Deliverable D10.2:

"Generic strategies for managing uncertainties"

Work Package 10: Uncertainty Management multi-Actor Network (UMAN)

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Executive Summary

This report presents the findings of Sub-Task 2.1 of the UMAN work package of EURAD project. UMAN is focused on developing a common understanding among European Waste Management Organisations (WMOs), Technical Support Organisations (TSOs) and Research Entities (REs) and civil society of strategies and approaches for managing uncertainties by sharing knowledge and identifying remaining and emerging issues. Sub-Task 2.1 is focused specifically on identifying generic strategies for managing uncertainties. The Sub-Task 2.1 work has largely drawn on responses from WMOs, TSOs and REs to a questionnaire produced for the UMAN project to facilitate information gathering.

The report discusses uncertainty management in the context of programmes for near-surface and geological disposal of radioactive waste, relevant regulatory requirements, safety assessment strategies, and activities aimed at reducing, avoiding or mitigating uncertainties.

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1. Introduction

1.1 Background

The fundamental safety objective set out by the International Atomic Energy Agency (IAEA) in respect of all facilities and activities in radioactive waste management is to protect people and the environment from harmful effects of ionising radiation [1]. The strategy adopted internationally at present to achieve this objective in respect of the disposal of radioactive waste is to contain the waste and to isolate it from the accessible environment to the extent that is necessary. Disposal facilities of different designs may be used to accommodate radioactive waste of various types. In particular, a near-surface disposal facility (on the ground surface or up to a few tens of metres below ground level) may be used for lower activity waste, while a geological disposal facility (constructed in tunnels, vaults or silos in a particular geological formation at least a few hundred metres below ground level) may be used for higher activity waste and spent nuclear fuel.

Disposal facilities are designed to ensure that safety requirements are met during disposal operations and after facility closure. In general, operational safety is provided by means of engineered features and operational controls, and post-closure safety is provided by means of engineered and natural barriers. In geological disposal facilities, the geology is generally selected to isolate the wastes and limit any migration of contaminants to the accessible environment. In near-surface disposal facilities, the geology may be less important owing to the short pathway between the waste and the biosphere but it may still play a role, for example, providing a stable environment. Disposal facilities are designed to be passively safe after closure, although monitoring and institutional controls might continue for a short period.

A radioactive waste disposal facility can be considered safe, from a technical point of view, if it meets the relevant safety standards specified by the responsible national regulator. The safety of a disposal facility is usually demonstrated in a safety case [2; 3]. Within the safety case, the performance of the facility is evaluated against quantitative safety standards using a safety assessment (or performance assessment). Assessment of the post-closure performance of the facility involves developing an understanding of how, and under what circumstances, radionuclides and chemotoxic substances might be released from waste packages, how likely such releases are, and what the radiological or other consequences of such releases could be to humans and the environment. Importantly, it is necessary to understand how the geological characteristics of the site and the components of the design will evolve and function. Inevitably, there are both quantifiable and unquantifiable uncertainties associated with such understanding and the uncertainties generally increase proportionate to the post-closure timescale being considered. In order to build confidence in the safety of a disposal facility, these uncertainties must be understood and characterised as far as possible so that they can be accounted for in the demonstration of safety for the facility.

Ensuring that uncertainties are accounted for is a key part of successful radioactive waste disposal programme planning, and benefits from continued sharing of methodologies and experience. The topic has benefitted in the past from exchange of ideas in a number of international collaborations, including a ‘Pilot Study’ on regulatory review and approval of safety cases for geological disposal facilities [4], the European Commission (EC) PAMINA project, which included work on the treatment of uncertainty in performance assessment and safety case development [5], and the Nuclear Energy Agency (NEA) initiative on Methods for Safety Assessment (MeSA) of geological disposal facilities [6]. This collaborative approach is continuing under the European Joint Programme on Radioactive Waste Management (EURAD), which has been formed to coordinate activities on agreed priorities of common interest between European Waste Management Organisations (WMOs), Technical Support Organisations (TSOs) and Research Entities (REs). EURAD includes the ‘Uncertainty Management multi-Actor Network’ (UMAN) and this report presents the results of the part of UMAN that is focused on consideration of strategies and approaches for managing uncertainties.

1.2 Objectives

EURAD has the specific objectives to:

a) Develop, maintain and consolidate the scientific and technical basis of safe radioactive waste management.

b) Address important and complex issues and enable expert networking.

c) Enhance knowledge management and transfer between organisations, Member-States and generations.

d) Engage with civil society.

Scientific and technical activities and knowledge management needs of common interest have been grouped into scientific themes that address different technical aspects of radioactive waste disposal. A EURAD Roadmap comprising Work Packages, Tasks and Sub-Tasks has been developed that aims to address key issues relating to these themes. Uncertainty management is a cross-cutting issue of importance to all themes and, thus, the EURAD Roadmap includes a Work Package (WP10) dedicated to uncertainty management (i.e., UMAN). The main objectives of UMAN are as follows:

- Develop a common understanding among the different categories of actors (WMOs, TSOs, REs and civil society) on uncertainty management and how it relates to risk and safety. In cases where a common understanding is beyond reach, the objective is to achieve mutual understanding on why views on uncertainties and their management are different for different actors.
- Share knowledge/know-how and discuss common methodological/strategic challenging issues on uncertainty management.
- Identify the contribution of past and on-going Research and Development (R&D) projects to the overall management of uncertainties.
- Identify remaining and emerging issues and needs associated with uncertainty management.

The UMAN project involves five tasks and this report is focused on Sub-Task 2.1 of Task 2. The overall objective of Task 2 is to compile, review, compare and refine strategies, approaches and tools for the management of uncertainties in the safety analyses and safety cases that are being used, planned to be used or being developed in different countries. Sub-Task 2.1 (generic strategies for managing uncertainties) provides a platform for other Task 2 work by systematically compiling a summary of the strategies and approaches used for managing uncertainties in radioactive waste disposal programmes and providing an assessment of their pros and cons.

The success of the UMAN project relies on interactions between the five tasks. The output of Sub-Task 2.1 will:

- Support work under Sub-Task 3.1 that is compiling views on the types of uncertainty that need to be addressed in a safety case and how these uncertainties evolve through the different disposal programme phases.
- Provide input to work to be performed in Task 4 that is aimed at investigating views on options for managing uncertainties associated with specific topics.
- Provide material to support activities under Task 5 that are focusing on developing a common understanding of viewpoints on uncertainty management and sharing knowledge on key issues. Task 5 involves interactions with a broad audience that includes representatives from civil society as well as from WMOs, TSOs and REs.

1.3 Scope and Approach

The EURAD Roadmap links activities to milestones typical of different phases of a radioactive waste management programme, drawing on the IAEA framework of waste disposal programme phases [7]:

- Phase 0: Policy, framework and programme establishment[1].
- Phase 1: Site evaluation and site selection.
- Phase 2: Site characterisation.
- Phase 3: Facility construction.
- Phase 4: Facility operation and closure.
- Phase 5: Post-closure.

Within a step-by-step approach to disposal facility development, information about uncertainties and how they can be managed forms an important input for the decisions to be taken at each step. How much uncertainty can be accepted at a given step depends on the decisions to be taken at that step. The way that uncertainties are managed is thus expected to evolve throughout the different programme phases.

The initial versions of safety cases are typically produced in the framework of a pre-licensing process in support of activities such as disposal concept development, dialogue with stakeholders, and site selection. A complete safety case including a safety assessment is then submitted in the framework of the licence application for the construction and operation of the facility. An update of the safety case is likely to be required before starting construction, with regular updates during the operation of the facility to take account of as-built properties, the characteristics of emplaced wastes, results from Research Development and Demonstration (RD&D) and monitoring programmes, as well any changes to the design, state of knowledge or regulatory requirements.

UMAN Sub-Task 2.1 is concerned with how uncertainties are managed through each of these phases. Information has been gathered on different approaches to uncertainty management, including how RD&D, site characterisation, site selection, design, construction and management measures can be used to avoid, mitigate or reduce uncertainties. A questionnaire was produced to facilitate this information gathering process under Sub-Task 2.1 and was distributed as part of a broader UMAN questionnaire. EURAD participants were asked to complete the questionnaire and this report provides a compilation and discussion of the responses received relating to Sub-Task 2.1.

1.3.1 1st UMAN Questionnaire

There are five parts to the 1st UMAN questionnaire and Parts 1, 3 and 4 are directly relevant to the work under Sub-Task 2.1. Part 1 establishes key contextual information about the respondent and the radioactive waste disposal programme of concern, including:

- The organisation the respondent is representing.
- The mission of the programme (i.e., the type of waste and disposal facility that is planned or being developed).
- The current phase of the disposal programme.

Part 3 identifies views on the types of uncertainties that should be addressed in safety cases and the evolution of these uncertainties throughout the programme phases. Question 3.2b focuses on measures that can be taken to deal with uncertainty evolution, which is of particular interest to Sub-Task 2.1.

[1] Phase 0 is not included in the IAEA framework, but has been added in EURAD to recognise the needs of Members States that are in the process of establishing a waste management programme.

Part 4 of the UMAN questionnaire pertains directly to Sub-Task 2.1 and seeks information on the uncertainty management methods being used in disposal facility development programmes, covering:

- Regulatory requirements or guidance pertaining to how uncertainties should be managed in demonstrations of disposal facility safety against regulatory criteria.
- How the management of uncertainties is addressed in the overall safety strategy, including their identification, mitigation and reduction through each phase of the disposal programme and each iteration of the safety case.
- How different types of uncertainty are managed in safety cases.

The questions from Parts 1, 3.2b and 4 of the UMAN questionnaire are included in Section A.1 of Appendix A.

1.3.2 UMAN Questionnaire Respondents

Representatives of WMOs and TSOs were asked to respond to the Sub-Task 2.1 questions in Parts 1, 3.2b and 4 of the questionnaire, covering the broad range of uncertainty management topics in the context of national frameworks for radioactive waste management. However, in anticipation that representatives from REs would not have ready access to such a broad scope of information on uncertainty management strategies, they were instead asked to focus on providing views on the management of uncertainty evolution (Question 3.2b) and on uncertainties relating to the very long timescales that require consideration in radioactive waste disposal facility safety cases (Question 4.3e).

The WMOs and TSOs that responded to the Sub-Task 2.1 questions are indicated in Table 1. Summary information about the mission and phases of the national disposal programmes of relevance to each WMO or TSO is shown in the table (from responses to Part 1 of the questionnaire). Table 2 lists the REs that responded to the Sub-Task 2.1 questions on the management of possible evolutions of uncertainties and on uncertainties associated with understanding disposal facility performance over long timescales. Further details of the respondents and the status of the disposal programmes are provided in the full responses to Part 1 in Sections A.2 and A.3 of Appendix A.

The responses confirmed how the implementation of near-surface disposal facilities (disposal at depths of up to a few tens of metres) is generally more advanced than that of geological disposal facilities. For example, many near-surface facilities for the disposal of short-lived low and intermediate level waste (L/ILW)[2] are operational (Phase 4) and one facility in the Czech Republic is closed (Phase 5). In contrast, in Europe, only one facility for the geological disposal of spent fuel (SF) is currently being constructed (in Finland) (Phase 3) and only two geological disposal facilities are at the site characterisation stage (in Sweden and France) (Phase 2). Most geological disposal programmes are at the planning or siting stages (Phases 0 or 1). Therefore, experience in uncertainty management methods through the different phases of disposal facility development programmes lies primarily with

[2] According to IAEA definitions:

- Low level waste (LLW) is waste that is suitable for near-surface disposal and may include material that requires shielding and containment for up to several hundred years because of its activity, as well as low concentrations of long-lived radionuclides. In some countries, such wastes are categorised as short-lived low and Intermediate level waste (L/ILW) and long-lived LLW.
- ILW is waste that contains long-lived radionuclides in quantities that require longer term containment and isolation (i.e., geological disposal). In some countries, such wastes are categorised as long-lived ILW.
- High level waste (HLW) is waste such as spent nuclear fuel and vitrified waste from spent fuel reprocessing that contains higher concentrations of radionuclides than ILW and requires containment and isolation in a geological disposal facility. In some countries, HLW refers only to vitrified waste from reprocessing; wastes such as spent fuel are categorised separately.

those developing near-surface facilities for short-lived or low-activity radioactive waste. This implies that there is less practical experience in a licensing or permitting arena of demonstrating how uncertainties associated with very long timescales of geological disposal system evolution are managed.

Table 1 – WMOs and TSOs that responded to Question 3.2b and Part 4 of the UMAN questionnaire, with disposal programme missions and phases indicated. Information has also been provided on the Lithuanian disposal programme by the Lithuanian Energy Institute (RE) and this has been included.

Organisation (Type)	Country	Disposal Programme Mission	Phase
ONDRAF/NIRAS (WMO)	Belgium	Near-surface disposal of LLW	2
Bel V (TSO)		Geological disposal of ILW, HLW and SF	0
SÚRAO (WMO)	Czech Republic	Near-surface disposal of L/ILW	4 (three facilities) 5 (one facility)
SURO (TSO)		Geological disposal of HLW and SF	1
Danish Decommissioning (DEKOM) (WMO)	Denmark	Geological disposal of L/ILW	0
VTT (TSO)	Finland	Near-surface disposal of VLLW	0
		Near-surface disposal of L/ILW	4 (two facilities)
		Geological disposal of HLW	3
ANDRA (WMO)	France	Near-surface disposal of very low level waste (VLLW)	2 and 4
		Near-surface disposal of short-lived L/ILW	4
IRSN (TSO)		Near-surface disposal of long-lived LLW	0 and 1
		Geological disposal of HLW and long-lived L/ILW	2
BGE (WMO)	Germany	Geological disposal of L/ILW	3 (one facility) 4 (two facilities)
		Geological disposal of HLW	0 or 1
TS ENERCON (TSO)	Hungary	Near-surface disposal of short-lived L/ILW	3 and 4
		Geological disposal of short-lived L/ILW	0
		Geological disposal of long-lived ILW, SF and HLW	1
Lithuanian Energy Institute (LEI) (RE)	Lithuania	Near-surface disposal of VLLW	3
		Near-surface disposal of L/ILW	3
		Geological disposal of long-lived ILW and SF	0
COVRA (WMO)	Netherlands	Geological disposal of L/ILW, HLW and SF	0
NRG (TSO)			
ARAO (WMO)	Slovenia	Uranium mine waste disposal	5
		Near-surface disposal of short-lived L/ILW	2
EIMV (TSO)		Geological disposal of SF (including investigating possibility of regional/multinational repository for HLW and SF)	0
ENRESA (WMO)	Spain	Near-surface disposal of L/ILW	4
SKB (WMO)	Sweden	Near-surface disposal of short-lived L/ILW	4

Organisation (Type)	Country	Disposal Programme Mission	Phase
		Geological disposal of long-lived L/ILW	1
		Geological disposal of SF	2
Nagra (WMO)	Switzerland	Geological disposal of SF, HLW and possibly long-lived ILW	1
		Geological disposal of L/ILW	1
SSTC NRS (TSO)	Ukraine	Near-surface disposal of VLLW and LLW	4
		Geological disposal of long-lived ILW and HLW	1
RWM (NDA) (WMO)	UK	Geological disposal of ILW (and some LLW), HLW and SF	1

Table 2 – REs that responded to Question 3.2b in the UMAN questionnaire on the management of the possible evolutions of uncertainties and/or to Question 4.3e on uncertainties associated with understanding disposal facility performance over long timescales.

Organisation	Country
SCK-CEN	Belgium
EnviroCase	Finland
CNRS	France
GRS	Germany
HZDR	
LEI	Lithuania
Institute of Nuclear Chemistry and Technology	Poland
IST-ID	Portugal
Institute for Nuclear Research (RATEN ICN)	Romania
Paul Scherrer Institut	Switzerland

1.4 Report Structure

Section 2 discusses the management of uncertainties in the context of regulatory criteria and guidance on demonstrating disposal facility safety. Section 3 discusses strategies for managing uncertainties and Section 4 provides a summary of findings and discusses needs for further development and activities. The questionnaire and responses are recorded in Appendix A.

2. Regulatory Context for Managing Uncertainties

The demonstration of safety of a radioactive waste disposal facility must be made in the context of the pertinent regulatory framework and the associated guidance and requirements. The regulatory requirements influence the types of uncertainty that need to be addressed in the safety demonstration. In some cases, regulators may provide guidance on how relevant uncertainties should be managed. This section reviews WMO and TSO responses to Question 4.1 of the questionnaire regarding regulatory context and guidance on the management of uncertainties. The safety reference levels developed by the Western European Nuclear Regulators' Association (WENRA) [8] and relating directly to uncertainty management are also briefly discussed.

2.1 Regulatory Criteria for Demonstrating Safety

The assessment of radiological impact on humans and the environment after disposal facility closure generally forms the core of a safety case, but other aspects such as non-radiological impacts may also require assessment [3]. Regulatory criteria for the protection of humans and the environment are generally expressed in terms of radiological dose and/or radiological risk limits and/or constraints for different receptors. In most countries, a dose limit is applied for workers and the public during the operational period and dose and/or risk constraints are applied for the post-closure period.

During operations, different dose limits might be applied for workers and the public, and different limits might be set for normal operation and accident situations. Questionnaire responses indicate that for normal operations the limits are generally on the order of 20 mSv/year for workers and 1 mSv/year for the public (e.g., Czech Republic, Ukraine), and for accident situations limits of 100 mSv/year could apply (e.g., Slovenia).

After closure of a disposal facility, the applied dose constraint for members of the public is typically in the range 0.1 to 0.5 mSv/year. In France, interpretation of the dose constraint depends on the post-closure timescale, with a constraint of 0.25 mSv/year applied for reference conditions on a timescale of at least 10,000 years; on longer timescales dose levels should not be unacceptable, with 0.25 mSv/year regarded as a reference level. Peak calculated dose may occur on timescales in excess of 10,000 years.

In some countries, the dose constraint or reference value depends on the post-closure evolution scenario being assessed. For example, in Belgium the reference value is 3 mSv/year for 'penalising' scenarios (stylised worst-case illustrations), in Slovenia the dose constraint is 10 mSv/year for 'altered evolution' scenarios and in France exposure levels associated with 'altered situations' should be sufficiently low in the context of an optimised system. In the UK, the consequences of potential human intrusion must be assessed in terms of dose using a stylised calculation, again in the context of optimisation.

Alternatively, or additionally to a dose constraint, a constraint on the annual risk to an individual member of a potentially exposed group is applied (e.g., Belgium, Switzerland, UK). The risk constraint is typically 10^{-6} per year, although a risk constraint of 10^{-5} per year is applied in Belgium for 'altered evolution' scenarios. The application of a risk constraint has the advantage that it allows the probability of occurrence of events and processes to be explicitly accounted for in evaluating compliance, although it can prove difficult to estimate probabilities of occurrence for unlikely events and processes.

As discussed in the PAMINA project [5], the quantity of risk has a closer relationship to potential health impacts than dose, in the sense that dose constraints are derived from a back calculation from an assumed tolerable level of risk (typically that which would be considered negligible by most individuals). Therefore, the use of individual risk as a regulatory performance measure avoids making the regulations dependent on the complex relationship between radiation dose and health impacts, which in the past has been subject to revision through changes in scientific advice. However, the use of a risk criterion places a burden on the safety case developer to remain aware of any changes in dose-to-risk conversion factors.

In many cases, assessments of radiation doses to non-human organisms and the accessible environment are also required (e.g., UK) and there is a need to demonstrate adequate protection against non-radiological hazards (e.g., Belgium, UK, Switzerland, Czech Republic). Also, regulations may require other safety indicators to be considered, such as relating to groundwater protection (e.g., Belgium, UK, Netherlands), or comparison to natural radiological exposure for times after the safety demonstration period during which the dose or risk criteria must be shown to be respected (e.g., Switzerland).

In addition to quantitative criteria, qualitative criteria need to be fulfilled to demonstrate safety (see e.g., the WENRA report [8]). Regulations generally refer to the principle of optimisation, which should be considered in the context of decisions about implementing uncertainty avoidance, reduction or mitigation options and the objective of ensuring that the detrimental impacts of disposal are as low as is reasonably achievable (ALARA). Regulators also require a substantiation that adequate defence in depth has been provided, as appropriate, through a combination of several layers of protection (e.g., safety functions provided by physical barriers, systems to protect the barriers, and administrative procedures) that would have to fail or be bypassed before there could be any consequences for people or the environment.

These various criteria for demonstrating the safety of radioactive waste disposal all have implications on how different types of uncertainty should be managed and addressed in safety cases. In particular, regulatory criteria influence how uncertainties in disposal system evolution are addressed, often by specifying different criteria for scenarios that describe how the disposal system is expected to evolve and scenarios that describe less likely, but possible, long-term disposal system evolution.

2.2 Regulatory Requirements and Guidance on Uncertainty Management

The need to address uncertainties when demonstrating the safety of radioactive waste disposal is typically emphasised in regulatory requirements and, in some countries, regulatory guidance is provided on how uncertainties should be managed. The WENRA Working Group on Waste and Decommissioning Requirements set out requirements relating to safety demonstrations for radioactive waste disposal facilities in the form of safety reference levels (SRLs) [8]. The SRLs were developed as a basis for harmonising regulatory approaches at a European level. Of direct relevance to uncertainty management:

- SRL DI-92 requires that all uncertainties significant to safety are identified and are adequately taken into account in the safety case, and that a programme of uncertainty management is described in the safety case.
- SRL DI-101 requires that the post-closure safety assessment includes a scenario analysis that considers the features, events and processes (FEPs) that might affect the performance of the disposal system, including events of low probability.

The WENRA report also identifies three different categories of uncertainty to be addressed in a safety case, and indicates how they may be managed:

- Uncertainties that have a minor influence on the results of a safety assessment may not need further consideration.
- Reducible uncertainties that have a substantial influence on the results of a safety assessment should be addressed through, for example, further research, improved modelling, or design modifications.

- Irreducible uncertainties that have a substantial influence on the results of a safety assessment should be addressed through, for example, analysis of specific scenarios, conservative assumptions, or probabilistic assessments.

In some countries (e.g., Belgium, France, Switzerland, UK), detailed regulatory guidance is provided on how uncertainties should be managed in radioactive waste disposal programmes. In other countries, no specific guidance is available (e.g., Denmark, Netherlands, Spain, Sweden, Finland). Where regulatory guidance is provided, the following aspects of uncertainty management are typically highlighted:

- The need to show how potentially significant uncertainties in the performance and safety of the disposal facility have been identified and characterised. Specifically, uncertainties in data and parameter values, process understanding, future events, assessment models and the overall long-term post-closure evolution of the facility are typically noted.
- The need to account for such uncertainties in comparison of assessment results with safety criteria, which may involve probabilistic approaches or sensitivity analyses to account for the effects of quantifiable uncertainties, or the definition of alternative evolution scenarios to account for non-quantifiable uncertainties.
- The need to consider how uncertainties can be avoided, mitigated or reduced. Typically, site characterisation activities, facility design, material tests and experiments, the analysis of natural or anthropogenic analogues, and the use of multiple lines of reasoning are noted.
- The need to establish a register of significant uncertainties (e.g., Belgium, UK).
- In some countries, it is required that wastes remain retrievable after disposal, at least for a certain period of time (e.g., Netherlands, Belgium, France, Switzerland). This may mitigate concerns that, ultimately, it may not be possible to reduce uncertainties sufficiently to satisfy all safety requirements. The nature of retrievability in the disposal concept and/or the required period that retrievability must be maintained is subject to dialogue between stakeholders.

3. Strategies for Managing Uncertainties

This section considers how the management of uncertainty is addressed in safety strategies for radioactive waste disposal facilities. First, in Section 3.1, the types of uncertainty that need to be managed in a radioactive waste disposal programme are listed in order to provide context to the discussion of uncertainty management strategies. In Section 3.2, a high-level summary is provided of how uncertainties are managed through the different phases of a disposal facility implementation programme, drawing on responses to Questions 4.2a, 4.2d, 4.2e and 3.2b. In Section 3.3, the elements of an uncertainty management strategy are discussed (Questions 4.2b, 4.2c, 4.2e, 4.3f and 4.3h). Section 3.4 then discusses options for managing specific types of uncertainty, focusing on those associated with the disposal facility programme, the waste inventory, disposal concepts, as-built properties, long-term disposal system evolution, data and models, and completeness of FEP and scenario analysis (Questions 4.3a to 4.3e and 4.3g).

