4.3.3. Assess the effects of future human actions, Domain Insight

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Overview

This domain is a part of the sub-theme 4.3 “Provide or confirm a description of the expected evolution of the geosphere (including the repository) in response to natural processes and future human actions (Long-term stability)”. It deals with the consideration of human actions that could affect deep geological repositories after their final closure, how they are taken into account in the safety assessment and the implications for the design, construction, operation and post-closure monitoring of these facilities.

Keywords

Scenario

Human action

Inadvertent human intrusion

Key Acronyms

DGR = deep geological repository

IHI = Inadvertent human intrusion

IHIS = Inadvertent human intrusion scenario

NES = Normal Evolution Scenario

AES = Altered Evolution Scenario

Definitions

IAEA Safety Standards Series No. SSR-5 provides some definitions. In addition, the following definitions help to highlight the different types of human actions that are to be considered:

- **Human actions:** Any future action related to repositories, carried out by humans, intrusive or not, and likely to alter the performance of the disposal system for the protection of man and the environment.
- **Ordinary human action:** Human action such as house building, road works, etc. that does not require major technological or industrial capabilities. Its impact is limited to a few tens of meters in depth (e.g., geotechnical drilling prior to building a house). Several hundred meters deep boreholes are excluded from ordinary human actions, regardless of their purpose (prospection, geothermal development, etc.). As a result, deep geological repositories (DGRs) are not affected by ordinary human actions.

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- **Inadvertent Human Intrusion (IHI):** Human action that directly impacts the integrity of a disposal facility (packages, cells, engineered barriers, intact or fractured geological medium close to the repository) with possible radiological consequences for the operator who is not aware of the presence of the repository or the associated risk prior to the intrusion. IHI can lead to different types of consequences in terms of impact:
    - **Direct impact** (external exposure, contamination, etc.) on individuals involved in the intrusion (archaeologists, drillers, road or tunnel workers, etc.). The use of excavated radioactive material (e.g., residential building on a contaminated ground) can also generate direct, chronic and delayed impacts.
    - **Indirect impact** of the intrusion that impairs the performance of the repository by creating a short circuit (abandoned borehole, etc.). The water transfer of radionuclides and toxic species resulting from intrusion generates a chronic impact.
- **Inadvertent human intrusion scenario (IHIS):** Scenario that considers a series of events, including at least an intrusion that causes failure of the waste containment safety function. This scenario affects humans by impairing the functionality of the disposal facility. Its purpose is to provide a quantitative assessment of the consequences of the loss of the "waste containment" safety function. IHIS may also involve natural events (erosion, etc.).

Foreword

In addition to the definitions given above, different types of future human action can be considered:

- **Post-closure human actions that enhance safety:** Some future human activities aim to protect radioactive waste repositories from intrusion. This concerns, for instance, active control (on-site surveillance to prevent access to the facility and monitoring the state of the facility after its closure) or passive control (maintaining an institutional memory).
  This topic, which may not be addressed in any other DI document and which is handled in a specific manner in DGRs, is briefly presented hereafter.
- **Long-term societal development:** The assumptions made to represent the evolution of human society, which is likely to influence the long-term impact of the DGR (e.g., emergence of a self-sufficient agricultural society, with technological knowledge and resources equivalent to the current ones, adaptation to climate change, etc.), and their integration into the safety assessment.
  This DI outlines the description of the evolution of society, which is essential for the definition of post-closure safety scenarios. This topic is also addressed by the DI *4.1.3 - Biosphere model*.
- **Unintentional human intrusions and indirect actions:** Refers to the way human actions that may impair the performance of DGRs. These human actions can be direct (human intrusions) or indirect (aquifer pumping). Human intrusions are commonly studied. In addition to intrusion scenarios, non-intrusive human actions must also be taken into account to assess the other post-closure safety scenarios.

