiological and other consequences of unintentional human intrusion should be analysed using reference scenarios based on current common human activities*." [8.7]

Radiation protection criteria

Specific protection criteria for human activities which unintentionally affect repository barriers are not prescribed in the draft guideline of the BMU, since neither the probability nor the type of impacts can be assessed with an adequate degree of reliability. In detail, the draft requires:

- "*High levels of radiation exposure >10 mSv/a that would effect a large number of people living in the vicinity [of the repository site] are to be avoided where possible*." [Comments to 8.7]
- "*No protection criterion is prescribed for people who come into direct contact e.g. by drilling into a waste container*." [Comments to 8.7]

Recommendation of the Working Group on Scenario Development

The Working Group defines human intrusion in the following way:

- "*Human intrusion (HI) is understood as any human activity after the closure of the repository mine that will directly damage the barriers within the backfilled and sealed mine workings and the isolating rock zone*."
- "*Human intrusion is considered as inadvertent if the awareness of the repository and the knowledge of the hazard potential of the waste emplaced have been lost. In the case of intentional intrusion, society is still aware of the repository and its hazard potential*."

2. Reference scenarios = stylised scenarios.

- "*…it is exclusively inadvertent intrusion that the safety case has to deal with. Intentional intrusion can only be placed in the responsibility of the respective acting society*."

Regarding suitable and effective measures against unintended human intrusion, the Working Group comes to the following conclusions.

Effective Measures Against Unintentional Human Intrusion

The Working Group holds the view, that:

- "*…suitable and appropriate measures have to be taken upon the planning and construction of a licensed repository in the future that hinder or prevent inadvertent human intrusion and/or reduce the consequences. These measures must not impair the safety of the repository.*"
- "*…the most effective measures against inadvertent intrusion consist of establishing the repository in deep geological formations and providing knowledge maintenance in the long run. This limits the possibility of inadvertent human intrusion and the occurrence of the resulting consequences.*"
- "*…the knowledge of the repository site and the hazard potential originated by the repository can be maintained over a period of several hundreds of years and be brought to the attention of those acting in case of any activities at the repository site. Based on documentation from German mining archives that are still in use and preserved to this day, a time span of 500 years can be assumed in this respect.*"

Treatment of Human Intrusion in a Safety Case

The Working Group holds the view that the evolution, way of life, and behaviour of the society, including human intrusion, cannot be predicted over time frames that have to be considered for the isolation period of radioactive wastes. Therefore human intrusion into the repository system cannot be excluded. Based on this assumption, the Working Group proposes that

- "*…human intrusion has to be treated with due consideration in the safety case. It is exclusively inadvertent intrusion that the safety case has to deal with*."
- *"…inadvertent human intrusion should only be assumed to take place after at least 500 years*."
- "*A comprehensive study of human intrusion on the basis of a systematic scenario development would require a not feasible prediction of human actions as well as of the state of the art in science and technology of future generations. Therefore the issue of HI has to be treated apart from the systematic scenario development and thus has to be dealt with separately in the safety case*."

Specification of Scenarios

The Working Group holds the view that selected scenarios shall be used for the purpose of balancing measures aimed at reducing consequences. These HI scenarios have to be derived based on the specific repository plans and site conditions. The HI scenarios need not be encompassing or conservative. In particular, the Working Group recommends that

- "*The spectrum of HI scenarios should be appropriately limited, e.g. for the host rock "salt" to exploratory drilling, the construction of a mine, and solution mining of caverns.*"
- "*The boundary conditions for the derivation of such scenarios have to be determined on a regulatory basis e.g. in a guideline.*"

Radiological Consequences

The Working Group holds the view that

- "*With the decision for the concept of concentrating and isolating the radioactive waste in a repository, the possibility inevitably has to be accepted that radiation exposure limits may be exceeded in the event of intrusion into the repository.*"
- "*…it is not possible to quantify appropriately the consequences associated with human intrusion due to the lack of predictability of the boundary conditions and other parameters to be assumed.*"

Conclusions

Both documents coincide regarding the following recommendations:

- Only inadvertent human intrusion has to be treated in the safety case.
- The reduction of the likelihood of HI can be ensured by information maintenance, and intrinsically, by a strategy of deep disposal.
- There is no possibility for stipulating protection criteria since human behaviour in the distant future is absolutely speculative.
- A limited number of selected (stylised) scenarios based on current human activities and technical abilities have to be treated in the safety case. A Guideline with specifications of reference scenarios for human intrusion is regarded as helpful but is not yet available today.

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Means to Reduce Human Activities at the Site: Markers, Records…Where Do We Stand?