3.1 Types of Uncertainties

The following types of uncertainties may have to be managed in a disposal programme:

- Programme uncertainties, i.e., uncertainties associated with the national radioactive waste management programme and other prevailing circumstances. These uncertainties include societal and political uncertainties relating to the waste to be disposed of, stakeholder conditions, the regulatory framework, the disposal concepts and schedule, available financial resources, and available skills and experience.
- Uncertainties associated with the initial characteristics of the waste, site and engineered components.
- Uncertainties in the evolution of the disposal system and its environment, including the effects of events and processes that may affect the initial characteristics of the disposal facility (e.g., hazards that may occur during construction and operation).
- Uncertainties associated with the data, tools and methods used in the safety case.
- Uncertainties associated with the completeness of the FEPs considered in the safety case.

Some of these uncertainties are relevant to the safety assessment and can be embedded in the formulation of scenarios and models, while other uncertainties can be managed outside the safety assessment through measures aimed at reducing, avoiding or mitigating them. The following sub-sections discuss how these different types of uncertainties may be managed.

3.2 Managing Uncertainties through Disposal Programme Phases

Safety strategies, and therefore approaches to managing uncertainties, are at different stages of development in different countries depending on the phase of the disposal programme. However, in general, an iterative approach is required to manage uncertainties in the performance of a disposal facility as the disposal programme progresses through each phase of its development. This includes an iterative approach to research and data acquisition activities aimed at reducing or mitigating uncertainties. At each stage in such a process, results from a safety assessment can be used to understand the parameters to which performance measures are most sensitive and therefore guide subsequent data acquisition activities and thus reduction of associated uncertainty in a meaningful way.

3.2.1 Early Programme Phases

At the earliest stages of a disposal programme, there may be many unresolved questions and uncertainties. The safety case should identify key uncertainties that may influence safety and the actions needed to manage them, especially with regard to the R&D programmes [8]. For example, the

Belgian programme refers to 'preparatory safety assessments' that are aimed at identifying potentially safety-relevant uncertainties and providing quantitative assessments of their impact on system performance and safety. Preparatory safety assessments are conducted repeatedly in parallel with system development and are used to determine the relevance of uncertainties to safety and provide guidance to RD&D activities (e.g., in terms of research prioritisation depending on the significance of the uncertainties). The 'formal safety assessments' are conducted as part of safety and feasibility cases.

Safety assessments may be undertaken in the context of a range of different disposal concept options where, for example, decisions are yet to be made on waste packaging options or the type and location of host rock for the facility (e.g., Netherlands, UK). For example, in the UK, generic safety assessments of illustrative geological disposal concept designs for different geological environments have been undertaken prior to identification of a site for a disposal facility. Such approaches enable key parameters associated with disposal system performance (and uncertainties in those parameters) to be identified, albeit in the context of credible generic assumptions about natural and engineered barrier system characteristics.

In some countries it is expected that a formal register of key uncertainties is maintained across iterations of the safety case, informed by safety assessment calculations (e.g., UK, Belgium). This register may be used to inform future phases of disposal system development (e.g., site characterisation activities and design modifications) and future research needs, with the aim of seeking to reduce or mitigate the key uncertainties.

3.2.2 Subsequent Programme Phases

Once a programme has proceeded beyond a generic phase and has arrived at an implementation phase, formal site-specific safety assessments are produced at each stage of disposal facility licensing as the implementation process progresses (e.g., to support applications for facility construction and to commence operations, as well as regularly during operations and to support the final closure application). Safety assessments may be carried out to support site selection, as an integral component of site investigations, or to support facility design. By the time a licence for constructing the disposal facility is applied for, any uncertainties and open questions that might undermine safety should have been addressed adequately to support the necessary regulatory decisions [8]. Generally, residual uncertainties will remain at any licensing stage, but it is important to show that they do not undermine the goals of the present stage and can be dealt with to the degree necessary for each future stage, as indicated in the questionnaire responses relating to the Belgian and Swiss geological disposal programmes.

3.2.3 Managing Emerging Uncertainties

Some uncertainties will decrease as new information becomes available (e.g., 'as-built' properties, monitoring data, and RD&D results), whereas activities associated with the programme (process modelling, safety assessment, siting, and construction) can lead to new viewpoints and sometimes new uncertainties. Various measures to deal with, mitigate or guard against the occurrence of new uncertainties have been identified by the questionnaire respondents:

- The implementation of a stepwise and flexible decision-making process where the validity of assumptions and choices made at one phase is verified during subsequent phases through RD&D, characterisation, monitoring and inspection activities.
- The implementation of an experience feedback programme based on construction and operational feedback as well as international experience.
- The use of proven methods and materials.

- The systematic implementation of quality management system principles (allocating responsibilities, defining processes, documentation and control/supervision) in the various activities carried out in the programme (modelling, design, construction).
- The promotion of a strong safety culture within organisations involved in the programme.
- The implementation of a continuous improvement programme.
- The mitigation of programme uncertainties and of associated risks (e.g., financial resources, stakeholder conditions, available knowledge and skill) (see Section 3.4.1).
- The implementation of the defence in depth principle which may include:
  - Measures to prevent deviations from normal operation and the failure of items important to safety. This can be done by using safety margins and reducing or avoiding, as far as is reasonably achievable, sources of uncertainty having the potential to jeopardise safety (e.g., by modifying the location or design of the disposal facility, and preserving knowledge about the repository). Control measures and procedures are also needed to prevent defects and damage to the disposal system.
  - Measures to maintain as far as is reasonably achievable (by host rock/site selection, design and the use of safety margins) the performance of system components when they are subjected to disturbances.
  - The implementation of a multi-barrier system approach providing the disposal system with independent and complementary safety functions and components so as to maintain a sufficient level of safety following the occurrence of an uncertain disruptive event or process.
  - Detecting deviations from normal operation, defects or damage to the disposal system so as to take corrective measures where needed (e.g., waste retrieval where allowed for).
  - Preventing the progress of, and mitigating the consequences of, accidents that would result from failure of previous measures.

The measures that can be adopted depend on the type of new uncertainty identified or anticipated.

3.3 Elements of an Uncertainty Management Strategy

The safety case is typically expected to include a description of the programme for uncertainty management consistent with the prevailing circumstances in the programme for implementing disposal. The uncertainty management strategy generally involves the following steps:

- Identification and characterisation of uncertainties to be managed.
- Analysis of the safety relevance of uncertainties.
- Representation of safety-relevant uncertainties in the safety assessment.
- Identification of uncertainties that need to be reduced, mitigated or avoided based on assessment results.
- Actions to avoid, mitigate or reduce uncertainties.

Each of these steps is updated progressively and iteratively as the disposal programme progresses. For example, the identification, characterisation and analysis of uncertainties is an ongoing process that needs to accommodate the identification of new and emerging uncertainties, as discussed in Section 3.2.3. The assessment of uncertainties on safety assessment results is iterated as new information on safety-relevant uncertainties is acquired through uncertainty reduction, mitigation and avoidance activities.

The elements of an uncertainty management strategy based on a stepwise and iterative process that is consistent with the framework and status of the disposal programme are illustrated in Figure 1.

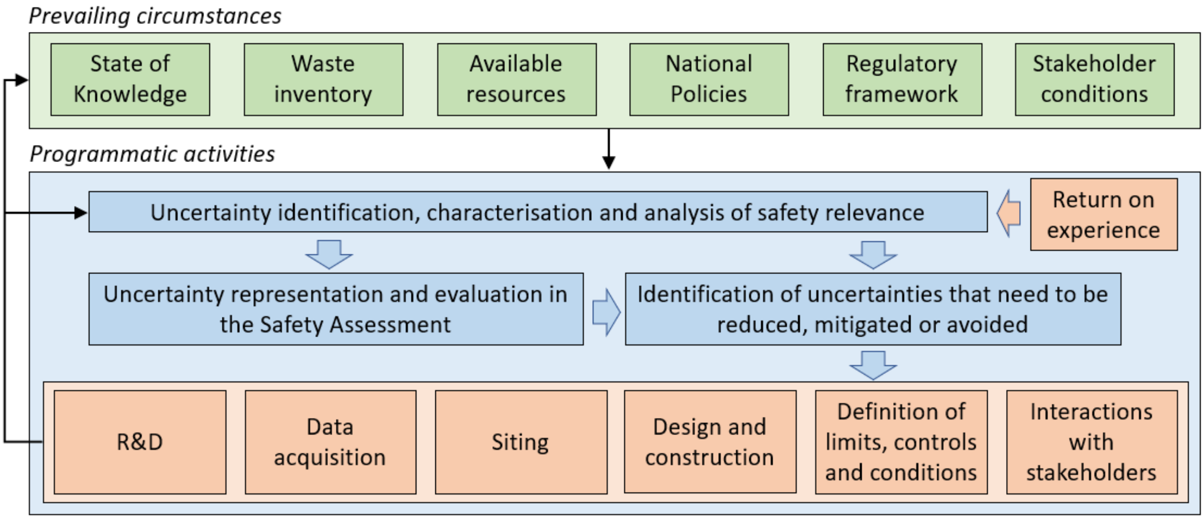

Figure 1 – Elements of an uncertainty management strategy

3.3.1 Identification and Characterisation of Uncertainties

The description of an uncertainty management programme should include information on how uncertainties will be identified and how they will be characterised [3]. Uncertainties relevant to the safety assessment have to be characterised with respect to their source, nature and degree, using quantitative methods, professional judgment or both [9]. Analysis of FEPs that could affect disposal system behaviour commonly forms part of the uncertainty identification process.

3.3.2 Analysis of Uncertainties and their Representation in the Safety Assessment

A variety of methods are available to analyse the safety relevance of uncertainties (e.g., through sensitivity analysis of the impacts of uncertainties on safety indicators). Methodological approaches to uncertainty and sensitivity analysis will be addressed in the framework of Sub-Task 2.3 of the UMAN project.

Uncertainties over future states of the disposal system are typically addressed by considering different scenarios of disposal system evolution (e.g., scenarios describing the expected behaviour of the disposal system and less likely scenarios in which barrier safety functions are assumed to be disrupted by specific FEPs).

There will be data and model uncertainty associated with each scenario and strategies for handling such uncertainties tend to fall into the following broad categories:

- Demonstrating that the uncertainty is irrelevant or of low consequence; that is, uncertainty in a particular process is not important to safety because, for example, safety is controlled by other processes.
- Addressing the uncertainty explicitly, for example using probabilistic techniques.

- Testing the sensitivity of the assessment to alternative credible models of uncertain processes.
- Bounding the uncertainty and showing that even the bounding case gives acceptable safety.
- Ruling out an uncertain FEP, usually on the grounds of very low probability of occurrence, or because other consequences, were the FEP to occur, would far outweigh concerns over disposal facility performance.
- Taking a stylised approach to handling an uncertainty. This is different to a bounding approach in that a stylised approach can go beyond the bounds of how a FEP might be parameterised in a system model to represent the FEP where few relevant data can be gathered. Usually, plausible assumptions are made that tend to err on the side of conservatism.

Probabilistic approaches can give insights into which parameters (and uncertainties) are important, but large uncertainties in input parameters do not always translate to large uncertainties in risk. Uncertainties in FEPs that affect key barrier safety functions associated with isolation and containment are likely to be most important. Deterministic approaches can be used to bound the effects of some processes. Quantitative assessment can be supported by more qualitative arguments, such as alternative lines of reasoning involving the use of natural and anthropogenic analogues. The preferred treatment of particular uncertainties may depend on the context of the assessment and the stage in the process of developing the disposal facility.

3.3.3 Assessment and Management of Remaining Uncertainties

At each major step of a disposal programme (i.e., at each key decision point), safety assessment should be performed in a manner that will enable the current level of understanding of the disposal system to be evaluated and the associated uncertainties to be assessed before decisions are made to proceed to the next step [3].

Ideally, the information comprising a safety case should be summarised and synthesised into a concluding statement regarding the degree of confidence that exists at the given stage of facility development and which, amongst other things, should address the remaining uncertainties and how they might be managed. This should consider:

- Which (if any) of the identified uncertainties are significant for safety.
- Whether and why it is appropriate to move to the next stage of facility development despite these uncertainties.
- What strategies should be employed to address these uncertainties (see Section 3.3.4).

Public acceptance is about being convincing and trustworthy enough, and thus the discussion about the remaining uncertainties in particular needs to be systematic, presented in plain language, transparent, and appreciative of diversity in the opinion and knowledge basis of stakeholders. Some uncertainties may best be managed and communicated by identifying and assembling multiple lines of evidence in the safety case that support assessment assumptions or findings, rather than by trying to constrain the assessment calculations themselves. For example, evidence from natural analogues is useful to support statements on the longevity of engineered materials and the overall performance of disposal systems, demonstration of continuous improvement of the models used in safety analysis builds confidence in scientific credibility, and use of different analogues for code validation provides assurance for the assessment models.

3.3.4 Avoidance, Mitigation, and Reduction of Uncertainties

Confidence in the safety case at any stage will be enhanced if each revision of the safety case includes a plan for further work, as necessary, to address significant unresolved issues, in particular to reduce significant remaining uncertainties or to reduce their relevance or avoid them entirely [3].

Strategies for addressing uncertainties will involve a mixture of reduction, avoidance and mitigation. The strategies and the mixture of techniques and measures will also adapt as programmes progress. Techniques include R&D, further data acquisition, constraining the inventory through decision-making, characterisation or processing of the waste, site selection and site characterisation, adapting the disposal concept, either at the high level or in detailed design, adopting particular construction methods, and adapting the management system (e.g., reduction of uncertainties on as-built properties by additional Quality Assurance/Quality Control [QA/QC] measures). The choice of particular measures depends, in part, on the state of the programme and on imposed boundary conditions. For example, site selection is not a measure usually considered after a facility has been constructed (except through retrievability and a major programme change), while a programme may not have an option to exclude wastes (although there may be the option to condition them in a certain way).

In the early stages of a programme, the results of a safety assessment provide essential input for identifying R&D needs. For example, successive safety assessments in the French programme were used to refine site investigations and focus on those features of the host rock found to be most significant in fulfilling its performance as a barrier [10]. An approach to mitigating the effects of uncertainties by design measures in the early stages of a programme is exemplified by the Belgian 'supercontainer' concept which, amongst other things, was introduced to circumvent uncertainties concerning near-field corrosion processes [11]. A change of the design of the facility can be proposed on the basis that there is confidence that an R&D programme can be defined and implemented in order to reduce any associated uncertainties. There is, of course, a risk that the R&D programme will identify other uncertainties. Therefore, such R&D programmes should be undertaken at early stages in the development of a disposal concept, to avoid a situation where unforeseen uncertainties later challenge the safety case.

In the later stages of disposal facility development, in addition to being a tool with which to develop confidence and to provide assurance that uncertainties significant to performance have been adequately addressed, the safety assessment is also an important tool for providing feedback to detailed design and for assessing the possibilities of further enhancing safety. A decision to move to the next step of repository development is an expression of confidence in the proposed concept based on the findings of the safety assessment and the safety case, despite the existence of uncertainties, some of which will inevitably remain.

Increased R&D is not likely to reduce unquantifiable uncertainties, particularly those relating to the very long timescales considered by assessments. Similarly, designing engineering for retrievability will not reduce such uncertainties. Although the concept of retrieval might provide some reassurance for the shorter-term, it cannot be guaranteed for long timescales. Indeed, relying on the reversibility of decision processes and/or retrievability of the waste may increase uncertainty in the assessments if the disposal system design becomes more complicated, although in Switzerland for example there is an explicit requirement that long-term safety shall not be impacted by measures that allow for retrievability. Unquantifiable uncertainties are sometimes termed aleatory or stochastic uncertainties. In practice, however, another classification used by WENRA [8] and Nagra (Switzerland) is between uncertainty that can *de facto* substantially be reduced ahead of some important decision, and uncertainty that cannot. Nagra's aim is to better distinguish between these two types of uncertainty where possible; this ambition is partly also motivated by new regulatory guidance to site selection.

3.4 Managing Specific Types of Uncertainties

3.4.1 Programme Uncertainties

Uncertainties in a radioactive waste management programme are related primarily to decisions on future energy policy (i.e., nuclear versus other technologies) and decisions on waste management practice (e.g., storage versus disposal, disposal of spent nuclear fuel as radioactive waste). The timing of reaching and reviewing decisions and their implementation, including the siting, construction, operation, and closure of facilities also creates programme uncertainties. Uncertainties in inventories and disposal concepts can often be readily quantified and used to compare options, evaluate the significance of programme uncertainties, and identify mitigation measures as discussed in Sections 3.4.2 and 3.4.3.

In Belgium, the regulator requires that risks associated with programme uncertainties be analysed in the safety case. The goal is to identify measures to reduce and mitigate these risks during the different programme phases. The management and mitigation of programme uncertainties are achieved through actions such as stakeholder communication and involvement, regular review of strategy, monitoring of the costs and allocation of resources. Where programmes experience delays, uncertainties can be mitigated by knowledge management and maintaining technical skills. Ensuring political awareness of the long-term necessity of sufficient resources and maintenance of competences is also important.

Programme uncertainties may decrease over time as successive decisions are made and a chosen programme is advanced. Many countries are at an early stage in their geological disposal programme and so programme uncertainties are generally managed by making a series of 'planning' assumptions about issues such as when facilities will become available, where facilities might be located, and what wastes will arise. However, for near-surface disposal, a number of countries already have proceeded along a programme to the point where facilities have, or are reaching, the end of their operational life. This has raised a different set of programme uncertainties related to closure and the possible need for remedial action in light of developing waste management practice.

Rather than safety assessment, a number of questionnaire respondents discussed the need to address programme uncertainties in cost estimation. In Slovenia, uncertainties in cost estimates are divided into project and technology 'contingencies'. Technology contingencies reflect uncertainties related to the maturity of the technologies used. They are based on the degree of uncertainty caused by use of innovative technologies. Project contingencies reflect the uncertainties related to the maturity of the project. This type of uncertainty covers expected omissions and unforeseen costs caused by an incomplete definition of the project and its engineering. Project contingencies thus compensate for the inherent estimated inaccuracy associated with each stage of a project.

The construction of a geological disposal facility in the Netherlands is anticipated to start in 2130. To manage uncertainties about the techniques that might be used for the disposal facility construction, operation and closure and their associated costs, only techniques that are currently available are adopted. New techniques will become available but will only be included when they have been tested and have been used/proven. For the cost estimate, a method is used that takes the uncertainty into account by allocating higher costs. Socio-economic costs are managed by collecting money for the facility upfront and the facility developer becoming the owner of the waste (and thus not being dependent on the long-term existence of organisations that have generated the waste).

Programme uncertainties are being further addressed by Sub-Tasks 3.4 and 4.2 of the UMAN project.

3.4.2 Inventory, Wasteforms, and Waste Packaging Options

As part of an international treaty, national programmes provide regular updated estimates of waste inventories to the IAEA. Programme decisions can lead to changes in the waste inventory. For example, whether to build new nuclear power stations, to reprocess spent fuel, or to treat certain materials as waste. The consequences of a decision can be quantified in terms of waste inventory and, therefore, options compared and managed using analyses such as safety assessment and cost estimation. Uncertainties in waste volumes owing to factors such as future energy policy can be managed cost-effectively by adopting a disposal concept that can be extended easily using the same construction methods (e.g., Netherlands).

Once decisions are made, there are also uncertainties in estimating waste arisings through uncertainty in characterisation, different waste conditioning and packaging options, and different programme timings. These uncertainties obviously reduce as programmes evolve and the wastes are actually packaged and emplaced. The uncertainties can also be managed by developing generic waste acceptance criteria (WAC) to ensure that the wastes conform to some standard. However, while generic WAC provide a boundary condition to, or derive from, the safety assessment for a particular facility, they may not address the uncertainty posed by any materials that do not conform to the WAC for the facility unless some margins are included in their definition. Uncertainties on the waste to be disposed of can also be handled to some extent through a careful and methodical analysis of the operations performed by waste producers. Furthermore, multiple and independent controls during waste acceptance allow minimising the possibility of emplacing waste packages that would not meet the WAC for the disposal facility.

Uncertainties in the waste inventory are generally addressed using alternative inventories in the same assessment. Generally, upper bounding values or conservative scaling factors are used to address uncertainty in an existing waste inventory (as opposed to uncertainty associated with programme decisions). Uncertainty in characterisation can be considered using statistical analysis of all historical data collected from nuclear power plants or other relevant facilities in operation (e.g., Spain).

Uncertainties in the waste inventory are being further addressed by Sub-Tasks 3.2 and 4.2 of the UMAN project. Uncertainties in spent fuel characteristics are being addressed by Sub-Tasks 3.5 and 4.2 of the UMAN project.

3.4.3 Disposal Concepts

Consistent with IAEA safety requirements, throughout the process of development and operation of a disposal facility for radioactive waste, an understanding of the relevance and the implications for safety of the available options for the facility shall be developed by the operator [12, Requirement 4]. The disposal concept adopted largely reflects the type of waste and associated facility (e.g., near-surface disposal of large volumes of low activity waste; geological disposal of medium volumes of higher activity waste; borehole disposal of small volumes of spent fuel), and the host rock for geological disposal concepts. Uncertainty in the concept at the planning stage, therefore, reflects decisions on these issues. Once the type of facility and the host rock have been decided, disposal concept uncertainties will become more constrained.

In France, the robustness of the disposal concepts is assessed through sensitivity analyses. This is also expected to be performed in the context of the general licence application in Switzerland. These sensitivity analyses may also account for human factors during the operational phase (defect in design or manufacture, human error, etc.).

In the UK, prior to identification of a site for a geological disposal facility, illustrative designs for the disposal of different categories of waste in different types of host rock are assessed to provide demonstrations of how safety cases could be made for such facilities.

3.4.4 As-Built Properties

A disposal facility shall be constructed in accordance with the design as described in the safety case and supporting safety assessment [12, Requirement 17]. Therefore, the safety assessment must address the feasibility and reliability of the proposed construction methods and the technical feasibility of the proposed design options. For novel techniques, the implementer will be expected to provide arguments confirming that technical feasibility can be demonstrated through a qualification programme that can reasonably be carried out within the time planned for project development. Where such arguments involve large uncertainties, the implementer will be expected to consider design alternatives, based on technical options that have been demonstrated on the basis of extensive feedback from industrial experience.

Analysis of potential material quality control or barrier emplacement errors may be used to define alternative disposal system evolution scenarios based on different assumptions about conditions at the time of facility closure. Other uncertainties in disposal system performance may be managed through decisions about backfilling and closure options and schedules (e.g., backfilling and sealing may be implemented or scheduled in a way that optimises reversibility or waste retrievability).

In some national programmes (e.g., Belgium, Sweden), uncertainties in as-built properties of disposal system components (i.e., deviations from the initial state that follow from undetected mishaps) are also taken into account in the safety assessment using specific scenarios or conservative model assumptions.

As part of the management system, a programme should be set up to ensure the quality of construction activities to provide confidence that the relevant requirements and criteria are met [3]. Feedback from experience during construction should also be taken into consideration. Furthermore, the licensee of a disposal facility has to record and assess the results of maintenance, periodic testing, and inspection. Results derived from these programmes are used to review the adequacy of the design, construction and operation of the disposal facility and to identify any implications for post-closure safety [8].

3.4.5 Long-Term Disposal System Evolution

In general, uncertainties in long-term evolution of a disposal system and of its environment are addressed in safety assessments as follows:

1. Uncertainties in parameter values may be captured in parameter value distributions for use in probabilistic assessments, or upper and lower values of a range for use in deterministic assessments. A probabilistic model of the system in which parameters are assigned probability density functions is challenging when there is a large number of uncertain parameters with ill-defined correlations.
2. Uncertainties in barrier performance may be captured by defining different scenarios of disposal system evolution based on different assumptions about how the barriers provide safety functions when subject to the effects of uncertain events or processes.
3. Uncertainties in conditions in the very long-term may be treated by defining different scenarios of disposal system evolution (such as associated with different assumptions about climate change and its impacts or seismic events) and assessing those scenarios deterministically.

Deterministic assessments generally consider a base or reference scenario which describes the features of the disposal system at closure and the way in which that system is expected to evolve. Deviations from the base scenario, caused by FEPs that may or may not occur are considered as variant scenarios. The Belgian Category A assessment makes a distinction between the reference scenario used to make a conservative assessment of the radiological impact of the facility and more realistic expected evolution scenarios used to perform uncertainty analyses, understand the behaviour of the system, and assess its performance.