1. Typical overall goals and activities in the domain of assessment of the effects of future human actions

This section provides the overall goal for the domain human actions, extracted from the EURAD Roadmap goals breakdown structure (GBS). This is supplemented by typical activities, according to the phase of implementation, needed to achieve the domain goal. Typical activities are generic and are common to most geological disposal programmes. The domain goal addressed in the following table exclusively refers to inadvertent human intrusions, while the current document deals with future human actions in general.

Domain Goal	
4.3.3 Assess the effects of future human actions (human intrusion by exploration activities, exploitation of natural resources within, above and below the host rock).	
Domain Activities	
Phase 1: Programme Initiation	Need for action: The knowledge of the existing or to be produced radioactive waste inventory enables, in countries where various repository types are available, to determine which wastes need to be disposed of in a DGR (long-lived wastes) and which ones can be disposed of in near-surface facilities (low-level and short-lived wastes).

Phase 2: DGR Site Identification Phase 3: DGR Site Characterisation	The selected site contributes to the long-term safety performance of the DGR. Site selection shall include criteria aiming to minimise the risks of unwanted future human action (e.g., no known valuable natural resources, no geothermal interest, etc.). On the contrary, the lack of surface or near-surface water may increase the risk of future deep prospection.
Phase 4: DGR Construction	Depth, design and construction features can significantly reduce the risk of unintentional intrusion into the DGR. However, they must not impair operation and post-closure safety. If possible, the use of valuable resources (high-value metals) should be limited to deep facilities to limit the risk of deliberate intrusion for recycling.
Phase 5: DGR Operation and Closure	The underground facility is closed to contain radioactive waste in the disposal system and delay radionuclide transfer to the biosphere and particularly to water resources. The use of deterrent markings is conceivable, but it should also be considered that they may arouse the curiosity of future generations, which might be counterproductive.

2. Contribution to generic safety functions and implementation goals

"Isolating waste from humans and the environment" and "contain radionuclide into the disposal system" are the major safety functions of radioactive waste repositories. To achieve these functions, consideration shall be given to:

- Limit the risk of waste coming into contact with the human environment due to natural events, at least during its radioactive period, for example by opting for a DGR. The risk of external hazards caused by natural events is dealt with in DI *4.3.1 - Geological and tectonic evolution* which analyses the expected geological and tectonic evolution and the risk of disruptive natural events, and assesses their impacts on the stability of the natural barrier.
- Prevent the risk of human actions that may occur after the human society is no longer aware of the repository's existence and its hazardous nature.

As the first point does not involve any human action, only the second point will be discussed further:

High-level long-term safety goal (Claims)	Tag used in EURAD roadmap documents to link to safety goal	Tag used in EURAD roadmap documents to link to safety goal	Features, characteristics, or properties of the system and / or its components that contribute to achieving the high-level safety goal: this can lead to the identification of safety functions (Argument)	Measurable or quantifiable parameter used for specification of safety function and input to design (Evidence)
Ensure isolation of waste from people and the accessible biosphere.	ISOLATION	GEOLOGICAL BARRIER	The DGR is sited, designed and implemented to isolate the waste from the human environment for thousands of years, in a stable environment unlikely to be disturbed by human activities, even if the location of the disposal facility is forgotten	• Location at an appropriate depth in a stable geological formation provides protection of the facility from the disruptive effects of geomorphological processes such as erosion and glaciation. • Location away from known areas of underground mineral resources and other valuable resources will reduce the likelihood of inadvertent disturbance of the geological disposal facility.

This global objective (Ensure isolation of waste from people and the accessible biosphere) can be addressed through several statements:

One of the objectives of the DGRs is to limit the risk of unintentional human intrusion.

The depth of the repository helps to fulfil the long-term protection function against erosion and to reduce the risk of human intrusion after the end of the monitoring phase. In most countries, DGRs are designed for the most hazardous and long-lived radioactive wastes, while the radioactive decay makes it possible to handle short-lived / low or middle activity wastes in surface repositories.

The choice of a site with no known valuable resources reduces the risk of mining, water pumping, geothermal drilling, etc. However, resources that are not considered valuable today may become valuable in the future. For example, a geological formation suitable for a DGR may become suitable for future deep-bore disposals.