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Background

SKB has been assigned the task of managing and disposing the spent nuclear fuel (timescale – 100 000 years) and a draft action plan for long-term preservation of information about the repository will be presented in connection with the siting applications in 2010. The draft action plan should contain:

- Proposals on procedures for how the plan can be kept up to date.
- Suggestions for how the implementation of information preservation can be done.

The responsibility for implementing the action plan rests with the industry, SKB, until the closure of the disposal facilities. Thereafter, the responsibility for the repository, and its action plan for preservation of information, is expected to go to the State.

Aims of Information Preservation

The aims can be articulated depending on timeframes:

- In the longer term:
  - To avoid damage by accident.
  - To allow for our generation and future generations to make decisions based on knowledge (use of the site, withdrawal of spent fuel…).
- In the shorter term:
  - To manage today's knowledge and information so that the long-term goals can be reached.

What Information Is of Interest to Preserve?

Regarding facts and know-how, it would be important to preserve information:

- Vital to safety, environmental protection and licensing.
- Facilitating possible further development.
- Of great scientific or social interest.
- On location and site information.
- On design, structure and properties of the repository.
- On the properties and content of radioactive waste and other substance.
- On results from and data used in safety analysis.

Regarding the time horizons to be addressed, these are:

- Today and near future.
- At the time of decommissioning and closing of facilities.
- Far future.
- Very far future.

Attention to Potential Incidents

The action plan should address potential events or incidents that threaten the integrity and use of preserved information. A currently-identified set of events and corrective actions is reported in Table 1.

Table 1. **Potential Incidents and Corrective Measures Regarding Preservation of Information**

Incident	Consequence	Measure
War/sabotage (Political)	File or markers are destroyed or degraded.	Geographic redundancy of archives.
Society continuity breaks (Political)	Loss of authority facts.	Geographic redundancy of archives. Markers.
Information preservation poorly performed (Social)	Information is destroyed entirely or partly.	Long-term mandate with clear responsibilities.
Change of language and importance of markers (Social)	Misinterpretation can lead to wrong behaviour.	Regular update and revision of archives and markers.
Environmental changes (Environment)	File or markers damaged or lost.	Geographic redundancy of archives.
Degradation of the medium (Technical)	Misinterpretations.	Update medium. Several media, markers and archives.

Target Groups

The plan should address specific target groups of individuals or institutions, such as:

- Planners and developers of new facilities (e.g. Mines).
- Politicians, decision-makers.
- Waste management companies, energy companies.
- Scientists;
- Members of the public, nearby residents.

Strategies for Preservation

Two alternative tracks:

- From generation to generation.
- Directly to a distant future.

From Generation to Generation

- Media and projected lifetime.
- Paper, 200-1 000 years.
- Microfilm, 200-300 years.
- Video, cd, dvd, discs, approximately 10 years.
- Magnetic media, (data) approximately 10 years.

Examples of preserved archives:

- Vatican archives.
- Parish registers and population registers(Sweden).
- Runestones and petroglyphs.
- Cave paintings and pyramids.

About the Upcoming Draft Action Plan

A draft action plan for long-term preservation of information about the repository will be presented in connection with the applications 2010.

The draft action plan should contain:

- Proposals on procedures for how the plan can be kept up to date.
- Suggestions for how the implementation of information preservation can be done.

Included Parts to the Draft Action

What should be preserved? (Information with focus on the content of the canisters and location of the repository).

Where should it be preserved? (In established archives, in connection to the repository, as markers in the landscape, in the collective memory).

How should it be preserved? (Format, language and medium).

Key Actions to Handle in the Action Plan

- Clear responsibility for collection, updating and revision of information.
- The most serious consequences:
  - Information disappears physically (physical loss).
  - The information is available physically, but cannot be understood or interpreted (epistemic loss).
- Main measures
  - International co-operation.
  - Geographical redundancy of information (archives).
  - Markers.

Table 2. **An International Perspective**

Country	Organisation	Focus for information preservation
Finland	Posiva	Successive transfer (archives), following the international development (IAEA)
USA	DOE	Successive transfer (archives) and direct transfer (markers)
Great Britain	NDA	Successive transfer (archives – NNA in Scotland), Contextual Information Frameworks (CIF)
Switzerland	NAGRA	Successive transfer (archives)
Germany	BfS	Successive transfer (archives)
Japan	NUMO	Successive transfer (archives) and direct transfer (markers), medium (silicon carbide)
France	ANDRA	Successive transfer (archives) and direct transfer (markers)
	IAEA	Successive transfer (archives), Contextual Information Frameworks (CIF)
	NEA	Recent work in the area of cultural markers

International co-operation:

SKB is receptive to international co-operation, for example under the umbrella of IAEA or NEA

Examples of earlier co-operation:

- KAN-Nordic co-operation 1990-1993.
- Conferences and reports under the umbrella of IAEA.

Coming: International task group for co-operation?