It is difficult to make a statement on anything related to human activities on a long timeframe; therefore, human activities relevant to long-term safety assessments are always likely to be highly uncertain. However, for natural and engineered barrier system evolution, it should be possible to reduce uncertainty over their long-term performance by doing more research. A better understanding of the system will always generally lead to less uncertainty, but there is a limit where the improvement in understanding becomes marginal with more work. An analysis of the system uncertainties can be used to define an appropriate timescale for probabilistic calculations of risk; that is a timescale during which all significant uncertainties can reasonably be represented explicitly.

For uncertainties that cannot readily be quantified, it is worth considering the timescale on which these become more significant than those that can be quantified. Specifically, at the point at which cycles of major climate change (including glaciations) become possible, significant unquantifiable uncertainties relating to the evolution of a disposal system exist. Beyond this timescale, deterministic 'what-if' calculations and reasoned qualitative arguments might be preferred over probabilistic analysis to illustrate possible system performance.

Qualitative arguments regarding uncertainties in long-term evolution might involve consideration of natural analogues, balancing increasing uncertainty with time against the decrease in radiotoxicity, arguments about the overall robustness of the disposal system and how small releases will be under any plausible conditions, comparison of calculated impacts to something understandable to the general public (i.e., an everyday reference), comparison to other risks, and comparison between disposal options (e.g. the impacts of 'leaving it lying around').

3.4.6 Data and Models

At the early stages of a disposal programme, the amount of data collected may be limited. But with time, it will increase. How data are stored and recorded is important:

1. A formal data management system can ensure the quality of data at all levels in the safety assessment models. The system may have a different nature for higher-level models, compared to what is needed for detailed data (e.g., from site characterisation).
2. There are likely to be various hierarchies of models through which data, and information about uncertainties need to be propagated. In some cases, this might be done mathematically, for example using models to provide upscaled parameters for a larger-scale model. In other cases, there may be an expert judgment input to define probability density functions or bounding values for parameters of a higher-level model, given experimental data and results of more detailed process models. The process followed to establish an expert judgment should seek to minimise biases using a formal, traceable and transparent approach.
3. A data management system will need to store metadata alongside the data itself, including provenance and sources of uncertainty.

For the Belgian regulatory body, ensuring the quality of the data involves identifying available knowledge relevant to the assessment, verifying the reproducibility of the results of measurements and experiments, justifying the non-consideration of *a priori* relevant knowledge and identifying, where appropriate, the cause of disparate or contradictory data.

Uncertainty in data can be propagated through the safety assessment by means of probabilistic calculations or by best-estimate values and so-called bounding values that represent physical limits or relatively unlikely values. In France, a scenario 'catalogue' has been developed to manage the fairly small amount of data acquired from R&D, notably in Tournemire. The catalogue is used by the various teams undertaking particular activities (including those developing scenarios and those modelling radionuclide transport) and is continuously fed with results of R&D from researchers. In the Swedish programme, the selection of the data for calculations of radionuclide transport conforms to a number of principles [13]. For instance, the selection of data should be justified either directly or via references to other critically-reviewed work. If the same parameter is used in different analyses, the same parameter values should normally be used, but if different data are used, the reason should be explained. The uncertainties in the data should always be discussed and quantified, if possible. Data with quantified uncertainties should be used, if possible, for probabilistic calculations. If there are no quantified uncertainties, realistic data should be used and, where warranted, conservative estimates considered.

The term 'model uncertainty' can be defined as the uncertainty in the calculation models used in the safety assessment (see e.g., [14]). Where realistic assumptions cannot be supported in models, assumptions can be made so that the consequences of unfavourable processes are overestimated and conversely so that the potentially positive consequences of favourable processes are underestimated or neglected [13]. Alternative models or alternative approaches to simplification are sometimes used to illustrate uncertainties caused by model simplifications.

Avoiding or minimising these uncertainties implies that the models and computer codes used in the safety assessment are verified and, to the extent possible, validated [8]. Model verification is the process of determining that a computational model correctly implements the intended conceptual model or mathematical model. It includes ensuring that the numerical solutions provided by the computational model are sufficiently accurate for their intended use. System code verification is the review of source coding in relation to its description in the system code documentation. Model validation is the process of determining whether a conceptual and/or computational model is an adequate representation of the real case being modelled, by comparing the predictions of the model with observations of the real case or with experimental data. Code validation is the assessment of the accuracy of values predicted by the code against relevant experimental data for the important phenomena expected to occur. For codes and models used in a post-closure safety assessment, validation usually involves comparing the results of specific process simulations with experimental data, field observations, and/or natural analogues. Monitoring programmes also contribute to building confidence in and refining the key assumptions and models made in the safety case [8].

Well-documented records of the decisions and assumptions made in the development of the models used in deriving a particular set of results for safety assessment purposes is also necessary to justify and allow traceability of model development processes [12].

3.4.7 Completeness of FEP and Scenario Analysis

It may not be possible to guarantee that all FEPs have been identified, but it is necessary to determine whether the scope of the identification is sufficient for the needs of the safety assessment [13]. At a high level, geological disposal is by itself a means of mitigating completeness uncertainty in that it makes large uncertainties related to the evolution of human societies insignificant for safety. The implementer of a disposal programme should also ensure that they have an adequate understanding of the characteristics of the facility and of its host environment, as well as of the factors that could affect its safety after closure for sufficiently long periods of time. Completeness uncertainty can thus be reduced through the use of well-understood and compatible materials for the engineered barriers and the selection of a host rock that is unlikely to be affected in the future by any unrecognised natural phenomenon or future human action. Further measures include the continuous application of a FEP management process throughout the disposal programme and the use of appropriate safety margins in the design of engineered repository components (e.g., cautious waste container thickness). Also, an RD&D programme that monitors and participates in a range of international collaborative projects in the field of radioactive waste disposal, along with a disposal programme that has a duration spanning several generations, help to reduce completeness uncertainty to acceptable levels.

As regards FEP management, a safety case is likely to include a FEP analysis with a justification of why FEPs are discarded from scenario development or how they have been treated. The scenario development methodology should also provide sufficient confidence in the completeness of the scenarios and, hence, minimise uncertainties associated with the completeness of the FEPs considered in the safety assessment. The respondents identified different FEP management approaches striving for the completeness of FEPs considered in the safety assessment:

- Cross-check of the FEP list used in the safety case with international and other programme-specific FEP lists.
- Cross-check of FEPs against identified safety functions.
- Audit showing which FEPs from internationally agreed lists are included in the models for different scenarios, and which are not, including justification.
- FEP screening and review by multi-disciplinary expert groups.
- Use of the FEP list as a tool for consistency and completeness checking during the development of the assessment basis. Such checks are a form of 'internal independent review' of ongoing activities that can lead to changes in the RD&D programme.
- Use of the FEP list for completeness checking at various points during safety assessment as part of the quality assurance of the assessment.

Altered evolution scenarios and what-if scenarios assuming the loss of a barrier or a safety function can also be used to assess the robustness and defence-in-depth provided by the disposal system. Such an approach allows substantiating that some degree of uncertainty in the completeness of FEPs would not jeopardise safety. For instance, if it can be shown that very long periods of time are still necessary before radionuclides leave the host formation, FEPs associated with shorter timescales in the overburden and biosphere can be neglected.

Measures to deal with the possible occurrence of new uncertainties during programme implementation will also contribute to the management of these FEP uncertainties (see Section 3.2.3).

4. Discussion and Conclusions

This report presents the findings of Sub-Task 2.1 of the WP UMAN of the EURAD project. UMAN is focused on developing a common understanding among WMOs, TSOs, REs and civil society of strategies and approaches for managing uncertainties by sharing knowledge and identifying remaining and emerging issues. Sub-Task 2.1 is focused specifically on identifying generic strategies for managing uncertainties. The Sub-Task 2.1 work has largely drawn on responses from WMOs, TSOs and REs to a questionnaire produced for the UMAN project to facilitate information gathering. Reports from IAEA and international collaborative projects such as the EC PAMINA project, the Pilot Study on regulatory review of safety cases, the WENRA initiative and the NEA MeSA project also provide extensive background on uncertainty management strategies.

4.1 Discussion

Responses to the Sub-Task 2.1 components of the UMAN questionnaire were received from eleven WMOs and eight TSOs. REs were asked only to consider specific questions regarding the management of uncertainty evolution and of uncertainties relating to the very long timescales that require consideration in radioactive waste disposal facility safety cases. Ten REs provided responses to at least one of these questions. Responses were highly varied in style and content, ranging from brief summary statements of approaches to uncertainty management or references out to technical reports and lengthy discussions of broader safety case strategies. However, this review has aimed to draw out from these responses a balanced view on general approaches to uncertainty management.

Respondents provided information relating to programmes for near-surface and geological disposal of radioactive waste. The development of near-surface disposal facilities is generally more advanced than for geological disposal facilities. The different safety requirements of near-surface and geological disposal facilities do not affect the need to manage uncertainties, although there is of course greater emphasis on the need to consider uncertainties in the long-term evolution of geological disposal systems for long-lived radioactive wastes.

Regulatory requirements influence the types of uncertainty that need to be addressed in a safety case. It is generally required to demonstrate that uncertainties are adequately taken into account and to describe the programme for uncertainty management in the safety case. In some countries, detailed guidance is provided on how uncertainties should be managed. In other countries, no such regulatory guidance is available.

Safety strategies, and therefore approaches to managing uncertainties, are at different stages of development in different countries depending on the phase of the disposal programme. In general, an iterative approach is required to manage uncertainties as the disposal programme progresses through each phase of its development, and an iterative approach must be taken to activities aimed at reducing or mitigating uncertainties. Note that, as well as producing safety assessments at disposal facility licensing stages, the production of safety assessments at early stages of facility development facilitates early identification of safety-relevant uncertainties and provides guidance to RD&D activities.

Given the typically long timescales in disposal facility implementation, it is important for suitable knowledge management systems to be in place. In some countries, a formal register of key uncertainties is maintained in order to ensure that knowledge is retained and informs future phases of disposal system development and research needs.

The process of identifying and characterising uncertainties, and defining activities to avoid, mitigate or reduce key uncertainties, is common to all disposal programmes. Generally, a FEP and scenario analysis is adopted to address uncertainties in the initial and future states of a disposal system, with a range of probabilistic and deterministic approaches used to evaluate the impacts of different types of uncertain parameters on safety and determine the uncertainties that are most significant to the safety case. Quantitative assessment of uncertainties can be supported by alternative lines of reasoning, such as the use of natural and anthropogenic analogues.

It is important also to consider other types of uncertainty, such as those associated with the radioactive waste management programme and other prevailing circumstances. Several of these uncertainties can be mitigated through actions such as stakeholder communication and involvement, regular review of strategy, monitoring of costs and allocation of resources. Uncertainty in techniques used for disposal facility construction, operation and closure and associated costs are difficult to assess, so techniques that are currently available are assumed. Uncertainties in the waste inventory are generally addressed by assessing alternative inventories, for example, associated with different assumptions about national programmes for building new nuclear power stations or different waste management routes. Uncertainties in disposal concepts also require consideration, especially prior to identification of a site for a disposal facility. For example, a range of illustrative concept designs may be assessed to cover the disposal of different types of waste in different potential geological environments.

Uncertainties in conditions at facility closure may be addressed through analysis of potential material quality control or barrier emplacement errors, which may be used to define alternative disposal system evolution scenarios. Other uncertainties in disposal system performance may be managed through decisions about backfilling and closure options and schedules (e.g., to optimise reversibility or waste retrievability).

The use of an appropriate data management system and the verification and validation of codes and models are important means to manage uncertainties associated with data and models used in the safety case.

Completeness uncertainty (i.e. relating to comprehensive understanding of FEPs that affect disposal system evolution) can be reduced through the use of well-understood and compatible materials for the engineered barriers and the selection of a host rock that is unlikely to be affected in the future by any unrecognised natural phenomenon or future human action. Further measures include the use of appropriate safety margins in the design of the repository. Also, conducting an RD&D programme that monitors and participates in international collaborative projects and the continuous application of a FEP management process throughout the disposal programme contribute to reducing completeness uncertainty to acceptable levels.

Strategies for addressing significant remaining uncertainties will involve a mixture of reduction, avoidance and mitigation activities, such as R&D, data acquisition, waste characterisation, site selection and site characterisation. However, increased R&D is not likely to reduce unquantifiable uncertainties, particularly those relating to very long assessment timescales. Similarly, designing engineering for retrievability will not reduce such uncertainties. More generally, there may be benefits in clearly distinguishing between uncertainties that can be reduced substantially prior to an important programme decision and uncertainties that cannot.

Various measures can be taken to deal with the possible occurrence of new uncertainties emerging in the course of the disposal programme. These measures include the implementation of a stepwise and flexible decision-making process, implementation of a management system in the various activities carried out in the programme, and use of the defence in depth principle or of a continuous improvement programme. The use of proven methods and materials as well as the promotion of a strong safety culture within organisations involved in the programme can also contribute to the identification or avoidance of new uncertainties.

Finally, stakeholder communication and involvement are important aspects of uncertainty management. Public acceptance requires discussions about the uncertainties to be systematic, accessible, transparent, and appreciative of diversity in the opinion and knowledge basis of stakeholders.

4.2 Needs for Further Developments

Topics in uncertainty management that could be developed further are as follows:

- Communication of uncertainty management with stakeholders, especially how uncertainties that are likely to be irreducible are addressed.
- Approaches to addressing uncertainties in long-term performance, especially where there are differences in regulatory requirements and guidance. For example, constraints may be applied for certain timescales (e.g., 10,000 years). Such constraints may be considered only as reference levels for assessments of, say, stylised scenarios of more uncertain events, such as may be associated with longer timescales. Alternatively, higher constraints may be applied for assessments on long timescales.
- Digital systems for data and uncertainty management to support knowledge management over long disposal programme development periods.
- Links between uncertainty management and FEP management.
- Links between uncertainty management and optimisation.
- Links between uncertainty management, defence in depth approaches, reversibility and retrievability.
- Links between uncertainty management and monitoring (e.g., contribution to model validation, confirmation of model assumptions and FEP analysis).
- Role of WAC in the management of uncertainties on the waste inventory.
- Management of uncertainties on the conditions at closure which are dependent on both the as-built properties (and thus involving demonstrating technical feasibility and QA/QC measures) and the ageing and prevailing conditions during the operational phase (and thus the link with the inspection, maintenance and monitoring programmes as well as with operating limits and conditions associated with the facility). There is also a link between scenario development and the design (see e.g., the work performed by the IAEA GEOSAF project on design envelopes and targets [15]).

5. References

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Appendix A. UMAN Questionnaire

Section A.1 shows Parts 1 and 4, and Question 3.2b of the UMAN questionnaire, Section A.2 presents tables of the WMO and TSO responses to these parts of the questionnaire and Section A.3 presents tables of the RE responses to Questions 4.3e and 3.2b.

A.1 UMAN Questionnaire Parts 1 and 4, and Question 3.2b

Table A-1 shows the questions that form Parts 1 and 4 of the UMAN questionnaire, as well as Question 3.2b from Part 3. Questions are shown in bold and guidance is provided as necessary on the type of information required in response.

Table A-1: UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – Part 4 –
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:*** ***1.1b From which country and organisation are you?*** ***1.1c Type of your organisation (WMO, TSO)?***	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:*** ***1.2b Please explain briefly your role in your organisation and your background.***	
1.3 What is the mission of your national radioactive waste disposal programme(s)? *Provide information on the programme mission, which might be, for example, to develop a near-surface disposal facility for the nation's short-lived intermediate level waste, or a geological disposal for spent fuel from civil nuclear power reactors.*	
1.4 At what phase is/are the radioactive waste disposal programme(s)? *The programme(s) might be at an early stage of concept development with no particular disposal site or geological environment identified (Phase 0: Policy, framework and programme establishment), a site identification and selection process may be ongoing (Phase 1: Site evaluation and site selection), characterisation of a candidate site(s) may be underway while licence may be being sought for construction (Phase 2: Site characterisation), the facility may be under construction (Phase 3: Facility construction), disposal operations may be progressing (Phase 4: Facility operation and closure) or the facility may be closed (Phase 5: Post-closure).*	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Part 4. Strategies for managing uncertainties
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.*** ***4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.***
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.*** ***4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).*** ***4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).*** ***4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.*** ***4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.*** ***4.2f Other information that you would like to add:***
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?*** *Provide information on how any uncertainties in the implementation of disposal facility construction, operations and closure are managed and addressed in a safety case (uncertainties in the schedule, socio-economic uncertainties,…).* ***4.3b How are uncertainties related to waste inventory managed?*** *Provide high level information on how these uncertainties are managed (uncertainties in the volumes, activities, physico-chemical properties,…). This may involve consideration of different inventory scenarios, based on different assumptions about waste (re-)processing (i.e. waste pre-treatment, treatment and conditioning options), disposal routes, future energy policy and reactor operation*

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)

schedules. Also, provide information on how these uncertainties are recorded and on how they are captured in safety cases.

4.3c How are disposal concept uncertainties managed?

Uncertainties in the disposal concept to be implemented may be substantial early in the disposal facility implementation programme. Provide information on how such uncertainties are managed. Prior to site selection and characterisation, this may be through generic safety assessments based on consideration of disposal concepts appropriate to different types of near-surface or geological environment.

4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?

Describe, at a high level, how uncertainties in the properties of the barrier system and in the conditions prevailing in the system (temperature, saturation,…) at the time of facility closure and in the long term after closure are managed (including the types of methods that are used to avoid, mitigate or reduce these uncertainties). For example:

(1) uncertainties in parameter values may be captured in parameter value distributions for use in probabilistic assessments

(2) uncertainties in barrier performance may be captured by defining different scenarios of disposal system evolution based on different assumptions about how the barriers provide safety functions when subject to the effects of uncertain events or processes

(3) analysis of potential material quality control or barrier emplacement errors may be used to define alternative disposal system evolution scenarios based on different assumptions about conditions at the time of facility closure

(4) uncertainties in conditions in the very long term (hundreds of thousands of years or more) may be treated by defining different scenarios of disposal system evolution (such as associated with different assumptions about climate change and its impacts or seismic events) and assessing those scenarios deterministically

(5) uncertainties in disposal system performance may be managed through decisions about backfilling and closure options and schedules (e.g., backfilling and sealing may be implemented or scheduled in a way that optimises reversibility or waste retrievability)

(6) in some cases, research and experiments may support uncertainty reduction, but uncertainty reduction may be challenging when considering very long-term evolution or human intrusion.

4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?

If yes, please answer to the questions e-1) and e-2). If no, please go to question f).

4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?

4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?

4.3f How are uncertainties in the understanding of key processes managed?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
The results of research on processes underlying barrier system performance and contaminant behaviour may be interpreted in different ways such as to lead to different understanding of processes at a conceptual level. Provide information on how such uncertainties are managed, such as through the implementation of different conceptual models of system behaviour. ***4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?*** *Large amounts of data on disposal system performance and contaminant behaviour will be acquired through the research and development activities that support the disposal facility implementation programme, as well as through waste characterisation, site characterisation, site selection and disposal system design, construction and monitoring. Describe procedures for recording and managing uncertainties associated with the data acquired through these activities and ensuring that they are propagated through to the safety assessment (e.g. through abstracted parameter value distributions). This may include bounding analyses or methods for representing acquired data in detailed system models and deriving parameter value distributions for safety assessment models based on the outputs of the detailed models.* ***4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?*** *Lists of potentially safety-relevant features, events and processes (FEP) are commonly used when designing and assessing the safety of disposal facilities. Describe procedures for managing uncertainties associated with the completeness of such lists as well as of considered scenarios. For example, it may not be possible to determine with certainty whether a FEP should be included in a safety case or how a FEP should be treated in the early phases of the disposal programme. How are uncertainties associated with such decisions recorded and managed?* ***4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.***
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases (only one question)
3.2: Some uncertainties will decrease as new information becomes available (e.g. “as-built” properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***

A.2 WMO and TSO Responses to UMAN Questionnaire (Parts 1 and 4, and Question 3.2b)

The WMO and TSO respondents to Parts 1 and 4, and Question 3.2b of the UMAN questionnaire are listed in Table A-2. The responses are provided in Table A-3 to Table A-21, as indicated in Table A-2.

Table A-2: WMO and TSO respondents to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

Organisation	Country	Type	Table No.
ARAO	Slovenia	WMO	Table A-3
COVRA	Netherlands	WMO	Table A-4
Danish Decommissioning (DEKOM)	Denmark	WMO	Table A-5
ENRESA	Spain	WMO	Table A-6
Nagra	Switzerland	WMO	Table A-7
ONDRAF/NIRAS	Belgium	WMO	Table A-8
RWM (NDA)	UK	WMO	Table A-9
SKB	Sweden	WMO	Table A-10
SÚRAO	Czech Republic	WMO	Table A-11
Bel V	Belgium	TSO	Table A-12
TS ENERCON	Hungary	TSO	Table A-13
EIMV	Slovenia	TSO	Table A-14
IRSN	France	TSO	Table A-15
NRG	Netherlands	TSO	Table A-16
SSTC NRS	Ukraine	TSO	Table A-17
VTT	Finland	TSO	Table A-18
SURO	Czech Republic	TSO	Table A-19
BGE	Germany	WMO	Table A-20
Andra	France	WMO	Table A-21

Table A-3: ARAO (Slovenia) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 27 September 2019 Part 4 – 30 September 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Leon Kegel	
1.1b From which country and organisation are you?	
Slovenia, ARAO	
1.1c Type of your organisation (WMO, TSO)?	
WMO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Safety assessment, Management, decommissioning, SF disposal, costing and funding	
1.2b Please explain briefly your role in your organisation and your background.	
Head of ARAO Planning and Development Section	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
To operate central storage facility for institutional RW, to develop and construct and operate a near-surface disposal facility for the nation's short-lived intermediate level waste and to develop and construct and operate a geological disposal for spent fuel from civil nuclear power reactors. In parallel we are also involved in activities related to possibility of establishment of regional/multinational repository for HLW&SF (dual track approach). ARAO is also responsible for performing long-term institutional control and maintenance of closed disposal sites of closed uranium mine.	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
LILW repository in phase of construction permit approval, construction envisaged in late 2020. HLW and SF repository in early planning stage, reference design based on SKB Sweden with costs estimates updated in 2019.	
Part 4. Strategies for managing uncertainties	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
Safety analysis (PA/SA) is planned as an integral component of the site investigations and monitoring stage. Several levels of the PA/SA are distinguished, since the level of detail grows with increasing knowledge on the site and on the concept (Basic or generic, basic modeling and modeling in parallel with and on the basis of data from the site confirmation phase and the site investigation studies).
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.2f Other information that you would like to add:
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
Uncertainties in costs estimates are estimated using a Monte Carlo simulation and added to the project costs. Contingencies are divided into project and technology contingencies. Technology contingencies reflect uncertainties related to the maturity of the technologies used. They are based on the degree of uncertainty caused by use of innovative technologies. Project contingencies reflect the uncertainties related to the maturity of the project. This type of contingency covers expected omissions and unforeseen costs caused by an incomplete definition of the project and its engineering. Project contingencies thus compensate for the inherent estimate inaccuracy associated with each stage of a project. Due to the uncertainties in the site characteristics and type of geological formation, it is difficult at present to assess the suitability of each excavation technique. The properties of the rock and the effectiveness of different excavation techniques will be examined during excavation of a characterization tunnel in the phase of underground testing facility construction.
4.3b How are uncertainties related to waste inventory managed?
Inventory of RW ans SF is tracked, reported and estimated regularly (annually for operational inventory, 5 years for decommissioning). Uncertainties are managed through conservative inventory estimated allowing/planning enough capacity. Also several scenarios are prepared and updated regularly based on inventory, major milestones, stakeholders decisions, ...
4.3c How are disposal concept uncertainties managed?
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
No
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
4.3f How are uncertainties in the understanding of key processes managed?
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
Currently no full program of uncertainty is performed. Only costs related uncertainties are monitored and appropriate measures are developed and implemented.