The risk of unintentional human intrusion is also minimised by surveying the disposal facility and perpetuating the memory (of its existence and its danger).

However, the risk of human intrusion cannot be totally ruled out.

The memory of the presence of a disposal facility cannot be preserved indefinitely (see Eckhard, 2020). Intrusion scenarios must be considered "inexorable" for surface repositories after their radioactive decay, but they are thought to be minimised for DGRs.

Exploration and research boreholes may be drilled even in absence of known natural resources, especially as unknown resources may become valuable and underground mining can become easier.

Inadvertent human intrusion scenarios are defined to assess the potential consequences and to challenge the robustness of the concept.

The design of DGRs may limit their potential consequences (e.g., through compartmentalisation).

Some scenarios also consider that the boreholes are not properly backfilled, thus contaminating the surrounding aquifers.

Some other reasons like the total loss of memory/information because of a deep-rooted social crisis or misinterpreted or misjudged information for unintentional human intrusion are listed in Eckhard (2020).

In addition, uncertainties concerning the evolution of the human society can also be qualified as "future human actions" that must be accounted for.

It is generally accepted that non-intrusive human actions and societal aspects that may worsen the performance of the disposal system must be considered for all long-term post-closure scenarios (see DI *7.3.3 - Scenario development and FEP analysis*)

As it is the future human society that would suffer the most serious impact, whatever the long-term post-closure scenarios, the target population is an agrarian group that uses water, has the technology to drill boreholes, but is not aware of the dangerousness of radioactive waste (see DI *4.1.3 - Biosphere model*).

As recommended by SSG-23 (see chapter 3.1), deliberate intrusions (knowing the presence of the DGR and its threat) and criminal actions are not handled in post-closure safety assessment.

The goal to "ensure long-term stability with respect to external events and environmental evolution" is not linked to human activity:

The design of a DGR makes it possible to prevent the effects of erosion, including anthropogenic effects (climate change) linked to human activity. It is generally accepted that a depth of a few tens to hundreds of meters provides protection against erosion and climatic hazards, depending on the uplift / erosion rate.

The site identification is based on a thorough investigation, thus preventing the occurrence of unknown faults or active seismic structures. As seismic risks are not caused by human actions, they are not discussed in this document. These subjects are dealt with as parts of domain insight documents *4.3.1 - Geological and tectonic evolution* and *4.3.2. - Climate change*.

3. International examples of future human actions

3.1 International standards and recommendations about future human actions

All international standards and recommendations agree that, in view to reduce the risk of intrusion, DGR designers and operators have to:

- Choose a site considering the potential occurrence of natural valuable resources;
- Build up several barriers between humans, their environment and the waste (analogous to the in-depth-defence principle);

- Implement surveillance beyond the administrative closure of the repository in order to extend the protection of humans and the environment from the waste as the short-lived radionuclides decay (which does not apply to DGRs);
- set up a memory programme so that the existence of the closed repository and the hazardous nature of the waste are known, thus postponing the risk of inadvertent intrusion.

In addition to these general requirements, the following paragraphs summarise international standards and recommendations about future human actions.

IAEA, Disposal of Radioactive Waste, Specific Safety Requirements No. SSR-5, Vienna, 2011

- Safety standard for the protection of people and the environment related to the disposal of radioactive waste, prescriptive for all IAEA member states,
- Considers that the available technological development for long-term scenarios should be taken as equivalent to current technology,
- Defines human intrusions as "*human actions that affect the integrity of a disposal facility and which could potentially give rise to radiological consequences. Only those human actions that result in direct disturbance of the disposal facility (i.e., the waste itself, the contaminated near field or the engineered barrier materials) are considered"*.
- Sets a dose limit of 20 mSv/year for people living close to the site. If this limit is not fulfilled, other waste management options must be considered,
- Considers that deep geological disposal is the most effective technical solution for reducing the risk of inadvertent human intrusion.