Table A-4: COVRA (Netherlands) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 3 October 2019 Part 4 – 4 October 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Jeroen Bartol	
1.1b From which country and organisation are you?	
COVRA, Netherlands	
1.1c Type of your organisation (WMO, TSO)?	
WMO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Safety assessment	
1.2b Please explain briefly your role in your organisation and your background.	
I'm both steering research in rock salt as doing some own research like the safety assessment. I'm also responsible for the safety case in rock salt. It is important to know that the Netherlands has an early stage program (Phase 0: Policy, framework and programme establishment) and it is expected that a GDF will be built around 2100. As it is an early stage program, our research program is relatively small. I have a background and a PhD in tectonophysics (geophysics) and I have experience with the numerical models and have worked as a software engineer before I started working at COVRA about 2 years ago.	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
The official motto of our company is to continue to take care of radioactive waste in the Netherlands. The program mission is to develop a deep geological disposal facility for all radioactive waste: thus, for low, intermediate and (non) heat generating high-level waste including spent fuel.	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
Phase 0: Policy, framework and programme establishment	
Part 4. Strategies for managing uncertainties	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***
Reference values have been derived for the safety indicators like the Effective dose rate, Radiotoxicity concentration in biosphere water, and Radiotoxicity flux from geosphere. Each safety indicator was accompanied by a reference value that can serve as 'yardstick' to judge whether a calculation outcome can be considered safe.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
There is currently no specific requirements or guidance pertaining to how uncertainties should be managed. However, in previous research the following approaches are used: (1) Demonstrating that the uncertainty is irrelevant to the safety assessment, (2) Addressing the uncertainty explicitly – for example through a probabilistic approach or through a series of sensitivity studies, (3) Bounding the uncertainty, (4) Ruling out the uncertain event or process.
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
The safety assessments are expected to be produced already at the early stage of a program, when a disposal concept is developed. This is done to do a safety assessment on different disposal concept that have been proposed.
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
In the previous, the uncertainties are identified using FEP's in combination with scenarios. Subsequently, models are used to analysis the uncertainties and their impact. And when necessary, the disposal concept is adjusted for example.
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
As we are still an early program, still little has been done on the treatment of uncertainties. However, in some older research, a FEP list is constructed and from this list, scenarios are identified that could lead to the failure of the barrier system. Subsequently, a large number of deterministic analysis has been carried out to determine the sensitivity of the calculated dose rates on model parameters, the bandwidth in the results of the dose calculations, relevant design characteristics subject to potential improvement. In a later program, a probabilistic safety assessment has been performed for assessing the impact of a selected number of model parameters for the salt, groundwater, and biosphere compartments on the calculated exposure.
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
The uncertainties (and the method used) are recorded and written in reports.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
The uncertainties (and the method used) are recorded and written in reports.
4.2f Other information that you would like to add:
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
Construction of the repository starts in 2130. Because of that, there are uncertainties about the techniques that can be used for the disposal facility construction, operation and closure and associated costs. These uncertainties are managed (or better avoided) by using techniques that are currently available. New techniques will become available but will only be included when they have been tested and have been used/proven. For the cost estimate, the SSK method will be used that takes the uncertainty into account with larger uncertainties resulting in higher costs. Socio-economic are managed by collecting money for the GDF upfront and becoming the owner of the waste (and thus not being dependent on whether an organization still exist after many years).
4.3b How are uncertainties related to waste inventory managed?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
For the Netherlands, the uncertainties for the (non) heat generating high level waste is relatively small. This is because the construction of the repository is planned in 2130 and the nuclear industry is relatively small in the Netherlands. Moreover, the last (and only) nuclear power plant will be closed decades before the construction of the repository and there is no incentive to not reprocess the waste anymore; reprocessing has been done since the start of the nuclear powerplant. However, there is still some uncertainties due to the future energy policy and in the disposal concept we manage this by considering a disposal concept that can be easily extended using the same construction methods (a flexible concept thus). In the safety case, only an estimate is made on what we expect based on the past, the assumed future energy policy and reactor operation schedules. Although this could change, this will have little effect as there is still significant time left to change a repository. These uncertainties are captured by the safety cases by mentioning the assumption that have been made.
4.3c How are disposal concept uncertainties managed?
The disposal concepts are used to identify the uncertainties in the GDF that need attention. When identified, additional data from other sources like scientific journals and reports and other WMO's is collected when possible. This gives a first order envelop on the uncertainties. With the additional data, a generic safety assessment will be performed for different geological environments en host rocks.
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
These uncertainties are managed by different methods. For the uncertainties in parameter values, we expect to use a probabilistic assessment or taking the extreme values for the different properties. Currently, only values were selected aiming to compute the outer envelopes of the expected variations (minimum and maximum values) of the primary safety indicator. The parameter variations were grouped in order to reduce the number of necessary computations, and to allow a more straightforward communication of the outcome. The grouping is performed on basis of understanding of the main features of the disposal system, understanding of the effect of parameter variations on the overall system performance, and on previous analyses. Furthermore, for some of the waste packages are not considered as an engineered barrier system. It is assumed that they fail immediately after closure of the GDF. This is unlikely as the waste package might provide some containment for a certain period. For the other engineered barrier, we assume that they fail at the first possible moment and hence we assume the most pessimistic scenario for the barriers. Also, different disposal system evolution scenario's will (and have been) be defined. These will include human intrusion scenario but also others based on FEPS.
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
Yes
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
It will be very difficult to make any statement on anything related to humans on such a long term and therefore that remains highly uncertain. For other, more nature/geology/natural or engineered barrier system it would be possible by doing more precise research. A better understanding of the system would eventually lead to less uncertainty although there is a limit. I do however think that reversibility of decision process and/or retrievability of the waste will increase the uncertainty as the system will become more complicated.
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
To a certain degree it could do. One could think about quantifying climate change in a more precise manner and the effects of the climate change on, for example, the ground water or stresses in the underground. Another subject would be the geological situation (geological stresses and possible geological events). I do, however, not think that doing any research on human civilization (human intrusion) will be useful. The latter will only be speculation.
4.3f How are uncertainties in the understanding of key processes managed?
If the processes underlying barrier system performance and contaminant are interpreted in different ways, we would implement different conceptual models and see how they perform and compare their performance in a quantitative manner. If the difference between the two is very limited, additional research might not be necessary although that will depend in many factors like how different the concepts are, the importance of the process for the whole system performance etc. If the difference in barrier system performance is large, then new research will be needed that specifically addresses the difference between the processes at conceptual level.
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
As we are an early stage program, the amount of data collected is still limited. But with time, we expect (and is essentially unavoidable) that it will increase. How this will be stored and recorded is still unclear, but I can image that it will be stored in a database that include as much as possible information like (if applicable) the location, errors in measurement, equipment used for measurement etc. We expect that the data from the database will be used for the safety assessment by taking, for example, the bounding values (maximum – minimum values), default values, distribution of the values and run numerical models for multiple values. But we currently have no procedures to do this and to handle the uncertainties.
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
The completeness of a FEP list will always be difficult to determine. There is currently no particular procedure, but as there are multiple FEP list available created by multiple different independent parties in different time periods (during the 90's and 00's etc), we compare these list and cross check if all the FEP's have been taken into account followed by a brainstorm session if there are no FEP's missing. Note that we cannot exclude this, but after decades one would expect that all have been considered and that the FEP list is relative complete. Based on the FEP's, different scenarios for the evolution of the repository system are developed. To ensure that not an unmanageable number of scenarios are selected, a screening procedure was applied to the FEP list in order to identify and compile a manageable number of representative scenarios. To simplify this screening procedure, it was proposed to perform this screening for several well defined "states" of the barriers in the multi barrier system. For a state of the multi barrier system it is easier to screen the FEPs because: (1) In bypassed barriers transport related FEPs can be neglected and (2) Each multibarrier system state implies a relevant time scale for the nuclides to arrive in the biosphere. If for instance the isolation shield in the salt formation is not bypassed it takes very long times before the nuclides leave the salt formation and consequently short time FEPS in the overburden and biosphere can be neglected. All the decisions are recorded in reports.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***

Table A-5: DEKOM (Denmark) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 1 October 2019 Part 4 – 2 October 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Ole Kastbjerg Nielsen	
1.1b From which country and organisation are you?	
DK, Danish Decommissioning	
1.1c Type of your organisation (WMO, TSO)?	
WMO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Management	
1.2b Please explain briefly your role in your organisation and your background.	
Man. Director, been in organization for 16 yrs, prior to that in the environmental sector for 11 yrs. Social Science educational background.	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
GDF for all waste inventory (LLW and ILW, including a small amount of irradiated RF).	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
Early stage with formulated policy (Parliamentary Resolution) and upstart of geological survey.	
Part 4. Strategies for managing uncertainties	
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Impact on humans and the environment.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
None formulated yet.
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
When sites have been identified and chosen, and host geology is known. The safety assessment strategy not formulated yet.
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
See above.
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).
See above.
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
See above.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
See above.
4.2f Other information that you would like to add:
No
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Too preliminary to answer.
4.3b How are uncertainties related to waste inventory managed?
Too preliminary to answer.
4.3c How are disposal concept uncertainties managed?
Too preliminary to answer.
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
Too preliminary to answer.
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain? *If yes, please answer to the questions e-1) and e-2). If no, please go to question f).*
No
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
The models should be developed in the way which could prove the forecast also for very long time frames. And the inputs should be real as much as possible. Currently the copper barier which is used for SF disposal is under reinvestigation. Many approaches are based on SKB method, therefore this should be well addressed. The use of bentonite is investigated, but the current results of models do not support the lab results (BEACON). Reversibility and retrievability is just an addition, if something would go wrong.
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
As stated above: all results of models and laboratory investigations should be in agreement.
4.3f How are uncertainties in the understanding of key processes managed?
We have only a very limited amount of irradiated RF; hence the uncertainty over very long time periods may not be very important.
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
Too preliminary to answer, but there is uncertainty in data on especially legacy waste.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
Too preliminary to answer.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
Relevant to ensure political awareness of the long term necessity of sufficient resources and maintenance of competences.

Table A-6: ENRESA (Spain) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 24 September 2019 Part 4 – 26 September 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
INMACULADA LOPEZ	
1.1b From which country and organisation are you?	
ENRESA, Spain	
1.1c Type of your organisation (WMO, TSO)?	
WMO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Safety assessment, Management	
1.2b Please explain briefly your role in your organisation and your background.	
I am currently the head of LILW engineering department. Previously responsible for licensing and safety of the LILW disposal site in Spain El Cabril.	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
El Cabril operation support and RBMA disposal enlargement project	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
Phase 4: Facility operation	
Part 4. Strategies for managing uncertainties	
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Dose criteria requirement for public. Neither requirements nor guidance is provided regard to the management of uncertainties.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
Just generic request to treat adequately potential uncertainties
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
In the early design phase
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
Uncertainty management requirements are not elaborated, just generic requirements for the assessment of potential impact of uncertainties exists
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).
Determinictic, sensivility analysis (data, parameters, assumptions and scenarios), periodical update of safety assessment to implement gained knowledge (I&D programs, monitoring and surveillance)
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
It is key to be aware that certain phenomena dominate the amount of possible radionuclide releases by a vast margin, especially in terms of canister performance (any defect, or change in defect size will drown out other influences). Handling the different level uncertainties needs care and analysis, not simple mathematical tools.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
N/A
4.2f Other information that you would like to add:

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
Uncertainties are managed adopting a graded approach based on developing in an iterative manner he safety case and implementing a quality assurance program.
4.3b How are uncertainties related to waste inventory managed?
Uncertainties in the volumen are managed taking into account inventory scenarios (mainly, NNPP operational schedules). Activity, taking into account statistical methods, based on laboratory essay data collected through years from all NNPP in operation and different waste streams generated. Some physico-chemical properties are object of specific research projects. These uncertainties are recorded in specific reports which support technical arguments used in the safety case. All these activities mentioned are subject to quality control.
4.3c How are disposal concept uncertainties managed?
Disposal concept uncertainties are managed through a multi-attribution analysis related some significant aspect in order to select the optimal option or the best fit the criteria required and later through generic safety assessment.
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
1) Uncertainties in parameter values are captured in sensitivity analysis considering upper and lower value of the range in which parameter value is (2) Uncertainties in barrier performance are captured by defining different scenarios of disposal system evolution based on different assumptions about how the barriers provide safety functions when subject to the effects of uncertain events or processes (3) Uncertainties in barrier performance are treated implementing a cuality control in the accquisition of primary material to manufacture components of the barrier (4) Uncertainties in conditions in the long term (hundreds of thousands of years) are treated by defining different scenarios of disposal system evolution (such as associated with different assumptions about climate change and its impacts) and assessing those scenarios deterministically (5) Uncertainties in disposal system performance is also managed incorporating in the design technical options which optimises reversibility or waste retrievability in case of needed)
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
No
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Bad question. Of course it is a challenge, but it is the reality of what we must design/plan for in the safety case. We implement models that ensure the safety.
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
Performing sensitivity analysis for key parameters used for safety/performance assessment
4.3f How are uncertainties in the understanding of key processes managed?
Scenario formulation, parameter variations, probabilistic modelling and sensitivity analysis
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
Establishing a GIS database allowing to have all acquired data available and comparable
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
Different tools for this exist and each have their advantages and disadvantages.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
Implementing a strong safety culture; implementing a continuous improvement program; promote quality

Table A-7: Nagra (Switzerland) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 4 October 2019 Part 4 – 4 October 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Kaempfer Thomas	
1.1b From which country and organisation are you?	
Nagra, Switzerland	
1.1c Type of your organisation (WMO, TSO)?	
WMO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Safety assessment	
1.2b Please explain briefly your role in your organisation and your background.	
section head safety analysis; PhD materials science, MSc Mathematics	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
Nagra's mission is to implement safe deep geological repositories (DGR) for all radioactive waste arising from the use of nuclear energy and from medicine, industry and research. This should occur in a timely manner, in compliance with the regulations and at justifiable cost. The current planning strategy involves developing proposals for siting two types of repository, one for spent fuel (SF), vitrified high-level waste (HLW) and possibly long-lived intermediate-level waste (ILW), referred to hereafter as the HLW repository, and one for low- and intermediate-level waste (L/ILW repository).	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
Phase 1 (with ongoing characterization of 3 potential sites)	
Part 4. Strategies for managing uncertainties	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***
The compliance criteria for the post-closure phase are a dose limit of 0.1 mSv/a and a risk limit of 10^{-6}/a for human radiation exposure (note: this second criterion might be changed in the next revision of the regulatory guideline; however, it will remain a risk criterion), along with a small number of regulatory guiding principles. During operation a number of additional requirements are valid, e.g. with regard to criticality and radiation protection. Environmental protection criteria for chemotoxic substances exist as well.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
Regulatory guidance sets out a number of principles of how uncertainty should be addressed in safety assessments and other assessments. For instance, quality assurance measures aimed at avoiding potential errors are to be applied in safety assessment. This implies that quality assurance measures for handling data and performing quantitative or qualitative analyses as part of the safety assessments have to be put in place and documented. Further examples are requirements for scenario development, model qualification, uncertainty analysis and sensitivity analysis.
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
Safety assessments are carried out almost continuously, yet more formally ahead of upcoming milestones. For instance, current safety assessment activities at Nagra provide input to the site selection process and prepare for the general licence applications. A safety case as such is expected for each licensing step.
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
The management of uncertainty is a highly iterative process, in which different sources of uncertainty are continuously identified, characterized, quantified, assessed, communicated, discussed, ruled out, reduced, or rendered of less impact as part of site investigations, design development, and RD&D.
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
There are various approaches being adopted, depending on the type of uncertain information. These include using reference and alternative scenarios, taking averages, stylized assumptions, bounding assumptions, conservative assumptions, deterministic and probabilistic uncertainty analysis, local and global sensitivity analysis, model comparison, model benchmarking, model validation, etc. In the safety case, alternative lines of reasoning will also be presented.
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
There are currently no formal procedures to collect and manage different sources of uncertainty on its own. However, the RD&D process is continuously updating its priority plan based on the relevance of existing uncertainty, and site investigation is triggered through a formal process of identifying investigation objectives (based on a classification of and an analysis of consequences for remaining uncertainty)
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
Again, no formal procedure is established. However, project and review meetings provide platforms to exchange uncertainty issues and how they should be addressed.
4.2f Other information that you would like to add:
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
Such uncertainties are not considered explicitly in the safety case, but implicitly through uncertainty related e.g., to the state of the disposal system at closure based on expert judgement.
4.3b How are uncertainties related to waste inventory managed?
Switzerland has decided to phase our nuclear energy production, thus the overall amount of waste to be disposed of is relatively well defined. Major uncertainty relates to future waste that does not yet exist, and to the state of the waste (e.g. spent fuel) during operation of the facility. Generally, upper bounding values are used for the inventory to address remaining uncertainty.
4.3c How are disposal concept uncertainties managed?
Major design variants (e.g. ramp access vs. shaft access) are sometimes considered as discrete alternatives in a safety assessment if deemed relevant. Generally, since the next step in the Swiss Programme is the application for general licence applications that define the basic concepts of the disposal facility, such conceptual uncertainties are expected to be reduced substantially during the next couple of years.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
Regarding the examples above: (1) Probabilistic distributions are a priori only defined for parameters that are identified to be important based on the outcome of sensitivity analysis. (2, 3, 4) yes, this is how it will be done in the next formal safety assessment. (5) There is currently no formal trade-off between uncertainties with regard to post-closure evolution and the design of retrievability measures (in fact, the Swiss regulations state explicitly that measures for retrievability shall not compromise long-term safety). Nagra is confident that geological disposal can be implemented as planned and will be safe. Yet, retrieval is considered as an important fall-back option. (6) for very long-term evolution or human intrusion, different scenarios and stylized assumptions will help to manage related uncertainty.
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
No
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
4.3f How are uncertainties in the understanding of key processes managed?
Uncertainty in conceptual understanding may be addressed through competing conceptual models and associated mathematical/numerical models, provided this source of uncertainty is considered relevant in light of the overall level of uncertainty.
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
In the recent past, uncertainty in data has been captured and propagated through to safety assessment mostly by means of best-estimate values and so-called bounding values that represent physical limits or relatively unlikely values. The definition of likelihood has mostly been the result of expert judgement, while taking statistical measures into account where possible. This approach is currently being refined, e.g. in aligning the meaning of bounding values or in identifying data uncertainties that require a probabilistic description in terms of a probability density function (PDF).
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
On a high level, deep geological disposal is by itself a means of reducing completeness uncertainty in that it avoids large uncertainties related to the evolution of human societies. On a detailed level, completeness uncertainty is reduced through the use of well-understood and compatible materials for the engineered barriers and the selection of a host rock that, on the basis of its stability and well-understood geological history, is unlikely to be affected in the future by any unrecognised natural phenomenon or future human action. Further examples are the continuous application of the FEP management process throughout repository development and the use of appropriate safety margins in the design of engineered repository components (e.g., cautious canister thickness). Also, an RD&D programme that monitors and participates in a range of international collaborative projects in the field of radioactive waste disposal, along with a disposal programme that has a duration spanning several generations, help to reduce completeness uncertainty to acceptable levels.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
A topic that has not been addressed with the above questions of Part 4 is that of the reducibility of uncertainty. Of course, there are those rather theoretical definitions of aleatory and epistemic uncertainty but, in practice, a more useful classification is that between uncertainty that can substantially be reduced ahead of some important decision, and uncertainty that cannot. Nagra's aim is to better distinguish between these two types of uncertainty where possible; this ambition is partly also motivated by new regulatory guidance to site selection.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
An important measure is to establish general design principles that relate to, e.g., the use of established methods and materials. Also, a step-wise approach with appropriate level of detail at each decision step that keeps options open might help to accommodate for not-yet identified or unexpected evolution of uncertainty.

Table A-8: ONDRAF/NIRAS (Belgium) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

<table>
<tr><th colspan="2">EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)</th></tr>
<tr><td>Date:</td><td>Part 1 – 27 September 2019
Part 4 – 28 September 2019</td></tr>
<tr><td colspan="2">Part 1. Background information</td></tr>
<tr><td colspan="2">1.1 Name, country and organisation
1.1a Name and surname:</td></tr>
<tr><td colspan="2">Depaus Christophe</td></tr>
<tr><td colspan="2">1.1b From which country and organisation are you?</td></tr>
<tr><td colspan="2">Belgium</td></tr>
<tr><td colspan="2">1.1c Type of your organisation (WMO, TSO)?</td></tr>
<tr><td colspan="2">WMO</td></tr>
<tr><td colspan="2">1.2 What is your background and role in your organisation?
1.2a Please select your field(s) of work:</td></tr>
<tr><td colspan="2">Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Safety assessment, stakeholders'involvement, ethics, international nuclear law</td></tr>
<tr><td colspan="2">1.2b Please explain briefly your role in your organisation and your background.</td></tr>
<tr><td colspan="2">I am a mining engineer awarded by the Faculty of Polytechnics of the University of Brussels (ULB), hold a Master in Advanced Studies in Philosophy of Sciences (DEA) awarded by the Catholic University of Louvain (UCL) and an Academic degree in International Nuclear Law awarded by the University of Montpellier(UM1). Since 2009, I work as a safety assessor for the long-term management of high-level waste and spent fuel and am responsible of the interactions with the Belgian regulatory body for the geological disposal. As such, I try actively to integrate the scientific, technical, societal and legal aspects in the geological disposal project. Besides, I am involved in several IAEA projects or platforms such as GEOSAF and ARTEMIS.</td></tr>
<tr><td colspan="2">1.3 What is the mission of your national radioactive waste disposal programme(s)?</td></tr>
<tr><td colspan="2">Belgian agency for radioactive waste and enriched fissile materials (ONDRAF-NIRAS) is the Belgian radioactive waste management organization. ONDRAF/NIRAS’ overall responsibilities cover all management steps for waste on the Belgian territory (outside the production sites). In particular, ONDRAF/NIRAS has the monopoly for long-term management (i.e. disposal) of radioactive waste. ONDRAF/NIRAS develops a near-surface disposal facility for the nation’s short-lived intermediate level waste and leads a 40 years - R&D program in order to develop a geological disposal for high-level waste and spent fuels from civil nuclear power reactors</td></tr>
</table>

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
1.4 At what phase is/are the radioactive waste disposal programme(s)?
Geological disposal: 40 years of R&D but PHASE 0 Surface disposal : licensing on-going and site chosen/ PHASE 2
Part 4. Strategies for managing uncertainties
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***
0.3 mSv/an as dose constraint for the reference scenario and 0.1 mSv/an as dose constraint for the expected evolution scenario of a RW disposal For altered-evolution scenarios, the risk constraint is 10^{-6}/year/scenario and 10^{-5}/year for the individual detriment corresponding to the set of altered scenarios 3mSv/year is a reference value for the so-called penalising scenarios related to disposal (excerpts from regulatory guidances) In the case of drinkable water, the European directive 2013/51/ EURATOM specifies the following: Radon 100 Bq/l Tritium 100 Bq/l

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Concentrations dérivées pour la radioactivité dans les eaux destinées à la consommation humaine (1)

Origine	Nucléide	Concentration dérivée
Naturelle	U-238 (2)	3,0 Bq/l
	U-234 (2)	2,8 Bq/l
	Ra-226	0,5 Bq/l
	Ra-228	0,2 Bq/l
	Pb-210	0,2 Bq/l
	Po-210	0,1 Bq/l
Artificielle	C-14	240 Bq/l
	Sr-90	4,9 Bq/l
	Pu-239/Pu-240	0,6 Bq/l
	Am-241	0,7 Bq/l
	Co-60	40 Bq/l
	Cs-134	7,2 Bq/l
	Cs-137	11 Bq/l
	I-131	6,2 Bq/l

(1) Ce tableau comporte les valeurs des radionucléides naturels et artificiels les plus courants. Il s'agit de valeurs précises, calculées pour une dose de 0,1 mSv et une ingestion annuelle de 730 litres, compte tenu des coefficients de dose fixés à l'annexe III, tableau A, de la directive 96/29/Euratom; les concentrations dérivées pour les autres radionucléides peuvent être calculées sur la même base, et les valeurs peuvent être mises à jour à la lumière d'informations plus récentes reconnues par les autorités compétentes de l'État membre.

(2) Ce tableau ne tient compte que des propriétés radiologiques de l'uranium et non de sa toxicité chimique.

As for the chemotoxics in the underground water, the directives 2006/118 et 2014/80/UE apply:

Polluant	Normes de qualité
Nitrates	50 mg/l

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Liste Minimale des polluants et leurs indicateurs pour lesquels les États Membres doivent envisager d'établir des Valeurs seuils conformément à l'Article 3

1. Substances ou ions ou indicateurs qui peuvent à la fois être naturellement présents et/ou résulter de l'activité humaine

   Arsenic

   Cadmium

   Plomb

   Mercure

   Ammonium

   Chlorure

   Sulfates

Transposed in regional decrees (Flemish region or Walloon region)

4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.

Regulatory guidance (FANC) sets up the following flow-chart for the management of uncertainties:

Au niveau de l'analyse de sûreté, l'AFCN propose de distinguer les étapes suivantes (voir figure 1) :

Etape 1. identification des incertitudes

Etape 2. caractérisation des incertitudes

Etape 3. analyse de la pertinence pour la sûreté

Etape 4. traitement des incertitudes

Gestion des incertitudes

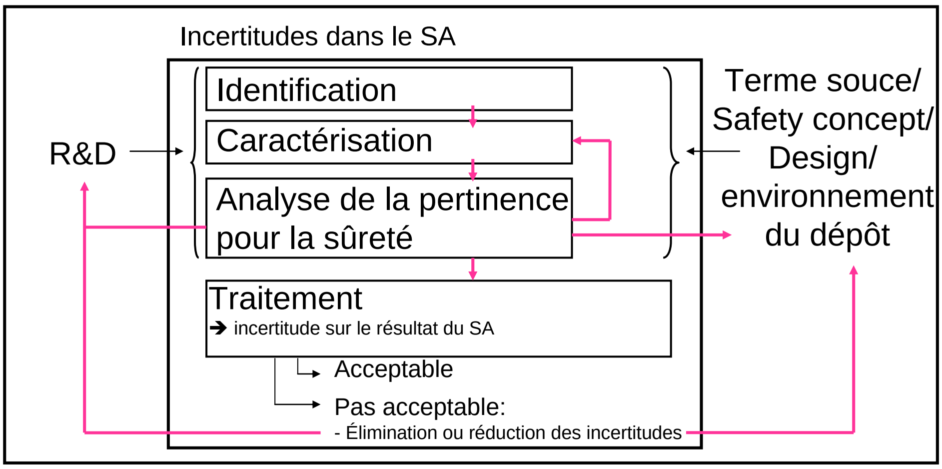

Figure 1 : Activités relatives à la gestion des incertitudes

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4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
See 4.2f
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
See 4.2f
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).
See 4.2f
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
See 4.2f
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
See 4.2f
4.2f Other information that you would like to add:
One response for all questions under 4.2 (a to f) has been provided by ONDRAF/NIRAS as follows: The Safety and Feasibility Statements as a Tool of the R&D An important high-level management choice made by ONDRAF/NIRAS was to *"… develop an integrating methodological tool to provide a synoptic view of the arguments supporting SFC1, address all requirements resulting from the safety concept, ensure that the safety principles are adhered to and enable the systematic assessment and evaluation of SFC1"*. The specifications for this tool and a short introduction of the tool chosen by ONDRAF/NIRAS, the safety and feasibility statements, are discussed in Section 2.6.1.4. This section provides a more thorough presentation of the safety and feasibility statements, their definition and purpose, their application within SFC1 and their current status and historical evolution. Definition and Purpose

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The safety and feasibility statements consist of claims regarding how the disposal system is expected to perform, and the properties that it has, relevant to the safety or feasibility of the system. Safety and feasibility statements are often expressions of the requirements on the disposal system as a whole, the various subsystems and the individual components. The statements are organised in a structured, hierarchical set, or tree, with lower-level claims underpinning higher-level claims as shown in Figure 3.2.

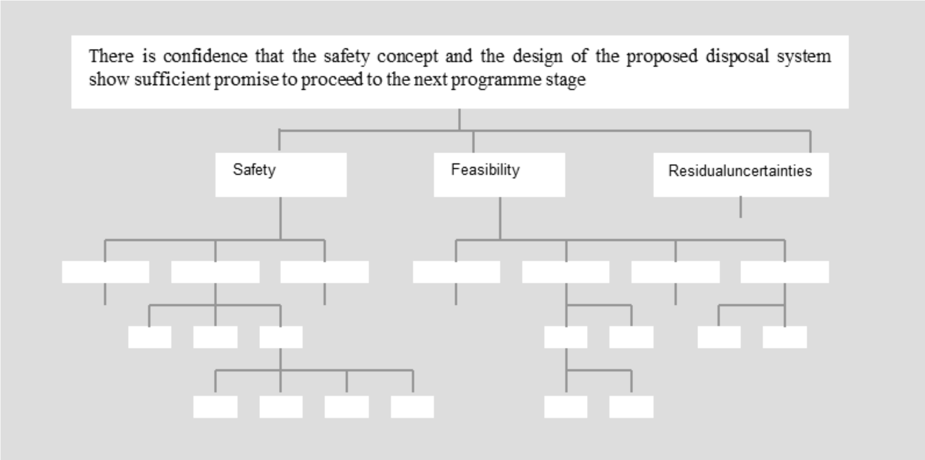

Figure 3.2 - Hierarchical structure of safety and feasibility statements

A first iteration of the set of safety and feasibility statements was made in the safety strategy document (ONDRAF/NIRAS TR2009-12E), the overall purpose being to support the safety strategy, and specifically:

the development of a safe and technically feasible disposal system based on an appropriate safety concept; and

the demonstration of the safety and feasibility of the disposal system (i.e. to support the safety case) via a theorem-demonstration approach.

The theorem-demonstration approach followed by ONDRAF/NIRAS was inspired by a certain level of pre-existing knowledge and understanding, such as the one developed from SAFIR and SAFIR2[3]. In the hierarchical structure, the top (high-level) statements are the most general ones and as the substantiation progresses the statements become increasingly more specific. For example a lower-level statement can be that the metal overpack for category C waste has no penetrating defects. Taken together these statements should substantiate the pivotal claim of SFC1 that "there is confidence that the safety concept and the design of the proposed system show sufficient promise to proceed to the next programme stage". This claim is underpinned by the three main branches of statements shown in Figure 3.2:

safety statements, which are discussed in more detail in Section 3.2.3;

feasibility statements;

residual uncertainties.

The feasibility statements aim to show that the proposed disposal system can be constructed, operated and progressively closed in a manner that is operationally safe and meets relevant technical

[3] The tool itself can be used however without pre-existily knowledge reflecting at the beginning general safety principles and following a strict top-down approach.

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requirements, and that its costs can be covered with the current funding mechanism. They comprise statements concerning (i) engineering practicality, (ii) operational safety, (iii) costs and (iv) quality assurance (see ONDRAF/NIRAS TR 2010-19E).

The residual uncertainties statements aim to show that uncertainties related to the proposed disposal system that remain at a given programme stage do not undermine the goals of the present stage and can be dealt with to the degree necessary for each future stage. Review and approval by the regulator of these propositions is one of the requirements that must be met, for the programme to proceed from one stage to the next. They comprise statements to the effect that (i), there are no uncertainties that call into question the capacity of the system to fulfil the requirements set for this Stage, which aims at "go-for-licensing" (see Section 2.2.2 and the upper feedback loop in Figure 2.3) and (ii), there are good prospects that future R&D will enable safety-relevant uncertainties for the requirements of the next stages to be reduced or even avoided (stages in the R&D loop, or the implementation loop depicted in Figure 2.3).

The structure and contents of this tree of statements are not static. Rather, they are developed iteratively as the programme progresses to account for changes in boundary conditions, as well as the better definition and firmer establishment of the safety concept and design and the development of the safety assessment.

Substantiation as a Guidance to RD&D Prioritisation

The formal safety assessment for SFC1 will only take place once key safety and feasibility statements are adequately substantiated given the objectives of the programme stage at hand, and, in particular, it is shown that the disposal system is most likely to evolve as defined by the safety concept. There will, however, be residual uncertainties, the consequences of which in terms of their impact on the safety functions will be evaluated in the course of the formal safety assessment (following which the right-most branch of the statements tree shown in Figure 3.2 is compiled).

In terms of the level of support available, safety and feasibility statements tend to be assessed from the bottom-up, beginning with lowest-level, most detailed statements and progressing to higher-level, broader statements (ONDRAF/NIRAS TR 2009-14E).

For the upper parts of the tree, the sufficiency based on the immediate lower-level statements can be evident or true by definition. For example, the statement that the "system is known" is evidently substantiated if the lower-level statements that "the system components can be characterised" and "the evolution can be bounded" are substantiated. Similarly, the statement that "the safety functions that have been defined can be relied upon" is, by definition, substantiated if the lower-level statements about the reliability of each individual safety function are substantiated.

The substantiation of the lower-level statements however, is generally not evident and it must be judged on the basis of the phenomenological understanding, documented for example in ONDRAF/NIRAS or other technical documents, and the arguments resulting from it. The evaluation of these arguments identifies any open issues that may need to be addressed through RD&D to strengthen an underpinning argument, as schematically shown in Figure 3.3, since an open issue that has a direct effect on the lowest-level statements will affect the ones above.

The relevance and significance of any open issues pertaining to the statements evaluated e.g. by expert judgement or by exploratory or safety calculations prior to the formal safety assessment for SFC1, which supports the formulation of an RD&D plan that sets proprieties for, e.g., experimental or literature studies and further exploratory or safety calculations. Issues that may have a negative impact to SFC1 are assigned the highest priority in the definition of the RD&D activities. For the open issues that do not have a negative impact for the current stage of SFC1, and hence are assigned lower priority at this stage, the issue is "flagged" for evaluation at the next stage. It is reasonable to

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expect that the level of support that will be required for statements in subsequent safety and feasibility cases will increase as the B&C programme progresses towards the licence application.

Through periodic reviews of the tree it can also be ensured that lower-level statements, which are substantiated, remain so in the light of advances in phenomenological understanding or changes, if any, in boundary conditions.

The use of the statements in the manner described above conforms to the management principle *"The integrating methodological tool shall be used to prioritise RD&D activities, manage the uncertainties within the current programme stage and assess the remaining uncertainties to be addressed in the next programme stage".*

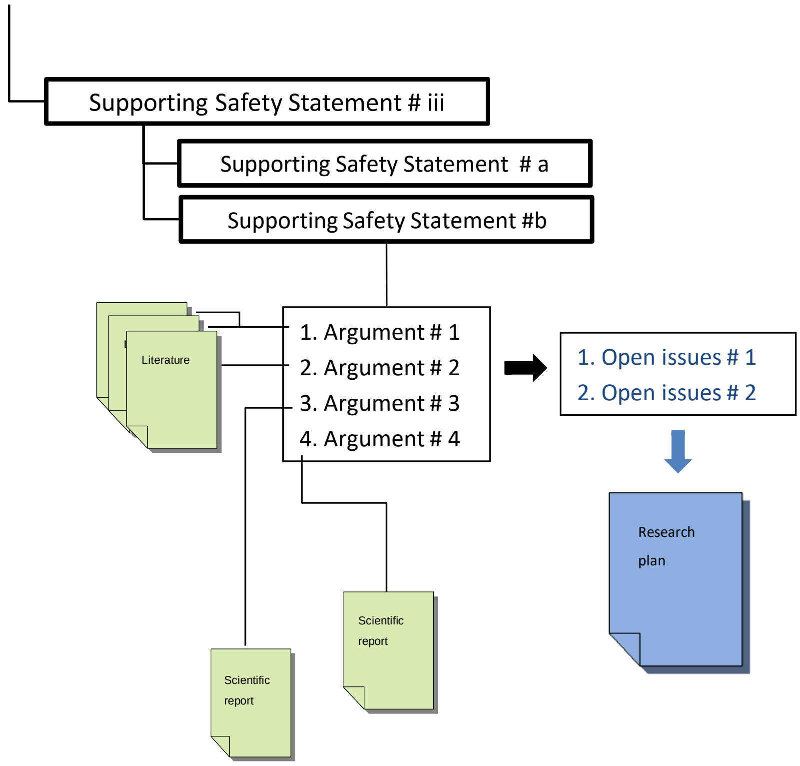

Figure 5.3 - The use of safety and feasibility statements for prioritisation of the R&D activities and development of corresponding RD&D plan.

Structure and Contents of the Safety Statements

Current Structure and Contents

The current structure of the safety and feasibility statements has been developed in anticipation of the formal safety assessment phase of SFC1. It has evolved over multiple iterations since the first set of the safety statements after SAFIR2 (Depaus and Capouet, 2012).

The structure of the safety statements branch is shown in Figure 3.4. At the highest level, this branch is defined by the statement that there is confidence in long-term safety. It is supported by the following three branches:

"the system is known"- the associated statements concern the characterisation and evolution of the system and its components (the features that are characterised include those that bring robustness and stability to the system and ensure long-term effectiveness of the safety functions, see below);

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"*the safety functions that have been defined are relied upon"* - the associated statements aim to show that the proposed disposal system will provide defence in depth over the long-term. *"the performance of the disposal system meets the requirements"* - the associated statements aim to show this on the basis of performance calculations and safety indicators, assessment of environmental impacts of chemically-toxic contaminants and comparison of these with nuclear and environmental regulatory requirements and other stakeholder requirements. Substantiation of the branch that the system is known is mainly based on knowledge acquired by the phenomenology pole, which identifies uncertainties and reduces them where necessary through RD&D. This substantiation is then challenged by the safety assessors (safety pole) who in turn want to underpin the substantiation of the statement that the safety functions have been defined, can be relied upon and, on the basis of exploratory safety calculations or substantiated expert judgements, the repository system meets the set requirements. Any knowledge gaps identified by the safety assessors that have a significant impact on the safety functions and the system performance must be considered through interactions with the phenomenology and technology poles and the RD&D plan must be adapted accordingly. Specific additional RD&D may also be required to support, e.g., the modelling of new scenarios and the calculation of new indicators identified by the safety pole. Keeping a certain level of autonomy between the development of the phenomenological knowledge and the development of the safety assessment, and the systematic interactions between the two groups, allows gaps in phenomenological understanding or inconsistencies in the abstractions made for the performance of the safety assessment to be identified, which is very beneficial to SFC1. At the same time it conforms to the management principle of *"… enabling and encouraging members to question, challenge and hence strengthen the evidence, arguments and analysis underlying SFC1"*. At the end of the preparatory phase the phenomenological statements are frozen and the substantiation of the statements concerning the safety functions is documented. The analysis of the argumentation of the lower level statements, and in particular, of its uncertainties, provides the basis for the definition of the scenarios and assessment cases of the safety case that will demonstrate compliance with the regulatory requirements. At the end of the formal phase, the statements concerning the performance of the system and its environmental impact are assessed against the respective regulatory requirements as well as the concerns of other stakeholders. This concluding phase leads to the substantiation of the statements (branches), *'The performance of the disposal system meets the requirements and the remaining uncertainties are identified and manageable'*. For the implementation phase, all the branches (long-term safety, feasibility, and residual uncertainties) must have reached the necessary standard of development.

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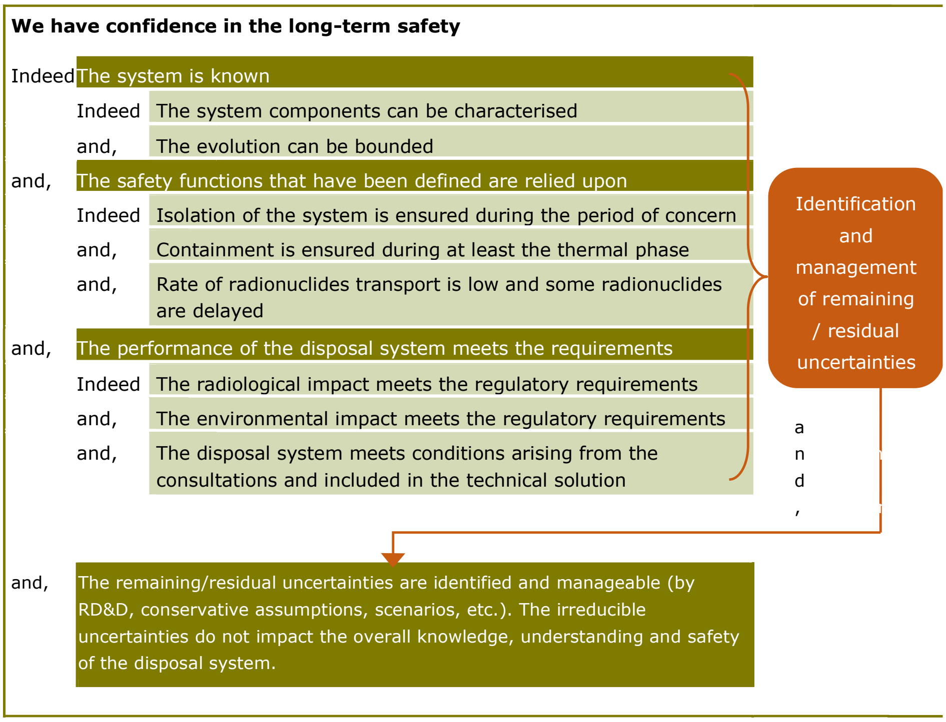

Figure 5.4 - Structure of safety statements in 2013

History and Evolution

The following paragraphs provide an outline of the history and evolution of the structure and contents of the safety statements, and the rationale for their present form.

After SAFIR2, a first set of safety statements was derived top-down from the safety functions. The on-going methodological work undertaken by ONDRAF/NIRAS in the framework of SFC1 has required a thorough rethink about the development and use of these statements. In particular, they have since been augmented with feasibility statements and progressively revised to take account of evolution in the boundary conditions (for example, new regulatory requirements) and in knowledge and understanding phenomenological factors affecting the validity of the statements, and also experience gained in their application as a tool for steering R&D and for supporting safety assessment. The statements are expected to be further refined or complemented, from one programme stage to the next, to reflect the more stringent requirements ensuing, in particular, from the necessity to progressively reduce safety-relevant uncertainties.

Minor revisions of the safety and feasibility statements have occurred as a result of interactions with stakeholders, such as the regulator, and of the development of the Waste Plan, which introduced, for example, the requirement of retrievability. More major modifications can be seen as a result of evolution of the programme from a focus on the justification of assumptions and derivation of parameter values for safety assessment modelling (SAFIR & SAFIR2) and towards the wider aspects of system understanding required for a safety case, driven by the iterative interactions between the safety assessors and the assessment basis poles (phenomenology and feasibility) during the preparatory phase of SFC1.

Proposals for potential modifications to the safety and feasibility statements have originated from discussions within ONDRAF/NIRAS. However, before implementation, these have also been discussed and evaluated in wider, interdisciplinary meetings (see Section 4.1). The final decisions on

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any modifications are however the responsibility of ONDRAF/NIRAS and are documented according to the structures defined in Section **Erreur ! Source du renvoi introuvable.**. The management system thus ensures that such changes are communicated to all relevant groups and all cross-checks are done to avoid any inconsistencies with other statements in the SFC1 and the assessment basis.

Specifically concerning the safety statements, evolution to date reflects the safety assessment methodology (ONDRAF/NIRAS TR 2009-14E), where two phases in the safety assessment are distinguished - a preparatory safety assessment phase and a formal safety assessment (Section 3.3). Preparatory safety assessments must give reasonable assurance to safety assessors, prior to the formal safety assessment being undertaken, that their findings will lend adequate support to the required safety and feasibility case. The preparatory safety assessment is thus carried out in parallel with the assessment basis development, and provides feedback to assessment basis development. In this context, the main role of the safety statements is the steering of the R&D. During this phase, the leaf statements i.e. the statements underpinned directly by the scientific knowledge in the assessment basis, are tuned to balance, on the one hand, the need to underpin higher-level statements related to the safety concept and requirements and, on the other, the specific types of evidence and arguments coming from assessment basis development. The first set of revisions, summarised in Box 3-1, occurred as a result of the preparatory safety assessment phase for SFC1.

The aim of safety assessment aims to evaluate quantitatively, why the disposal system is safe, taking into account the perturbing processes and events and associated uncertainties that could affect the validity of safety statements underpinning of the safety functions of the disposal system. In this context, the main role of the safety statements is to support the formulation of scenarios and assessment cases demonstrating compliance with the regulatory and other stakeholder requirements. The second set of revisions, summarised in Box 3-2, occurred in response to the needs of the formal safety assessment for SFC1.

Box 3-1: First set of revisions

The first set of revisions focussed mainly on the leaf safety statements. Initially, at the end of 2009 and through 2010, the main effort centred on reducing the level of complexity of the statements by ensuring each statement related to a single, well-defined idea or concept. To support this effort, the statements were renamed in order to indicate the safety function to which each statement is related.

In 2011, a review of the statements was undertaken to address various weaknesses that had been identified, such as different levels of detail between statements at the same level and a lack of completeness, that the statements did not cover all aspects of the R&D programme. Furthermore, the distinction between "necessary" statements and "nice-to-have" statements was dropped since it was found not to be useful.

Also in 2011, a check of consistency of the statements with NEA FEPs was performed (Galson, 2011a), as well as a preliminary study of the consistency of the safety statements with the feasibility statements (Galson, 2011b).

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Box 3-2: Second set of revisions

A weakness in the safety statements tree remaining after the first set of revisions, relevant for the formulation of scenarios in the safety assessment, was the lack of clear representation of evolving conditions. Furthermore, the principles of defence-in-depth, robustness and optimisation were not apparent in the statement structure and the linkage between the safety statements and feasibility was unclear.

A new structure for the safety statements (Figure 5.4) was evolved progressively to address these weaknesses. For example, within the upper-most statement, which relates to phenomenological knowledge about the system, statements about the nominal properties of the system and its components are separated from statements concerning evolution.

Using this new structure, it has been possible to critically assess the preliminary formulation of the reference scenario and reference case developed in the course of preparatory safety assessment in the light of uncertainties and open issues in phenomenological knowledge. This assessment was carried out in a workshop held in October 2011 at SCK-CEN in Mol, at which the aim was to establish a definition of the reference case for SFC1. The assessment also clearly highlighted those factors on which the robustness of the system rests.

The Role of the Safety and Feasibility Statements within the SFC1 Management System

The introduction of the safety and feasibility statements in the ONDRAF/NIRAS programme resulted in significant changes to the programme management. A notable change is the re-organisation of the RD&D programme around the need to substantiate the statements, leading to a more efficient and pertinent prioritisation of the issues.

As explained in Section 2.5.3.1, the highest-level safety statements are derived from the safety principles and the resulting safety functions - containment, retardation, isolation – that the disposal system has to fulfil to achieve the fundamental safety objective of protecting man and the environment from the risks associated with long-lived radioactive wastes and spent nuclear fuel. The safety statements link every activity performed in SFC1 to this fundamental safety objective of the project and ensure that SFC is *safety-driven*. Furthermore, the use of the safety and feasibility statements contributes to the fulfilment of a large number of management principles and directives of the management system, as synthesised in Section 2.7.

The safety and feasibility statements implement the principle: *'For the development and for sustaining an effective management system, it is imperative to have a clearly defined safety strategy with specific safety principles for the safety and feasibility case and for its development'*. Because the safety and feasibility statements are founded on the safety principles and the resulting safety functions, their derivation enforces the clear definition of a safety strategy, in addition to ensuring a safety-driven SFC1 as mentioned above.

The organisation of the statements in two panels, one for safety requirements and one for feasibility requirements, which are then developed top-down from the most general to the most specific, fulfils the management principle to "*provide a synoptic view of the arguments supporting SFC1, address all requirements resulting from the safety concept, ensure that the safety principles are adhered to and enable the systematic assessment and evaluation of SFC1".* Their regular evaluation to judge the progress of a RD&D plan in resolving specific issues or to assess the impact of the substantiation of

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one, low-level statement on other higher-level statements (in particular those related to the safety functions) demonstrates that *' … the safety case shall be developed in a stepwise manner with rigorous evaluation at the end of each step'.*

The branch in the hierarchy of safety statements dedicated to remaining uncertainties, completed at the end of the formal phase and upon submission of the safety case to the regulatory authorities, provides a rational foundation for the RD&D plan of the next safety case. It conforms to the principle of optimisation within a program stage and throughout the successive stages, since it facilitates the iterative process of continuous improvement to meet the system requirements. The management principle '*prioritise RD&D activities, manage the uncertainties within the current programme stage and assess the remaining uncertainties to be addressed in the next programme stage'* is therefore properly implemented. Note that the management of the uncertainties with the safety and feasibility statements satisfies the QA requirement of traceability.