IAEA, Geological Disposal Facilities for Radioactive Waste, Specific Safety Guide No. SSG-14, Vienna, 2011

- Focuses on the safety of radioactive waste geological repositories,
- Considers that the primary means for limiting the risk of inadvertent human intrusion are site selection and disposal depth,
- States that "*The safety assessment should include some stylised calculations of the consequences of inadvertent human intrusion into the closed disposal facility".*

IAEA, The Safety Case and Safety Assessment for the Disposal of Radioactive Waste, Specific Safety Guide, No. SSG-23, Vienna, 2012

- Lists the international standards applicable to the safety assessment of radioactive waste repositories,
- Separates surface repositories from deep geological repositories,
- Defines human intrusions: "*Only those human actions that result in direct disturbance of the disposal facility (i.e. the waste, the contaminated near field or the engineered barriers) are considered human intrusion*",
- States that *"intentional disruptive actions should not be considered in safety assessments*",

- According to SSG-23, *"human activities that reach depths greater than 30 m are much less likely, but include drilling (e.g., for water, oil or gas), exploration and mining activities, geothermal heat extraction or the storage of oil, gas or carbon dioxide",*
- Emphasises the waste's diversity and possible "hot spots" when assessing the potential impact of inadvertent human intrusions (relevant to the waste's acceptability in surface repositories),
- States that "*for geological disposal facilities, care should be taken when making quantitative use of the results obtained for human intrusion scenarios, in particular when comparing these to other scenarios (e.g*., *for purposes of* optimisation *of protection and design). The most effective measures against inadvertent intrusion involve establishing the disposal facility in deep geological formations and providing knowledge maintenance in the long term."*

ICRP, Radiological Protection in Geological Disposal of Long-lived Solid Radioactive Waste, ICRP Publication 122, Ann. ICRP 42(3), Elsevier (2013).

- States that "*the design-basis evolution of the geological disposal facility […] does not include either severe disturbing events of very low probability that may disrupt the facility, or inadvertent human intrusion*",
- Consequently, it does not apply any dose or risk constraints to IHIS (inadvertent human intrusion scenario),
- Recommends that the design of the disposal system limits the risk of intrusion: *"For inadvertent human intrusion, the design and siting of the facility should include features to reduce the possibility of such events*".

HIDRA

HIDRA was an international project dealing with Human Intrusion in the context of Disposal of RAdioactive waste, under the guidance of IAEA. It was carried out in 2 phases, the first of which has produced a draft report, which is available online (https://www-ns.iaea.org/downloads/rw/projects/hidra/hidra-draft-report.pdf) and the second was to implement the general methodology on generic sites based on a set of real data provided by the participants.

Here are some of HIDRA's recommendations:

- Concerning the relevance of the scenario considering worker exposure to a drilling core from the repository (e.g. a fragment of spent fuel or vitrified waste): Since the safety regulators require this scenario to be addressed, the resulting doses should be used to highlight the danger of high-level (HL) and intermediate- and low-level (IL-LL) waste and to explain the need for deep disposal,
- Indirect consequences of intrusions on the performance of the disposal facility: This scenario assumes that the intrusive borehole is not properly backfilled,
- Concerning the probabilistic approach: It is generally accepted that it is not possible to calculate the probability of an intrusion in the future, which means that inexorable and improbable

intrusions are considered at the same level. Participants discussed the concept of "relative probability" or "geometric probability" to account for the probability of a deep borehole intercepting a waste cell.

3.2 International examples of IHIS implementation

In addition to the HIDRA draft report, which provides a thorough overview of the handling of IHIS, the following documents have been published by WMOs or regulators. They describe the safety assessment of radioactive waste repositories.