The safety and feasibility statements implement the principle: *'The integrating tool shall be used to ensure that a high level of comprehensiveness is achieved and auditing against FEPs with potential detrimental effects is carried out'.* The use and role of the safety and feasibility statements in scenario development and in completeness checking is discussed in Section 3.4.1, where it is demonstrated how this management principle is implemented in the SFC1 methodology. Note that the 'substantiation' process (Section 3.2.2) leads to a multiplicity of supporting arguments for a safety statement, which contributes to the comprehensiveness requirement and also fulfils the safety principle of robustness.

Finally, through their clear structuring, the safety and feasibility statements facilitate the review and audit of SFC1 and enable it to be confirmed that the safety principles passive safety, robustness, defence-in-depth and best available techniques are met. Through these reviews, confidence in the demonstration of the safety case is enhanced and the demonstrability principle is also met. Thus they implement the principle : *'Expert reviews and audits shall be performed to ensure and confirm the quality of the assessment basis, methods, tools and results and that the repository system is developed considering multiple safety functions and FEPs that could potentially compromise one or more barriers or safety functions have been considered'.*

The discussion above shows the important role of the safety and feasibility statements in the development of SFC1. Their introduction as the integrating methodological tool to be used has been one of the key management decisions and has led to a substantial advancement of the safety assessment methodology and the management system for SFC1.

Comparison with Approaches of other National Programmes

To our knowledge, there is no strict analogue to the safety and feasibility statements internationally. However, especially over the last decade, an increasing emphasis on safety functions in the national geological programmes has allowed the structuring of R&D with a view to prioritising the issues according to their importance to safety level. In particular, many organisations have decomposed and translated the high level safety functions of their disposal systems into technical and functional requirements, so as to provide a link between the acquisition of scientific and technical knowledge and the requirements of safety and feasibility. The examples of two advanced national programmes are described in the following paragraphs.

An overview of all international developments with respect to assessment methodologies is given in Box 3-3, Section 3.3.1.

Nagra, Switzerland

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Nagra´s safety assessment methodology, as applied in Project Opalinus Clay [Nagra 2002], is built on a range of assessment principles with among others, the use of multiple arguments for safety. The disposal system is described and documented in the safety case in terms of a "system concept" and a "safety concept". The system concept includes a description of the key features of the system, events, processes and interactions that may affect its evolution, and of the possible paths that its evolution might take. The system concept corresponds to the left-most branch of the ONDRAF/NIRAS safety statement hierarchy shown in Figure 5.4. Based on the system concept, a conceptual understanding is developed of why the disposal system is safe - this is the safety concept. It includes a description of attributes of the disposal system that, based on scientific investigations and design studies, are expected to be key contributors to the safety functions of the disposal system. Due to the key contributions that these features make to the safety functions and the high level of scientific understanding that is available for them, allied to their insensitivity to perturbations (robustness), they are termed the "pillars of safety" of the disposal system. In the R&D carried out subsequent to Project Opalinus Clay, priority has been given to phenomena directly connected to the pillars of safety, since a further enhancement of understanding in these areas will strengthen future safety cases. The safety concept can be taken to correspond to the central branch of the ONDRAF/NIRAS safety statement hierarchy shown in Figure 5.4. The integration of scientific knowledge within the system concept and safety concept makes extensive use of "audit meetings" between the safety assessment group and staff from the science and technology group (e.g. geologists) in which the safety assessment group explains to the science and technology group how specific scientific information is being used within safety assessment. In these meetings, the key responsibility of the science and technology group is to provide feedback to the safety assessment group (either "agree" or "don't agree, suggest modifications to the approach as follows …."), with several iterations if necessary. A bias audit group has the role of ensuring that all relevant scientific understanding is taken into account in the safety assessment. The meetings serve a similar function to the ONDRAF/NIRAS interaction meetings (Section 4.1). Scenarios and assessment cases are developed from a consideration of uncertainties affecting the evolution of the system. The super-FEPs (broad groupings of related FEPs) that are represented within the scenarios and assessment cases are audited against a separately developed project-specific FEP database in order to promote completeness. Some poorly understood phenomena that are known to be favourable to safety are deliberately excluded from the scenarios and assessment cases. If there are judged to be good prospects for more realistic modelling of these phenomena at later stages of the programme (following advances in scientific understanding, or the development of improved models, codes and databases), they are termed reserve FEPs. The existence of such phenomena can be cited as a qualitative argument for safety margins within the safety case. **ANDRA, France** In its safety assessment ANDRA uses a functional analysis that is similar to the ONDRAF/NIRAS approach. The functional analysis aims at presenting how the safety functions are provided in different spatial and time frames, by decomposing them into subfunctions that are fulfilled by specific components of the repository. Each function or subfunction can be divided to a level of detail appropriate for the implementation (ANDRA, 2005). As in the ONDRAF/NIRAS approach, subfunctions are derived top-down from the safety functions. Important remarks on ANDRA's approach, also relevant for the ONDRAF/NIRAS approach, are as follows:

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There is no unique way to decompose the safety functions into component-specific subfunctions (similar to lower-level safety statements underlying high-level safety statements). Rather, the safety assessor chooses to make the decomposition, underpinned by the existing knowledge of the system, so as to provide enough confidence in the components to achieve the safety. This existing knowledge comes from previous programme stages.

Each safety function or subfunction (or safety statement) can contain a safety margin (not always quantifiable) that incorporates the idea of robustness of the system.

Even if the completeness check is a challenge one can keep in mind that the verification must be ongoing since the derivation of the functions (following a "logic tree") is only one realisation among many possible functions and function structures.

The Safety Assessment Methodology

Basis for Methodological Development

Long-term or post-closure safety assessment (referred to simply as safety assessment or SA in the present report) is the means by which various lines of evidence, argument and analyses for the long-term, radiological and non-radiological safety are identified and critically assessed. Typically, the main line of argument concerns the definition of scenarios and assessment (calculation) cases.

The results of the analyses of the scenarios and assessment cases, expressed in terms of safety indicators such as dose and risk, are compared with regulatory limits or guidelines. Additional performance and safety indicators may be calculated to enhance understanding of system performance and to improve the reliability of the results of the safety assessment (IGSC, 2012). In Belgium, after the domestic and international peer reviews of SAFIR2 in 2001 (ONDRAF/NIRAS TR 2001-05E and TR 2001-06E) and 2003 (NEA, 2003), which was the last major formal safety assessment exercise and a milestone in ONDRAF/NIRAS research, development and demonstration (RD&D) programme, ONDRAF/NIRAS decided to refine and formalise its safety assessment methodology. This update took account of ONDRAF/NIRAS own evaluation of the strengths and limitations of the methodology previously used, in particular regarding the treatment of uncertainties, as well as the conclusions and recommendations from the reviews of SAFIR2 and also recent international discussions and developments in safety assessment methodology (see Box 3-3). It was undertaken with a view to the requirements of SFC1 and subsequent safety and feasibility cases and the need to ensure coherency with the safety strategy.

Box 3-3: Example of international developments since the publication of safir 2

Following the completion of safir 2, several national programmes have published new safety assessments. Key safety assessments for disposal facilities for high-level waste and spent fuel include the following:

- in Switzerland, Project Opalinus Clay includes a safety assessment of a geological repository for spent fuel, vitrified waste from spent fuel reprocessing, and long-lived intermediate-level waste in a clay formation (Nagra NTB 02-05);
- in France, Dossier 2005 includes a safety assessment of a geological repository for waste types similar to those considered in Project Opalinus Clay, also in a clay formation (ANDRA CRP ADP 04-0001, 04-00022 and 04-00025);
- in Sweden, SR-Can and SR-Site include safety assessments of a geological repository for spent fuel in crystalline rock (SKB TR 06-09, TR 11-01).

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The methodologies adopted in these and other recent assessments share many common features, and, although each national programme learns from the experience of others, each one develops a methodology to suit its own specific needs, for example to fulfil the national regulatory requirements and meet aims of the current stage of the repository programme.

Safety assessment methodologies have been extensively reviewed and recommendations for future safety assessments have been made in a range of projects conducted under the auspices of the nea and the iaea. Key reports related to safety assessment methodology or aspects thereof include:

- the work on safety and performance indicators by the IAEA (IAEA TECDOL-1372), (Becker et al., 2003) and (Becker et al., 2009)
- the safety case report developed by the NEA (NEA 2004);
- the NEA timescales initiative (NEA 2006);
- the IAEA and NEA safety requirements for the geological disposal of radioactive waste (IAEA WS-R-4);
- the MeSA initiative (Van Luik et al., 2012).

The work on the safety case by the nea in particular emphasises the role of safety assessment and the safety case in the context of the stepwise process of disposal system planning and development, guided by an appropriate strategy.

The safety cases that were developed in the last decade are characterised by a high degree of sophistication and specialisation to satisfy the requirements of the respective national programmes. The safety assessment methodologies adopted within these safety cases, however, exhibit a number of common elements and conclusions (MeSA (Van Luik et al., 2012), paper #1, Sec.4), for example:

Safety assessment provides an analysis of the assessment basis gathered during the programme stage and at earlier stages, and guides iterative development of the disposal system and of the assessment basis by identifying key-safety relevant issues and setting priorities. Safety assessment, as applied to this latter aim, is preparatory safety assessment for the following stage.

The two-way feedback between safety assessment and development of the disposal system and assessment basis provide direction to the RD&D programme. Safety assessment can provide input to the setting of requirements and can evaluate impacts of the various features, events, processes and their associated uncertainties on the safety functions. Conversely, detailed knowledge is an important input to ensure that the disposal system is appropriately abstracted in the safety assessment models.

The role of the safety assessment in the active phase of RD&D leads to a variety of modelling activities. Besides the tools for the radiological assessment, further tools need to be designed and implemented, for example: to challenge the robustness of the system, to identify competing requirements and to perform sensitivity analyses of properties of the system or parts thereof.

Finally, the structure of safety assessment activities has greatly benefited from the increasing use of the safety functions in national programmes.

Overview of the Safety Assessment Methodology

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An overview of the safety assessment methodology is given in Figure 3.5 and discussed further in the safety assessment document (ONDRAF/NIRAS TR 2009-14E). This methodology, designed in 2009, follows the international trends. Applying this methodology in preparation to SFC1 has led to the refinement of some concepts and definitions, as well as of the methodological steps for safety assessment. The purpose of the present section is to provide and updated overview of the methodology, including revised definitions of concepts such scenarios and categories of phenomenological uncertainties. The link between the methodology and the management principles defined in Chapter 2 is explained in the following sections. Section 3.3.3 describes the development of scenarios and assessment cases, including associated completeness checking. The specific issues of uncertainties in safety parameters and the derivation of the safety-relevant parameter values are explained in Sections 3.3.4 and 3.3.5 respectively. Lastly Section 3.3.6 addresses the use of expert judgement and expert elicitation. As shown by the pale blue boxes in Figure 3.5, safety assessments are carried out in two main phases: a phase of preparatory assessment, and a phase of formal assessment. Safety assessment, whether preparatory or formal, requires an adequate knowledge base and analysis tools, which are collectively termed the assessment basis. The assessment basis incorporates knowledge acquired by ONDRAF/NIRAS in the course of over 25 years of RD&D on geological disposal in poorly indurated clays, as well as knowledge from other national waste management programmes.

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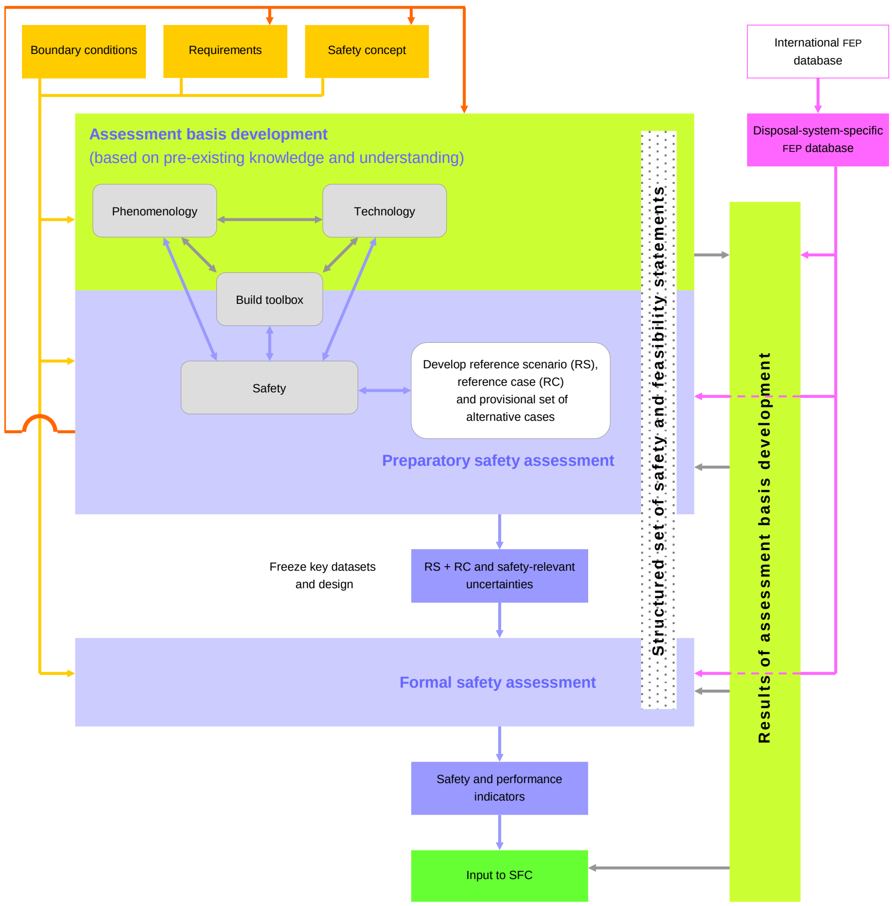

Figure 5.5 - Overview of the safety assessment methodology. (RS: reference scenario; RC: reference case)

The aim of preparatory safety assessments is to identify potentially safety-relevant uncertainties and to provide quantitative assessments of their impact on system performance and safety. This phase is characterised by intense interactions between the three poles - safety, phenomenology and technology - and leads to the development and refinement of the assessment basis, based on the safety concept and in agreement with the objective and the subsequent requirements set for the programme stage at hand. Preparatory safety assessments are conducted repeatedly, on the basis of phenomenological evidence from the assessment basis, and in parallel with system development.

Preparatory safety assessments include both safety calculations and exploratory calculations. Safety calculations model the migration of the contaminants throughout the disposal system to the biosphere. They give a quantitative assessment of the performance and safety of the disposal system with the use of safety and performance indicators, such as dose and risk. Their results are compared with regulatory limits or guidelines. All other calculations carried out during preparatory safety assessments are called exploratory calculations. They are quantitative analyses aimed to study the sensitivity of the long-term safety of the disposal system to parameter and model assumptions. They serve different purposes, such as:

To evaluate the impact of a particular process or uncertainty on system performance and hence determine its relevance to safety. This is an important element of scenario development and completeness checking, structured around the safety statements as explained further, below, and

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also provides guidance to RD&D. For example, exploratory calculations estimating the gas generation and removal rates for B&C waste have highlighted the need for further RD&D in this field for the disposal of category B waste. Exploratory calculations may also identify which uncertainties have negligible impact on system evolution and performance and, therefore, do not need to be further addressed by RD&D or can be given lower of priority. For example, gas generation is of low priority for category C waste compared with category B waste. To test the robustness of a system, particularly with respect to uncertainties that are difficult to quantify or bound. For example, the sensitivity of safety indicators to the half-life parameter of irradiated fuel is an analysis commonly performed to understand the importance of this parameter for long-term safety. To bound the extent of perturbations. For example, exploratory calculations carried out using simplified and conservative models provide an upper limit of the extent of oxidised zone in Boom Clay. Safety and exploratory calculations carried out in preparatory safety assessments can serve to identify any significant deficiencies in current knowledge and understanding and in the plans to address these in the RD&D programme, thus providing feedback to assessment basis development. Through such calculations, the safety analysts gain stepwise confirmation that the disposal system is most likely to evolve as defined by the safety concept and will fulfil each safety function in the manner required. This evolution is termed the reference scenario (the categories of scenarios defined by ONDRAF/NIRAS include the reference scenario, based on the safety concept, several altered scenarios and human intrusion scenarios). The preparatory safety assessment phase is completed, when the reference case can be confirmed. The terms "scenario", "reference scenario", "altered scenario", "assessment cases", "reference case" and "alternative case" are defined in Box 3-4, below. **Box 3-4** **Scenario**: a set of high-level descriptions of possible evolutions of the disposal system, in simplified terms. These high-level descriptions share a common time-deployment of the safety functions. **Reference scenario**: a scenario in which the safety functions evolve in the manner defined by the safety concept. The reference scenario takes account of processes and events likely to occur and assumes that (1) there are no unexpected or significant undetected features in the environment surrounding the disposal system that could significantly perturb its safety functions, and (2) intrusion into the repository or its immediate geological environs by humans does not occur within the period covered by safety assessment. **Altered scenario:** a scenario that represents alternative evolutions of the disposal system with a lower probability of occurrence than the reference scenario and which result from events or processes other than human actions that may significantly impair one or more safety functions. **Assessment case**: a specific realisation of a scenario based on a particular set of assumptions, design or natural features, processes and parameters values. The reference scenario includes the so-called reference case and multiple alternative cases that adopt different assumptions.

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Reference case: a realisation of the reference scenario in which the system is assumed to be implemented according to the specified design. The assumptions behind this case are associated with a conservative or a more realistic set of parameter values and modelling choices.

Alternative case: a case within a given scenario defined to illustrate the impact of uncertainties in conceptual models and in parameter values.

Formal safety assessments aim to show in a quantitative manner, why the disposal system under consideration can be judged to be safe, satisfying all relevant regulatory and stakeholder requirements relating to the programme stage at hand. (There may be remaining uncertainties and these must be fully acknowledged.) They also aim to highlight and prioritise the main open issues that remain to be treated in the next programme stage. Formal safety assessments are quantitative and as exhaustive as possible; they are conducted every few years as part of a safety and feasibility case. They aim to illustrate the performance and safety of the disposal system in a suitable set of consolidated[4] scenarios and assessment cases, and of safety and performance indicators. This includes illustrating the robustness of the system to less likely scenarios in which one or more safety functions are partly or fully impaired, termed altered scenarios, and to human intrusion scenarios, as well as analysing alternative cases within the reference scenario.

Altered scenarios represent alternative evolutions of the disposal system with a lower probability of occurrence than the reference scenario and which result from events or processes other than human actions that may significantly impair one or more safety functions. The derivation of altered scenarios is described, below. Human intrusion scenarios represent alternative evolutions of the disposal system resulting from future human actions. Their probability of occurrence cannot reliably be quantified, but as set out in the safety concept, the probability is kept low by siting and design measures.

For each of these scenarios, one of several calculation cases will be developed. Alternative cases within a given scenario are defined to illustrate the impact of uncertainties in conceptual models and in parameter values. In the case of the reference scenario, alternative cases are also used to evaluate the impact of design options. The use of alternative assessment cases is valuable, for example, to show that different model assumptions lead to similar results or to focus future RD&D on the uncertainties to which safety and performance are most sensitive. For example, comparing the results of the evaluation of (more realistic) alternative cases with those of the (more conservative) reference case also provides an indication of the degree of conservatism introduced in the reference case and, hence, of the safety margins. Some alternative cases represent situations with a lower probability of occurrence than the reference case, whereas others may represent evolutions of the system with a similar probability of occurrence as the reference case, or where the relative probability of occurrence is hard to define, such as alternative climate evolutions.

Formal safety assessments may also include specific calculation cases defined by the regulator. Key datasets within the assessment basis, as well as the repository design and also the boundary conditions, strategic choices and requirements of the safety strategy are frozen for the formal assessment.

[4] The number of altered-evolution scenarios to be evaluated in a formal safety assessment is reduced through "consolidation", where several different scenario uncertainties lead to similar or identical sets of assumptions concerning the evolution of the safety functions (as for example in the case of two different sources of uncertainty leading to a loss of the engineered containment safety function during the thermal phase). Similarly, a single assessment case can be used when some model and parameter uncertainties lead to similar or identical sets of alternative model assumptions and parameter values.

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Interactions between safety assessors and experts in phenomenology and technology are important in both preparatory and formal safety assessment to ensure that the phenomenological and technological information and uncertainties are well understood and correctly abstracted in the scenarios and calculation cases that are analysed. Development of Scenarios and Assessment Cases and Completeness Checking SFC1 is to be based on a formal safety assessment that must be comprehensive, in the sense that all perturbing phenomena and uncertainties that could impact on the evolution and performance of the repository have been taken into account. As illustrated in Figure 3.8 and described above, a preparatory phase of safety assessment is undertaken prior this formal phase, the outcome of which is the confirmation of a reference scenario, initially postulated based on the safety concept, and a reference case, as well as a set of perturbing phenomena and uncertainties to be further examined. From these, a provisional set of scenarios and calculation cases is derived. As part of the quality assurance of safety assessments, completeness checks are conducted during preparatory assessments and during formal assessments. Confirmation of the reference scenario, i.e. confirmation that the disposal system is most likely to evolve as defined by the safety concept involves the substantiation of the safety and feasibility statements with the multiple lines of evidence generated from the RD&D programme, including safety and exploratory calculations, and the identification of any associated uncertainties. The development of the reference case entails sustained, structured interactions between safety assessors and experts in phenomenology and technology to abstract the knowledge acquired from the most recent RD&D results in the safety assessment models and databases. The process of safety assessment "abstraction" is here the process of developing a safety assessment model from relevant phenomenological knowledge, taking into account the limitations, and uncertainties in, this knowledge, as well as requirements related to the intended purpose of the model. These requirements may include, for example, the types of safety and performance indicators to be calculated, the robustness or conservatism of the calculation results and ease of verification of the computer code used to implement the model. Abstraction entails a degree of simplification, which can include geometrical simplification, the simplified treatment of variability in space and time and the omission of poorly understood phenomena that are confidently expected to lead to lower consequences than those calculated using the model. Abstraction can also be important when developing models aiming at performing exploratory calculations since, similarly to the safety models, they are often based on conservative assumptions. During the preparatory phase, the results of the working versions of the reference case derived from the abstraction process provide a snapshot of the level of safety that the current results of the RD&D programme can support. Analyses of these working versions also give insights in the impact of various uncertainties and provide guidance to RD&D and expert discussions. It is ensured that the conservatism of the working versions of the reference case is appropriate to evaluate the current degree of compliance with the main regulatory criteria. As the reference case is developed or amended through iterations, a list of uncertainties emerges that leads to a provisional list of additional scenarios and assessment cases (including alternative cases for both reference scenario and a one or more assessment cases for each altered scenario). Uncertainties here include all perturbing FEPs of low likelihood (e.g. geological events), as well as uncertainties associated with expected processes, design options and alternative conceptual models of relevance to safety relevant perturbing phenomena.