- BMU (Germany), Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste, as of 30 September 2010.
- GRS (Germany), Studies relating to human intrusion into a repository, Report pertaining to Work Package 11, Preliminary Safety Case of the Gorleben Site, GRS – 280, ISBN 978-3-939355-56-4, 2014.
- NAGRA (Switzerland), NAGRA technical report 02-05, Project Opalinus Clay, Safety report, Demonstration of disposal feasibility for spent fuel, vitrified HL waste and long-lived intermediate-level waste (Entsorgungsnachweis), December 2002.
- SKB (Sweden), Handling of future human actions in the safety assessment SR-Site. Swedish Nuclear Fuel and Waste Management CO. Report TR-10-53, 2010.
- SSM (Sweden), SSMFS 2008:21, Regulatory Code; The Swedish Radiation Safety Authority’s regulations concerning safety in connection with the disposal of nuclear material and nuclear waste, ISSN 2000-0987, 2008.
- EA (United Kingdom) and NIEA (Northern Ireland), Geological Disposal Facilities on Land for Solid Radioactive Wastes Guidance on Requirements for Authorisation, UK, February 2009.
- Buser, M. 2010: Literaturstudie zum Stand der Markierung von geologischen Tiefenlagern. Bundesamt für Energie. Bern.
- ESK – Entsorgungskommission 2012: Guideline on human intrusion into a repository for radioactive waste.
- NEA – Nuclear Energy Agency 1999: Future human actions at disposal sites. A report of the NEA working group on future human actions at radioactive waste disposal sites. Paris.
- Posiva 2013: Human intruder dose assessment for deep geological disposal. Smith, G.M; Molinero, J; Delos A.; Valls, A.; Conesa, A.; Smith, K.; Hjerpe, T. Working report 2013-23. Helsinki.
- Andra (France), 2022 Dossier d’autorisation de création de l’installation nucléaire de base (INB) Cigéo PIECE 7 Version préliminaire du rapport de sûreté PARTIE III Démonstration de sûreté Volume 8 La démonstration de sûreté après fermeture Chapitre 10 (in french).
- Andra (France), 2016 Safety Options Report - Post-Closure Part (DOS-AF) Volume III Safety assessment Chapter 4 Inadvertent Human Intrusion Scenarios.

4. Integrated information, data or knowledge that impacts understanding of future human actions

Managing the risk of inadvertent human intrusion

Since geological disposal facilities are predominantly intended for HL and long-lived wastes (linked to sub-theme *1.5 Management Solutions*), an active control phase, even if extended to several centuries, will not sufficiently mitigate the potential effects of inadvertent human intrusions. The risk of post-closure inadvertent human intrusion can be analysed by differentiating active control, passive control and memory loss phases.

- During the active control phase, the societal control consists of a physical security at the disposal site. Therefore, inadvertent human intrusions can be excluded.
- During the passive control phase, the societal control consists of knowledge management, record keeping, land use restrictions and site markers. The design safety features are maintained and the inadvertent human intrusion is unlikely – major IHIS can be excluded from safety assessment.
- After the loss of memory, there is no longer any knowledge of the site's existence and its dangerousness. All safety barriers can fail, except depth, which remains the main feature that limits the risk of intrusion.

SSR5 points out that "*The specific aims of disposal are: (a) To contain the waste; (b) To isolate the waste from the accessible biosphere and to reduce substantially the likelihood of, and all possible consequences of, inadvertent human intrusion into the waste*". Human intrusions are taken into account by stylised scenarios that complement the safety scenarios assessed for the post-closure safety assessment (Normal Evolution Scenario (NES), Altered Evolution Scenario (AES) and possibly what-if scenarios). According to SSG23, "*only those human actions that result in direct disturbance of the disposal facility (i.e., the waste, the contaminated near field or the engineered barriers) are considered human intrusion […]*".

IHIS mainly concern surface repositories, as they can result from ordinary human actions, such as roadworks. In the scope of DGR projects or facilities, these scenarios are considered highly unlikely. They are nevertheless studied, for example as stylised scenarios. These scenarios do not aim to determine which wastes are acceptable since DGRs are designed to handle all types of waste, including HL – long-lived radioactive wastes, and their potential impact mainly reflects the dangerousness of the stored waste.