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The provisional set of scenarios and calculation cases is then confirmed and consolidated with particular attention given to ensuring no potentially safety-relevant perturbing phenomena and uncertainties have been overlooked. This is referred to as "completeness checking". The process whereby a final, approved set of scenarios and calculation cases is derived is illustrated in Figure 3.6. Key tools for the development and completeness checking of scenarios and calculation cases include: the safety (and feasibility) statements, a database of features, events and processes (FEPs), storyboards illustrating the phenomena occurring within specific compartments of the disposal system under consideration (see Chapter 4), and the results of exploratory and safety calculations from the preparatory safety assessment phase. The use of the safety statements and a FEP database as tools for completeness checking conforms to the management principle *"The integrating methodological tool shall be used to ensure that a high level of comprehensiveness can be ensured and auditing against FEPs with potential detrimental effects is carried out."* Peer review by internationally acknowledged experts and confirmation by the phenomenological and technology poles also contributes to completeness checking. The use of peer review conforms to the management principle *"Expert reviews and audits shall be performed to ensure and confirm the quality of the assessment basis, methods, tools and results and that the repository system is developed considering multiple safety functions and FEPs that could potentially compromise one or more barriers or safety functions have been considered."*

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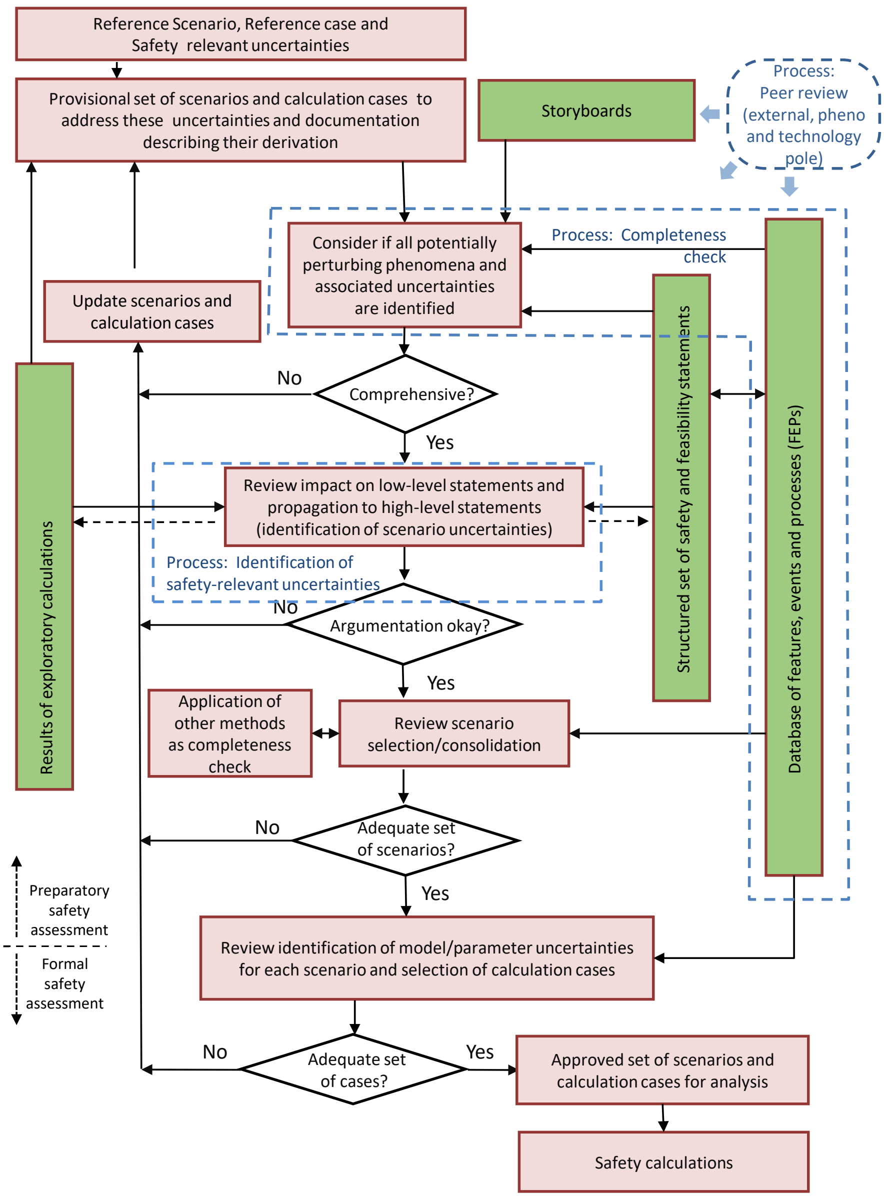

Figure 5.6 - The overall process to ensure an adequate range of scenarios and calculation cases. Key tools for this process are shown in green. Two more specific processes (boxes in blue dashed lines) are shown in more detail in the figures below.

Completeness of Potentially Perturbing Phenomena and Uncertainties Considered

The first step is to check whether there are any potentially safety-relevant perturbing phenomena and uncertainties that are not represented in the provisional set of scenarios and calculation cases from the preparatory phase, or in the models used for their evaluation. Any omissions need to be described and justified, keeping in mind that some perturbing phenomena, interactions and uncertainties will have already been judged irrelevant to safety during the preparatory phase. The provisional set of

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scenarios and calculation cases from the preparatory phase is updated as necessary if unjustified omissions are identified (see next step).

The safety statements (especially the lowest-level leaf statements), storyboards illustrating the understanding of the evolution of the system on the part of the safety assessors in each scenario, as well as other tools and methods, e.g. PROSA (ONDRAF/NIRAS, 2001), are useful to focus discussions on possible omissions with phenomenological experts. The FEP database is also used to check for the omission of any FEPs from the safety statements and storyboards and the omissions rectified if necessary. In addition, all possible interactions between safety relevant FEPs have been considered. Completeness checking of the safety statements using the FEP database is illustrated in Figure 3.7.

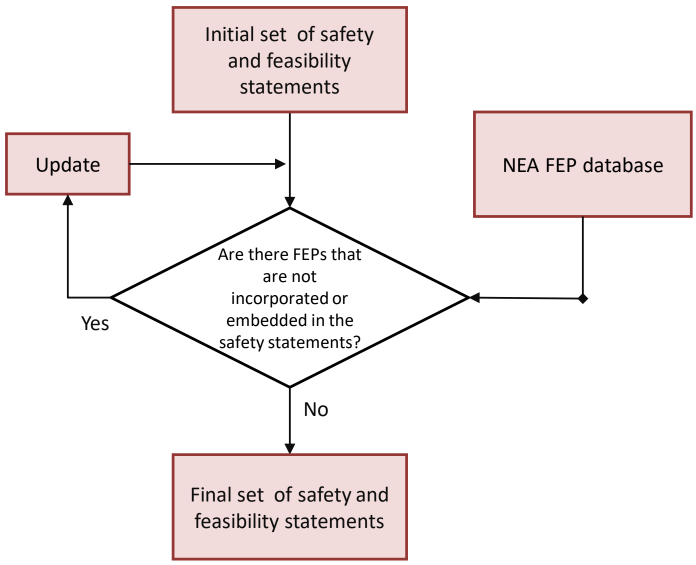

Figure 5.7 - Consistency check between the FEP database (here the NEA FEP database) and safety and feasibility statements

Currently, ONDRAF/NIRAS uses the NEA FEP database (NEA 2000). Its usefulness for completeness checking lies in the fact that it has been derived independently from the safety statements around which the ONDRAF/NIRAS RD&D programme is structured. By checking for completeness with respect to this database, it can be ensured that FEPs identified in other national programmes have been taken into account or are screened out for recorded reasons in the safety assessment. The database is arranged in a standard format allowing knowledge comparison between different disposal concepts. It is planned to integrate knowledge acquired in the ONDRAF/NIRAS programme and structured in FEPs (ONDRAF/NIRAS TR 2013-08E), in disposal-system-specific FEP catalogue, based on the NEA structure, with an accompanying description of each FEP. This catalogue will be regularly updated during the assessment basis development.

Identification of Safety-relevant Perturbing Phenomena and Uncertainties

In the next step, any perturbing phenomena and uncertainties that are not represented in the provisional set of scenarios and calculation cases are assessed in terms of their safety relevance. The process by which this is accomplished is illustrated in Figure 3.8, and is elaborated in the safety assessment methodology report (ONDRAF/NIRAS TR 2009-14E). Key tools supporting this process are the safety statements, along with exploratory and safety calculations.

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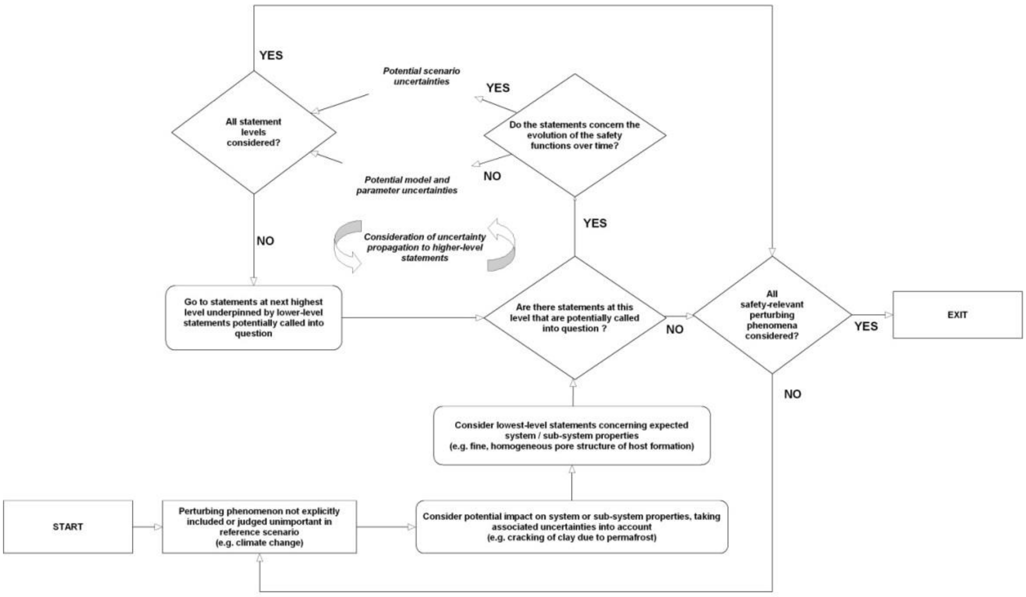

Figure 5.8 - Identification of any remaining safety relevant phenomena and the associated uncertainties

Review of Scenario Selection

The reference scenario assumes the validity of the highest level of the safety and feasibility statements. Those perturbing phenomena and uncertainties with the potential to propagate to, and to call into question, the highest-level statements (as indicated, e.g. by the results of exploratory and safety calculations) can lead, either individually or in combination, to other scenarios that need to be considered in the formal safety assessment.

Methods to derive scenarios other than that described above may also be considered to ensure the adequacy of the selected set, e.g. based on the multi-barrier perspective.

Review of Model/Parameter Uncertainties and Calculation Case Selection

Once the adequacy of the set of scenarios is confirmed, the models and parameters needed to analyse each scenario are defined or reviewed. All underlying modelling assumptions are systematically identified, together with their associated uncertainties. Where these uncertainties are significant, the possibility of alternative assumptions is considered. All plausible alternative modelling assumptions and combinations thereof are considered in identifying a set of calculation cases for quantitative analysis. Some of those combinations may not, however, be taken further on the grounds they will clearly lead to lower consequences than the reference case (or other cases within the same scenario), there is value, however, in analysing some of them as they may provide illustrations of safety margins. Other combinations may be disregarded because they are physically impossible, on the grounds of very low probability (i.e. combinations of multiple unlikely assumptions), or because their impact is already covered by another combination.

Uncertainties in safety parameters and the derivation of values for these parameters for use in calculation cases are described, below.

The range of scenarios and calculation cases illustrating specific uncertainties and combinations of uncertainties may be complemented by more hypothetical calculation cases to illustrate system robustness, i.e., what-if cases that illustrate either extreme conditions not expected to arise in reality

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or the functions of specific barriers, i.e., hypothetically disregarding one or more barriers to illustrate the effects of others.

Consolidation, Final Audit and Analysis

Finally, after freezing of the assessment basis, the formal safety assessment may begin. The approved set of scenarios and calculation cases is first consolidated in a systematic and transparent manner and again audited against the FEP database. The analysis of the scenarios and assessment cases can then take place.

Uncertainties in the Safety Parameters

Background

Some parameter values needed to analyse scenarios and calculation cases are subject to little or no uncertainty and are readily specified. "Raw data" may be used directly as model parameter values if;

the model parameters relate to the same quantity as the data (this may not be the case if, for example, model parameters refer to spatially averaged quantities and the data are in the form of point measurements),

the data are not subject to significant uncertainty (e.g. parameter values taken from the design description, such as package dimensions), where uncertainty is limited to the feasible level of precision during fabrication, and

the experimental conditions under which they are measured either do not affect the measured value or are representative of the conditions expected to prevail in the repository system (at least in the scenario under consideration);

In most cases, however, parameter values are derived from experimental and other types of data, where uncertainties in the data, and the representativeness or applicability of the data, are important considerations.

As part of the preparation for SFC1, a thorough consideration has been made of the treatment of the uncertainties in the values assigned to safety parameters. Such consideration was recommended by the International Review Team (IRT), who pointed out the difficulty in tracing the arguments underlying the choice of parameter values used in the safety assessment for SAFIR2. Traceability was rendered more difficult by the extensive use of conservative values that, while acceptable from the point of view of demonstrating safety, led to an unrealistic description of the system. The use of conservative values made the assessment of the safety margins more difficult and was judged to increase the risk that safety-relevant processes may have been overlooked. The approach is also not consistent with the desire to optimise the system through the management of the open issues the successive iterations of the safety cases (ONDRAF/NIRAS, TR 2009-12E). Because of these concerns, ONDRAF/NIRAS developed a new approach for the treatment of the parameter uncertainties that would re-establish coherence without sacrificing/amending the concept of a robust system design set out in the framework of SAFIR2.

Uncertainties in safety assessment can be divided into the two broad categories of epistemic and the aleatory uncertainties. Aleatory uncertainties reflect the impact of the inherent variability in some phenomenon, e.g., the timing of an event or the spatial distribution of some property: the number of observations performed under the same conditions does not decrease such uncertainties, but may allow the better description of the phenomenon in terms of, say, probability density functions. Thus, aleatory uncertainties are considered as random and irreducible in nature. Epistemic uncertainties, on the other hand, may be reduced by a developing a better understanding of the phenomena to

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which the uncertainties pertain (Crawford and Galson, 2009). However, recent reviews (Crawford and Galson, 2009; NEA, 2010) pointed out that categorisation of uncertainties as either aleatory or epistemic is not always clear-cut. Many uncertainties include elements of both although the treatment of the epistemic character usually requires more attention in the safety assessment for a geological repository.

Safety assessment involves the understanding of many complex, coupled physical phenomena. It requires the interaction of a number of disciplines to describe these phenomena to the degree required to plan and implement a geological repository. Moreover, a particular feature of a geological repository is the long period over which the repository is expected to fulfil its safety functions. This aspect of long times into the future imposes some inherent limitations on the understanding of system evolution in the long term that cannot be overcome solely by studies in the laboratory or field. As well as aleatory uncertainties, epistemic uncertainties will inevitably remain that are, in practice, irreducible or almost irreducible (Crawford and Galson, 2009). Expert judgment and expert elicitation are, therefore, needed to characterise and manage the uncertainties associated with safety assessment within a geological programme, and are discussed further, below.

In the SAFIR2 safety assessment, the uncertainties identified at that programme stage were expressed using probability density functions (PDFs), irrespective of their aleatory or epistemic character. Although PDFs can be an appropriate means of describing aleatory uncertainties, their use in the case of parameters largely affected by epistemic uncertainties can result in an ill-defined and possibly misleading description of these uncertainties. Indeed, since epistemic uncertainty is related to a lack of knowledge of a specific phenomenon, the PDFs used to represent uncertainties of this type in SAFIR2 were difficult to justify. As pointed out by the IRT, the PDFs that were chosen reflected a certain "degree of belief" expressed by the experts in the possibility of a parameter taking a given value. This degree of belief could depend on a variety of factors specific to the expert her/himself, such as access to relevant information, educational background and even personality traits, such as an over-confident or pessimistic attitude. As a consequence, the PDFs assigned when assessing a particular phenomenon will vary between experts, especially when considering phenomena and their evolution over long time scales. Thus, even the best-estimate value of a parameter provided by an expert may be understood only as one representative value characterising the expected behaviour of this phenomenon. For these reasons, ONDRAF/NIRAS has decided (ONDRAF/NIRAS TR 2009-12E; ONDRAF/NIRAS TR 2009-14E) to modify the treatment of the uncertainty of safety parameters in its current safety assessment methodology.

Expert and Source Ranges

A brief discussion of the way uncertainties associated with the safety parameters are handled in SFC1 is given in the following paragraphs, further details are given in (Depaus and Capouet, 2011).

In SFC1, safety assessment parameters can be variables used directly as input to the safety assessment models. They can also include the results of exploratory calculations that justify the basic assumptions of the safety models. Safety assessment parameters can be directly associated with a safety function, e.g. the corrosion rate of the overpack, or they can be associated with a set of interacting, safety-relevant processes, such as the release of gas resulting from the degradation of engineered barrier components or waste.

The treatment of uncertainties in safety assessment parameters in SFC1 focusses on the determination of intervals of possible or expected values, and not on the derivation of PDFs as in the past. Multiple lines of evidence and reasoning are sought to support the selected intervals. Therefore, when an expert is asked to give his/her state of knowledge over a specific parameter and to evaluate the associated uncertainty, they are requested first and foremost to set numerical bounds limiting the

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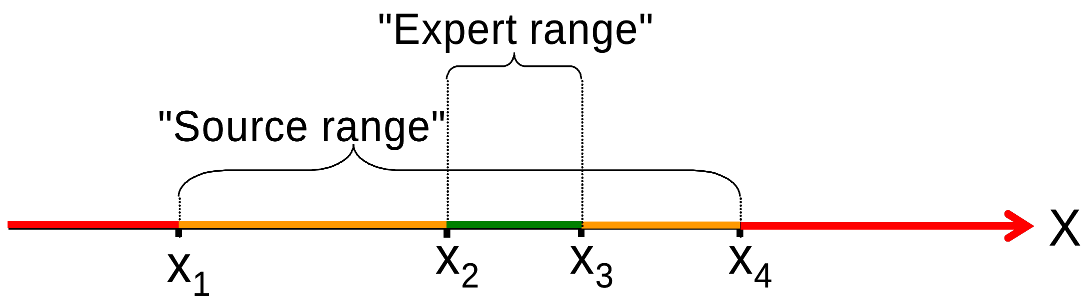
uncertainty range, rather than to provide a best estimate or PDF[5], although a best estimate may also be provided if there is sufficient evidence and reasoning to support it. The approach is based on the principles of fuzzy set theory.

When deriving the above-mentioned intervals for safety parameter values, the safety assessors will, in collaboration with the phenomenological experts, capture the phenomenological uncertainties with two different ranges of parameter values, taking into account the hypotheses that define the scenario at hand (see Figure 3.9).



Legend:

[x2,x3] = range within which the value of X should lie, to the best of the experts knowledge i.e. “(fully)realistic values”

\ ]x1,x4[= range of values that should be ruled out for X, to the best of the experts knowledge, i.e. “unrealistic” (or “unsupported”) values;

[x1,x2[U]x3,x4] = range of values that experts cannot entirely rule out for X, but which would be somewhat surprising, i.e. somewhat less “realistic”

Fig. 1 Representation of expert (likely/realistic) and source (support) ranges

Figure 3.9 - Representation of expert (likely/realistic) and source (support) ranges

The **expert range** (ER) is the range within which the parameter value is expected to lie.

The **source range** (SR) is the range outside of which the parameter value is very unlikely to lie, considering current knowledge.

Parameter values for calculation cases are selected from these two ranges, with all parameter values used in the reference scenario and the related calculation cases generally taken from the expert range. The most pessimistic value of the expert range is normally selected for the reference case, which can be the expert range maximum or minimum, depending on the parameter in question[6]. Use of the two ranges as a basis for setting parameter values allows the evaluation of the robustness of

[5] These bounds, may, in practice, be derived in several steps, and involve collaboration between phenomenological experts and safety assessors. For example, the phenomenological experts may find it most convenient or appropriate first to define a PDF from their experimental results or observations, before the bounds required for the treatment of parameter uncertainties in SFC1 are defined.

[6] Although this approach is largely conservative, there can be instances where it is unclear whether the maximum or minimum value of a specific parameter is the most conservative, since this depends on the values assigned to other parameters. An example is the diffusion coefficient of organic matter in the Boom Cay. As shown in Fig. 4-7 of Smith (2014), whether higher or lower values of this parameter lead to the highest dose rates can depend on the value assigned to the concentration of organic matter in the Boom Clay.

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the system and the safety margins with respect to international recommendations and regulatory requirements.

In the special case of biosphere dose conversion factors (BCFs), rather than defining source and expert ranges, fixed values are defined even though there is considerable uncertainty associated with these values. This is because the purpose of the BCFs is to provide a relative measure of the consequences of radionuclide release from the repository system in different calculation cases based on a given set of (uncertain) assumptions regarding the biosphere. There are substantial uncertainties in the values assigned to the BCF, but there are counterbalanced by the strong conservatism of the many of the hypotheses used in the evaluation of dose rates, e.g. the hypothesis that there is a self-sustaining family living above the repository that exclusively uses drinking and irrigation water extracted from a well located at a position where the concentration of contaminants released from the repository are calculated to be the highest.

The technique of using source and expert ranges has already proved useful for many safety parameters. Level 5 reports document the two ranges and any discussions and decisions are documented in MoMs (Section 4.1.2). A "best estimate" of the true value may also be defined if there is agreement on such a value by the experts.

Derivation of Ranges

An overview of the process for deriving parameter ranges from "raw data" is given in Figure 3.10. It should be noted that raw data, in the present sense, can include not only empirical, phenomenological data from the field and laboratory (recorded data interpreted as physical or chemical parameters, such of hydraulic conductivities and solubility limits, along with uncertainties associated with the ranges of measured values), but also the broad information and evidence available from e.g. natural or anthropogenic analogues and other sources, including the results of exploratory calculations or process modelling results.

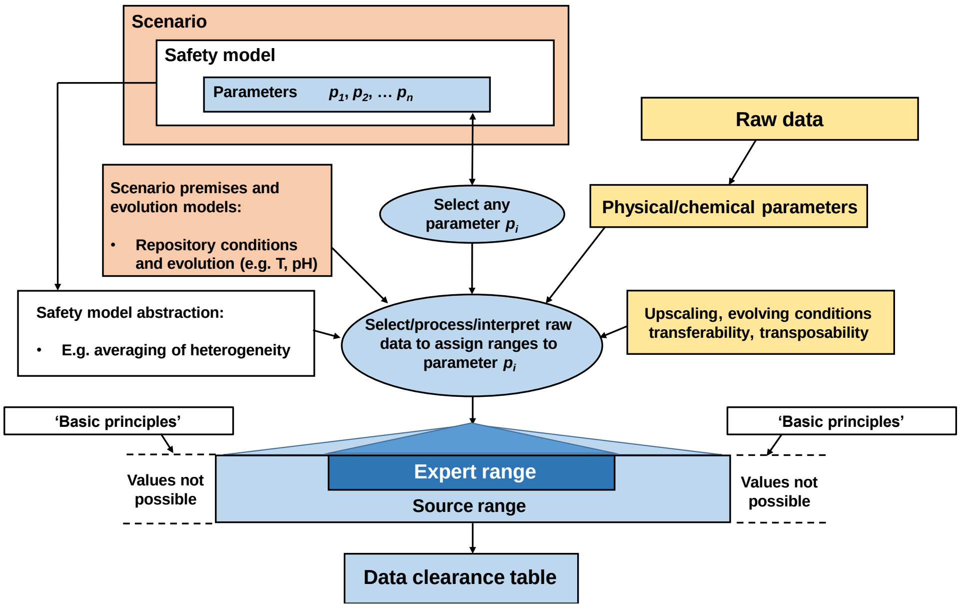

Figure 3.10 - Overview of process for deriving parameter ranges from "raw data"

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The derivation of parameter ranges has to take into account not only uncertainties in the raw data themselves, but also other factors, such as the premises inherent in the scenario under consideration, and the applicability of the raw data to the conditions of interest for that scenario over the course of the assessment period. Specific issues that must be taken into account are: **Upscaling**, which refers to the applicability of the phenomenological data, collected at the scale of the laboratory over relatively short intervals of space and time, to the larger spatial and temporal scales of interest to safety assessment. **Evolving conditions**, which refers to the impact of phenomena occurring over time on the validity of phenomenological data obtained today, including both internal phenomena within the disposal system and external events (ONDRAF/NIRAS, 2009e). **Transferability**, which refers to the transfer of parameters values, measured locally, e.g. in boreholes, to the whole Boom Clay zone. These include, for example, hydraulic parameters. Assuming vertical homogeneity, the main concern here is a horizontal variability, either from one borehole to another or from a borehole to a larger area. **Transposability**, which is a measure of the extent to which the knowledge obtained in one host rock (parameter values, process understanding, conceptual models or high-level conclusions) can be assumed to apply to another host rock. Based on basic host rock properties and prevailing conditions, it may, for example, be concluded that one host rock can serve as a proxy for another, or that this is not the case and each host rock has to be studied separately. These issues impact differently on the source range and expert range. The expert range is typically based on the most representative or reliable data, or on detailed expert reasoning, whilst the source range encompasses a larger range of data, including softer data or simpler reasoning. More specifically, information taken into account in defining the source range can include data that are not necessarily representative of the phenomenon or situation under consideration, or of the scenario at hand, or that is not deemed to be particularly reliable, but nonetheless cannot be excluded as irrelevant at the current programme stage. It may relate, for example, to a site or host rock that is different from those under consideration in the safety assessment, but sufficiently similar that the information has some relevance (i.e. a degree of transferability or transposability). In order to derive the expert range on the basis of these broad types of information, the safety assessor and/or phenomenological expert has to select the information that he/she considers as the most reliable or representative of the phenomenon under consideration in the scenario at hand (see the discussion of the qualification and validation of experimental data in Section 3.4.3). The degree of belief is presumed to be the same for all values within the expert range, i.e. they are judged to be "reasonably possible". Between the bounds of the expert range to those of the source range, the degree of belief decreases. Values here are considered to be "somewhat possible", meaning that they lie in a "fuzzy" region where they cannot be defined as likely, but neither can the experts entirely exclude them as impossible. In the non-parametric approach adopted here, the precise shape of this decrease in belief does not have to be quantified. In is sufficient to say that the degree of belief decreases monotonically from the bounds of the expert range to the bounds of the source range, while values outside the source range are excluded, i.e. judged to be "not at all possible". As well as ranges reflecting the ranges of, and uncertainties in, empirical measurements, the source range can also reflect uncertainties related to the nature of the process (or set of processes)being represented. For it to be included in the source range, this type of uncertainty should not call into question the validity of the system-level model (and its safety parameters) used in the safety assessment; if it does, then this uncertainty is more appropriately addressed by analysing calculation cases based on alternative model assumptions.