In the case of an inadvertent intrusive drilling, two contamination pathways can be considered:

- The direct impact on the workers who perform the intrusive drilling, since they are in direct contact with the waste cores extracted from the repository. Drilling cores also impact uninvolved persons and the environment far beyond the intrusion;

- The indirect impact that may result if the borehole is not properly sealed, creating a bypass through the geological formations, thus changing the geological environment of the repository and increasing transfers to the biosphere.

The latter is not always taken into account, as the assumption of an ineffective sealing is unlikely (given the current technologies and regulations) and its combination with the intrusion can be ruled out.

Deliberate intrusions

Deliberate acts that result in disruption of the facility are not addressed in post-closure safety assessment. There are, however, intermediate situations, such as the drilling operator who intercepts the facility and deliberately decides to continue drilling (this case is implicitly taken into account), or the scrap metal dealer who, unaware of the potential hazard, decides to drill in order to recover some valuable materials stored in the facility (this latter case is usually ruled out).

Dose threshold and design feedback

The dose thresholds defined by IAEA (SSR5) (1 mSv below which no consideration is necessary, and 20 mSv, above which the facility design must be improved) only apply to surface facilities (see SSG-23). However, ICRP 122 defines two cases for a DGR: an emergency (the driller must not be exposed to a dose exceeding 100 mSv) and indirect effects (water contamination caused by drilling must not lead to an exposure exceeding 20 mSv).

In addition, the study of IHIS contributes to the robustness of the safety demonstration and the analysis of these scenarios can lead to the optimisation of the disposal concept, such as compartmentalisation. It should be noted that this optimisation must neither impair disposal safety during operation and post-closure phases nor induce a substantial cost surplus (see GBS theme 5 - Disposal Facility Design and Optimisation). For example, the addition of a steel-based anti-intrusion barrier, which would increase the gas pressure caused by corrosion, is to be banned.

Managing human actions in other scenarios

According to SSG-23, human actions that do not cause any direct intrusion into the repository are not classified as IHIS. As they may enhance transfer of radionuclides and toxic species to humans and their environment, they must be taken into account in the assessment of other scenarios (NES, AES) if they are “reasonably probable”. For instance, this applies to the drilling of a well to pump water from an aquifer in contact with the DGR host formation, for drinking, animal watering or irrigation purposes.

5. Maturity of knowledge and technology

The following topics are further developed in the HIDRA draft report.

5.1 Advancement of safety case

As it is not possible to predict the evolution of society and human actions, the post-closure safety assessment is based on generic human intrusion scenarios, defined in accordance with the recommendations of SSR5, SSG-23 and ICRP-81. These scenarios are defined according to the context, the safety strategy, the waste types and the natural environment. Three contexts causing intrusion are considered: drilling (leading to direct exposure of workers during drilling, followed by the contamination of the water table), conventional mining (leading to direct exposure of miners, followed by the contamination of the water table) or non-conventional mining (leading to direct exposure of miners, followed by the contamination of injected products and the water table). As already mentioned, surface excavation is not taken into account for DGRs and intentional intrusions are not studied.

It should be noted that the results of IHIS are directly linked to the strategy of concentrating the most hazardous waste in a single DGR. These results, which correspond to basically improbable scenarios, (in contrast to the plausible scenarios identified in DI *7.3.3 - Scenario development and FEP analysis*), may be somewhat striking. These scenarios are considered as design extension scenarios and they are not to be compared with dose criteria. Nevertheless, some countries have chosen to demonstrate that potential impacts do not cause deterministic effects.

These results do not need to be taken into account in the facility design and the inventory of stored wastes (as DGR is the ultimate management option for the most hazardous wastes, see DI *2.1.2 - Waste Acceptance Criteria*). In any case, this feedback must not impair the performance of the facility in normal conditions. As a result, although the definition and conceptualisation of IHIS must be consistent with those of NES (see DI *5.1.4 - Design qualification*), there is no need to include conservative data choices that ensure maximising results.

Features designed to limit the potential impact of IHIS lie in the choice of site: depth of implantation, low hydraulic gradient across the host formation (see DI *4.1.1 - Site descriptive model*), absence of valuable natural resources in the vicinity of the site, low population density, availability of surface drinking water, etc. These criteria are discussed in sub-theme *6.1 - Establish site selection process and site screening*. The benefits of a long-term active monitoring programme (see DI *1.2.3 - Allocate responsibilities*) are limited, given the long half-life of the radionuclides stored in a DGR.

5.2 Optimisation challenges and innovations

At this stage, assessment of IHIS mainly confirms that geological disposal is necessary for HL and IL-LL wastes. As for any post-closure safety scenario, IHIS are defined in a deterministic manner, and they inevitably include maximising choices. For example, the intrusion scenario selects the disposal cell, which contains the most hazardous wastes. More realistic results could be provided by introducing a probabilistic analysis that takes into account the cross-section of the various components relative to that of the DGR footprint. Given current practices, the implementation of a probabilistic approach cannot be expected in the short or medium term.

6. Uncertainties

Current knowledge does not allow us to predict long-term future human actions. As a result, IHIS are defined in a stylised way and their quantitative assessment includes structuring safety choices. We consider a level of technological development comparable to today's, which makes it possible to carry out deep drilling even though there are no valuable resources, but the necessary controls to limit the risks of hazardous excavated material are not carried out. Intrusion is achieved in the cell that contains the highest radiological inventory. One can also assume that contrary to current regulations, the boreholes are not properly sealed, facilitating contamination of aquifers. Contaminated water is pumped for farming use, without any sanitary or radiological control. Finally, the population considered for the impact study is assumed to live in total self-sufficiency. This accumulation of unfavourable hypotheses, which makes it difficult to draw reliable conclusions regarding the performance of the repository and to highlight any potential design improvement, may not be applied to design extension scenarios such as IHIS.

The management of future human actions must also take into account the uncertainties relative to human and societal evolution. Major governance paradigm changes may result in more or less careful waste management. For example, the acceptance of the disposal facility could decline during the operating period. A major crisis could even threaten the final closure of the repository, thus jeopardising its long-term safety. The "human and social sciences" approach is not further developed in this paper, but it should be known and taken into account.

In the same spirit, malicious acts and deliberate intrusions are not taken into account. For example, a scrap metal dealer who tries to reach the disposal facility without being aware of its danger is considered a deliberate intrusion scenario that is therefore not studied. The facility design, through its depth and location, aims to limit the risk of intrusion, but only an active surveillance programme can prevent intrusions. Beyond the monitoring phase (active control), the memory phase (passive control) must be maintained as long as possible, beyond 500 years after the final closure of the repository, to limit the risk of inadvertent intrusion. These safety features, which depend on the evolution of human society and human actions, involve incompressible uncertainties.

7. Further reading, external Links and references

Discussions about waste management are underway within ICRP. For example, Technical Group N°127 deals with Exposure Situations and Categories of Exposure (https://www.icrp.org/icrp_group.asp?id=201).

The technical report resulting from HIDRA's work has not been published yet. However, the draft version is available via the following link: https://www-ns.iaea.org/downloads/rw/projects/hidra/hidraII-draft-tor.pdf.

HIDRA's work on IHISs is also mentioned in "Scenario Development Workshop Synopsis - Integration Group for the Safety Case" following a workshop held in Paris in 2015, under the guidance of the NEA-OECD https://www.oecd-nea.org/jcms/pl_19690/scenario-development-workshop-synopsis-integration-group-for-the-safety-case?details=true.

Concerning the passive control, a NEA working group deals with "Remembering the past in the future: Building awareness of radioactive waste repositories together" (https://www.oecd-nea.org/jcms/pl_67956/remembering-the-past-in-the-future-building-awareness-of-radioactive-waste-repositories-together).

Concerning the description of biosphere and future human actions herein, reference works are BIOCLIM 2003 (climate change) and BIOASS 2003 (future biosphere) https://www-pub.iaea.org/MTCD/Publications/PDF/Biomass6_web.pdf.

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