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As noted above, the expert range and source range are derived by safety assessors, in collaboration with the phenomenological experts. Expert judgement (potentially within an expert elicitation process, see below) is particularly important when, for example, data from two different campaigns are inconsistent or contradictory and the difference cannot be easily explained. It has been observed that experts can sensitive to the way the question is formulated (e.g. whether the issue is expressed in terms of "possibility" or "expectation"). It could be argued that the formulation of the question could therefore bias the outcome. However, this potential issue of bias is largely overcome by the fact that the ranges provided by the experts have to be justified by multiple lines of evidence. Furthermore, minor variations in the estimated ranges resulting should not unduly impact the safety assessment, since the performance of the system is designed to be robust with respect to uncertainties. Nevertheless, a lesson learned from applying this approach so far is that problem definition is important and discrepancies between experts opinions can often be traced to different interpretations of the questions asked, or assumptions and bias inherent in the way a question is posed. Expert Judgement and Expert Elicitation In this report, expert judgment is defined as an inference or an evaluation by an expert based on an assessment of data, assumptions, criteria and models, where the expert is expected to be a recognised authority who has an extensive background in the subject area. The issues addressed by expert judgment can be (i) qualitative, for example the evaluation of the process, features and events to be considered in SFC1, the conceptual and numerical models to be used, etc., or (ii) quantitative, for example the determination of the source and expert ranges for parameters. In general, expert judgment can be viewed as a representation of the expert's knowledge at the time of response to a question posed to the expert. The use of expert judgment is an integral element in the development of the assessment basis and the performance of safety assessments. It is the principal means by which uncertainties in FEPs, in scenarios and in parameter values associated with the natural barrier, the engineered barriers or the interaction between the two are identified and described. A large part of these uncertainties results from the spatial and temporal scales that are considered in the safety assessments. This results in the need to upscale from laboratory and point field measurements (e.g. in a borehole) to much larger spatial scale, and to describe the evolution of the engineered barrier system over time scales that extend beyond what can be observed in experimental work. In the case of the natural system, future evolution can be bounded on the basis of what is known about its past evolution (over periods of up to hundreds of millions of years) to its present state, but these bounds can be quite uncertain; expert judgment is needed to define where they lie. Expert elicitation is the process by which expert judgments are obtained[7]. Recognising that expert judgment is the product of knowledge-based cognition (Meyer and Brook, 1987), the aim of the expert elicitation process is to ensure that the conclusions reached and decisions made are traceable, transparent and well-founded in the knowledge available. The origins of formal elicitation date to the early 1950s with the development of the Delphi method (Dalkey 1967). This gave the impetus for the development and further refinement of similar methods and processes for the elicitation of judgments, not only for addressing technical issues, but also for supporting decisions in policy making in various sectors (e.g. Knol et al., 2010). Although these methods and protocols differ in the detail, they are all based on a common set of principles, which include: a clear definition of the issue to be addressed,

[7] In the literature, the term expert judgement is often used to describe the expert elicitation process. Here we distinguish between the expert judgement, i.e., the "deliverable" from the expert, and the method used to obtain this deliverable, namely the elicitation process. A detailed discussion of the terminology used here can be found in DeWispelare et al (1994).

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a clear definition of the context, scope and intended use of the elicitation sought, selection of experts so that divergent opinions can be considered and addressed in the derivation of judgments, recognition and reduction of both individual and group biases (e.g. due to different initial assumptions and knowledge base of the experts), traceability and transparency, and thorough documentation and reporting. A clear definition of the issue, context, scope and intended use of the elicitation allows an expert to consider an issue not just in isolation, but also to identify possible interactions with other phenomena that may occur e.g. in the evolution of a repository system. The expert should be aware of how parameters are used in the model at hand: this is important since a process and its parameters in a safety assessment model will often lump several processes and "hide" assumptions that may not be applicable in some conditions. The expert must clearly describe the rationale followed to derive a safety parameter value from the experimental or observed data: safety analysts that have a global view of the system may be able to identify any assumptions made by the expert that would not hold for the conditions assumed in the safety assessment. Encouraging an expert to consider and discuss their own evaluation and also divergent opinions contributes to a better definition of the range of uncertainty for a given process or a parameter. Expert elicitation can be formal or informal. Formal expert elicitation is a rigorously structured process and normally involves several experts. It consists of a series of steps and normally involves expert training and de-biasing sessions. These sessions acquaint the experts with the form in which they will be asked to produce their judgements, to clarify the assumptions that will be shared by the experts and to identify biases that might affect their judgments during the elicitation (DeWispelare et al., 1994). An informal expert elicitation is based on the same principles as formal elicitation, but is less rigorous and may lack some of the steps, such as the preparatory and training steps mentioned above. It can involve a few or just one expert, uses simpler tools and can take the form of a series of structured meetings with the experts. It should be emphasised, as remarked in De Wispelare et al (1994), that the degree of the formality of the elicitation process is associated with the method used to obtain the information and should not be falsely associated with a certain level of quality of the expert judgment obtained. As discussed above, assessing the impact of uncertainty and uncertainty itself is a key element of expert judgment and driver for the expert elicitation approach. For the systematic identification and characterisation of different types of uncertainty, Knol et al. (2010) introduced a typology framework, which consists of a number of dimensions and was used in the area of environmental health assessment. Four of the dimensions that are relevant in the context of expert elicitation for SFC1 are summarised below. The "location" dimension is used to identify the part of the system with which the uncertainty is associated, for example if it concerns a feature, an event, a process, or a model input parameter. The "nature" dimension is used to distinguish between epistemic and aleatory uncertainties, as discussed earlier. The dimension of "range" of uncertainty indicates the form by which it can be described, for example in statistical terms, in terms of level of likelihood, or, in the context of the safety and feasibility case, source and expert ranges. The fourth dimension has been labelled "recognised ignorance" and applies in cases where estimates or judgments cannot be established and expert judgment is used to give insight into what is not known and to what extent this "ignorance" is important for the issue being addressed. The principles presented above are similar to those followed by other waste management programmes. For example, Nagra (Nagra NTB 02-05) places emphasis on the: i) clear definition of

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the context of the elicitation sought, ii) adoption by the experts of a broad view in their approach and inclusion of divergent opinions in the discussion; iii) clear definition from the experts of the conditions and application range of results; iv) obtaining unbiased judgments; v) traceability of judgement, and vi) documentation. In Nagra´s approach, experts are required to express uncertainty ranges, but whether additional conservatism should be considered is the responsibility of the safety assessors, who should be able to assess, in the context of the system evaluation, a) which processes or phenomena do not have an impact and can be excluded; b) which portion of an uncertainty range should be modified to add conservatism in the derivation of the parameter values. Suggestions made by the experts, the rationale supporting them, the possible limitations and applications, any potential for conflicts or inconsistencies with other information, as well as final expert recommendations, are documented in the Minutes of Meetings
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
4.3b How are uncertainties related to waste inventory managed?
1. Introduction For the safety assessments in the framework of the RD&D on geological disposal as a solution for high-level and/or long-lived waste a thorough knowledge of the waste is essential. The radiologically most penalising waste types are the spent nuclear fuel from the nuclear power reactors and the waste produced by reprocessing this spent fuel. In 2016 and in the framework of the SFC-1, Synatom has officially asked ONDRAF/NIRAS to generate a provisional inventory for their irradiated fuel assemblies and for their (potential future) reprocessing waste, according to updated ‘mixed’ and ‘open-cycle’ scenarios. These inventories should be built using the FICAR tool. At the request of ONDRAF/NIRAS, Synatom provided current and more detailed information on the average and maximum burn-ups associated with the different initial enrichment ranges of fuel assemblies. In addition, Synatom provided the number of assemblies for each initial enrichment range, the type of cladding material and the average and maximum Fission Gas Release (FGR) (Synatom, 2016b). This note describes the methodology for the calculation of the radiological inventory of the spent fuel assemblies and the reprocessing waste (CSD-V and CSD-C) in both the ‘open cycle’ scenario and the ‘mixed’ scenario. The results of the calculation are presented and compared with data used for previous scoping calculations performed during the period 2010-2012 (i.e. those comprised in Data Clearance Table 2.2). Assessment of the uncertainties of the calculated data are not within the scope of this report and will be treated separately. **2. Historical background** In the 1990’s, Synatom has provided ONDRAF/NIRAS with a first inventory of the irradiated fuel from the Belgian power reactors (based on a 40 years operation of the seven reactors) (Synatom, 1996). This radiological inventory was calculated at 50 years after discharge using the ORIGEN2 code (with standard cross sections libraries) for 16 fuel assembly types representative of the whole Belgian fleet, in terms of design, initial enrichment and burnup. This information was included in the official ONDRAF/NIRAS technical inventory reporting of 2003-2004 (Cosemans, 2004).

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In view of the forthcoming first safety and feasibility case (SFC-1), Tractebel (subcontracted by Belgatom in the framework of a Belgatom/ONDRAF/NIRAS contract funded by Synatom) has performed inventory calculations for 4 fuel assembly reference types expected to be “design-cases” for the Belgian disposal system (de Wouters, 2005).

These calculations were performed at end of irradiation, using the CASMO-ORIGEN2 system (for the assembly active zone) and the MCBEND transport code (for the assembly out-of-active zones). This applied methodology leads to a more accurate evaluation of the inventory build-up in the Belgian assemblies and allows the splitting of the inventory between three assembly major parts (‘fuel’, ‘claddings’, ‘structures’, see §3.1.3).

Additionally, Excel workbooks named “FICAR” were developed by Tractebel to allow ONDRAF/NIRAS to perform sensitivity studies on the calculated inventories, regarding:

- the impurity contents and the decay time, for the 4 reference fuel assemblies (FICAR-v0),

- the initial enrichment and the burnup for one reference fuel type only: UOX-ENU fuel in 12 feet geometry, representing the largest fraction of the Belgian assembly fleet (FICAR-v3, updated version).

At the end of the 2000’s, the “FICAR tool” was used by ONDRAF/NIRAS to build bestestimate averaged inventories per assembly geometry (8,12,14ft. for UOX-ENU fuel and 12ft. for MOX fuel), using updated information on the Belgian fleet, from SYNATOM.

These calculation results have also been used to simulate the radiological inventory of the waste (CSD-V & CSD-C) that would originate from the full reprocessing of the Belgian fleet. All these inventories were used for the purpose of scoping calculations prior to the SFC-1 and implemented in the Data Clearance table 2.2 (as mentioned above).

It is important to note that the number of characterized (safety-relevant) radionuclides of spent fuel assemblies has evolved with time. The official ONDRAF/NIRAS technical inventory reporting of 2003-2004 includes 36 radionuclides; the Tractebel calculations and thus the scoping inventories give a radiological inventory for 56 radionuclides.

Today, ONDRAF/NIRAS has identified 58 radionuclides with a potential impact on the waste management up to the long term. Among them, only Be-10 and Mo-93 are not included in the FICAR tool. Their inventory in spent fuel will be assessed on the basis of information from open literature (see §3.1.4).

3. Spent nuclear fuel inventory

This section describes the calculation of the spent fuel assemblies inventory. This inventory corresponds to the source term in case of an ‘open cycle’ scenario (thus no further reprocessing), but is also to be used as an input for the mixed scenario.

3.1 Methodology

The Synatom letter of 29 March 2016 (Synatom, 2016b) groups each assembly type into 3 (8ft. and 14ft. UOX) or 4 (12ft. UOX) groups. A last group comprises the 144 12ft. MOX assemblies that were irradiated between 1995 and 2010.

A number of properties are associated with each group: typical initial enrichment, initial enrichment range, number of assemblies, types of cladding used and distribution within the group, average and maximum burn-up, loading period and average and maximum FGR.

For the calculations, the groups are further subdivided:

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1) according to their cladding types: assemblies cladded with Zircaloy-4 or PCA-2b (which include Nb as trace impurity) are calculated separately from assemblies cladded with M5 or Zirlo (which include Nb as alloying element, thus with a significantly higher content); 2) according to the type of UOX: 290 ERU assemblies were irradiated in Doel 1 (8ft) from 1994 to 2009. These will be calculated separately from the ENU assemblies using the additional information provided by Synatom by e-mail (de Limelette, 2017d). Amongst the 12 and 14ft. assemblies, a minor fraction contains 'mixed RepU' fuel1. This is not taken into account when determining the 12ft. and 14ft. assembly inventory. The FICAR tool (de Wouters, 2005) will be used to determine an average and maximum radiological inventory for each assembly type. Using the updated version, FICAR-v3, variations in initial enrichment and burn-up can be assessed for 12ft geometry. Since this is essential to our exercise, this version will be used to calculate the inventories of all the UOX-assembly groups. Adaptations to make it useable for the 8ft and 14ft assemblies had to be made and are described in section 3.1.3. The assembly groups defined in the aforementioned Synatom letter allow no differentiation between the Tihange 1 12ft. 15x15 assemblies and the Tihange 2 and Doel 3 12ft. 17x17 assemblies. Since the FICAR worksheets don't allow to calculate 12ft 15x15 assemblies, all 12ft. assembly inventories will be calculated as if they have a 17x17 geometry. It is also important to note that no contribution to the radiological inventory external to the fuel assembly itself (e.g. from the primary circuit, from water in the storage pools,…), has been taken into account. 3.1.1 Material compositions and impurities The compositions of and impurities in the materials present in as-fabricated fuel assemblies are of importance to determine the activation products activity. Since reliable best estimates of impurities content are not readily available, a conservative approach is followed. For each impurity element, a bounding value has been 1 Uranium from reprocessing (RepU) that has been mixed with fresh ENU to reach an adequate enrichment; the resulting uranium vector is different from that of ERU (RepU directed to enrichment process). selected, based on the values used for the calculations perormed by Tractebel on reference fuel assemblies (de Wouters, 2005) which were extracted from fuel vendor's specifications and the values proposed in the Synatom letter of 29 March 20162. For some elements, values were still lacking. Those were completed based on literature (Evans *et al.*, 1984; NEA, 2016) or on a hypothetical "similarity basis", where deemed relevant. In the case of Inconel and stainless steel, upper values for the components iron and nickel are taken since they lead to activation products as Mn-54, Fe-55, Co-60 and Ni-59/63. Since chromium is an extremely minor contributor to the Co-60 and H-3 activity, it is not necessary to apply the upper bound value. For Inconel, the concentration of chromium is thus adapted in order to have a mass balance of 100wt%. For stainless steel, even with the lower bound value for chromium (taken from (Evans *et al.*, 1984)), the followed approach leads to a mass balance of more than 100wt%. The inconsistency on the mass balance has no further impact, so this lower bound value is taken. In the case of zirconium alloys (Zircaloy-4, PCA-2b, M5 and Zirlo), there is only one major component (Zr), which leads to Zr-93 as an activation product. Consequently, the conservative approach also leads to a mass balance of more than 100wt%. The same composition is used for all four zirconium alloys, except for the Nb content. Zircaloy-4 and PCA-2b, with a Nb impurity content of 200 ppm, have a summed mass of components and impurities of 100,171wt%. M5 and Zirlo, with a Nb-alloying element content of 1,2wt% have a summed mass of components and impurities of 101,351wt%.

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Table 1 gives an overview of the material compositions and impurity contents used in the calculations. The origin of the used values is indicated by colorization of the cell (see the legend for the explanation). Values that have been modified compared to previous calculations, are shown in red.

2 In their mail of 24/02/2017 (de Limelette, 2017c), Synatom let O/N know that the used impurity values for UOX and the structural materials are rather best estimate. Since no additional data has been received, this has not yet been taken into account in this report. O/N is participating in an international workgroup that a.o. aims at harmonizing impurity levels and reprocessing process parameters (such as carry-over fractions, see §4.1.2) used in calculations by WMO's of spent fuel and reprocessing waste inventories.

3.1.2 Half-lives of calculated radionuclides

The FICAR workbooks summarize the half-lives used throughout the workbook on the 'Résumé' worksheet. Since these half-lives differ for some radionuclides from the reference half-lives used and agreed upon for ONDRAF/NIRAS's safety assessments for geological disposal, the values in the 'Résumé' worksheet were replaced by these values.

It was checked that all instances of half-lives in the workbooks link back to the values on the 'Résumé' worksheet.

Zry4&PCA-2b / M5&Zirlo (wt%) Inconel 718 (wt%) INOX (wt%) UO2 (wt%)

Zirconium 97,624**55** Fer 11,984 Fer 65,**44** Bore 0,00025 Etain 1,7 Nickel 55 Chrome **16,5*** Cadmium 0,00079 Fer **0,32** Chrome 21 Nickel 13,5 Dysprosium 0,0031 Chrome **0,19** Niobium + Tantale 5,5 Carbone 0,1 Europium 0,0006 Oxygène 0,17 Molybdène 3,3 Manganèse 2 Gadolinium 0,0003 Carbone 0,027 Titane 1,15 Silicium 1 Samarium 0,0005 Azote 0,008 Aluminium 0,8 Cuivre 1 Chlore **0,0025** Cuivre 0,005 Silicium 0,35 Azote 0,10 Fluor 0,0025 Cobalt 0,002 Manganèse 0,35 Phosphore 0,045 Aluminium 0,075 Silicium 0,012 Cuivre 0,3 Soufre 0,03 Calcium 0,075 Aluminium 0,0075 Carbone 0,08 Cobalt 0,1 Magnésium 0,075 Bore 0,00005 Cobalt 0,08 Chlore 0,0130 Silicium 0,075Cadmium 0,00005 Bore 0,006 Niobium 0,0300 Titane 0,075 Chlore 0,002 Phosphore 0,015 Molybdène 2,5 Chrome 0,1 Hafnium 0,01 Soufre 0,015 Calcium 0,0020 Molybdène 0,05 Hydrogène 0,0025 Tantale 0,1 Selenium 0,0070 Fer 0,05 Manganèse 0,005 Chlore 0,002 Brome 0,0008 Nickel 0,05 Nickel 0,007 Azote 0,008 Lithium 1,3E-05 Zinc 0,02 Plomb 0,013 Calcium 0,003 Zirconium **0,002** Carbone 0,010 Titane 0,005 Selenium 0,007 Argent 0,0002 Azote 0,0075 Tungstène 0,01 Brome 0,0008 Cuivre 0,01 Uranium total 0,00035 Lithium 0 Cobalt 0,0025 Calcium 0,003 Zirconium 0 Manganèse 0,01 Magnésium 0,002 Argent 0,0002 Plomb 0,01 Molybdène 0,005 Argent **0,00005** Niobium 0,02 / 1,2 legend Phosphore 0,005 Max. over reference cases (de Wouters, 2005) Sodium 0,002 Synatom letter (Synatom, 2016b) Vanadium 0,005 Max. data from (Evans *et al.*, 1984) on 304L Selenium 0,007 Added on similarity basis Brome 0,0008 SF-COMPO (NEA, 2016) Lithium 0 **0,123** Updated in comparison to previous calculations Argent 0,0002 16,5* minimum value from (Evans *et al.*, 1984) on 304L

3.1.3 Adaptations to the FICAR-12ft-v3 workbook for the 8ft. and 14ft. assembly inventory calculations

3.1.3.1 Description of the adaptations to the FICAR-12ft-v3 workbook for the 8ft. and 14ft. assembly inventory calculations

As mentioned above, the FICAR tool provides inventories for three distinct parts of the assembly, using different evaluation methodologies depending on the axial position of the considered assembly component (within or out of the active zone of the assembly). This is represented at Figure 1 (based on (Labilloy, 2008)).

Figure 1: Fuel assembly components

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In the analyses below, the term 'structures' refers to Part 1, the term 'claddings' refers to Part 2 and the term 'fuel' refers to Part 3. The FICAR tool consists of 4 v0-workbooks for respectively 8ft-UOX, 12 ft-UOX, 14 ft- UOX and 12ft-MOX assemblies, and 1 updated v3-workbook for 12ft-UOX assemblies. They are fully named 'FICAR-8ft-URE-4.25%-55GWd', 'FICAR-12ft-UNE-4.5%-55GWd', 'FICAR-14ft-UNE-3.8%-45GWd', 'FICAR-12ft-MOX-7.7%-50GWd' and 'FICAR-12ft-UNEV3- Complement', but further in this document will be abbreviated to FICAR-8ft-v0, FICAR-12ft-v0, FICAR-14ft-v0, FICAR-12ft-MOX and FICAR-12ft-v3. The updated version (FICAR-12ft-v3) has some major advantages compared to the first version workbooks. The main objective of the update was to make it possible for ONDRAF/NIRAS to perform calculations with varying initial enrichment and burn-up. To achieve this, fitting polynomials or rational functions to a set of ORIGEN2 results were added to the new version. Furthermore, the axial distribution of burn-up was taken into account as well as some other changes. The modifications are described in more detail in (de Wouters, 2005, Appendix E). However, the FICAR workbook was only updated for the 12ft. UOX fuel assemblies. In order to calculate the inventories for 8 and 14ft. fuel assemblies for varying initial enrichments and burn-up, some adaptations were made to the 12ft. version. - Masses of Zr-alloy, Inconel, stainless steel and UO2 in the fuel assembly The worksheet 'masses' summarizes the masses of all different components (plenum springs, nozzles, cladding/guide/instrumentation tubes, grids and fuel). Since these masses remained unchanged between the first and the updated version of FICAR, one can straightforwardly replace the values for the 12ft assembly in the FICAR-12ft-v3 workbook with those of the 8ft and 14ft assemblies as a first step to calculate the inventories of the latter two. - Non-active zone of the fuel assembly ('structures' + a small fraction of 'claddings') In (de Wouters, 2005), presenting the FICAR workbooks, it is stated that "*The sensitive parameters affecting the results [for the structures outside the active lenght] are essentially the distances separating the component from the fuel region, and therefore a separate calculation has been made for the 8-foot, 12-foot and 14-foot assemblies.*" The calculation methodology for the non-active zone of the fuel assembly has not changed between the first and the updated versions of FICAR. Thus, for the 8ft and 14ft assemblies, the results from the first version (v0-workbooks) of FICAR could be taken. Indeed, when the input data (half-life, BU, IE, irradiation time), the data on the geometry (masses, compositions and impurities) and the worksheet 'données' of FICAR- 12ft-v3 are made equal to respectively FICAR-8/14ft-v0, both versions calculate the exact same activities. Since the worksheet 'données' is not used for the calculation of the active part (except the total UO2 mass), it is chosen to replace the worksheet 'données' in the FICAR-12ft-v3 workbook with the worksheet from respectively the FICAR-8ft-v0 and -14ft-v0 workbooks to calculate the inventory in the non-active zones of the 8ft and 14ft assemblies. In that way, a duplication of the number of workbooks to be processed is avoided and the input data and the data on the geometry of the assemblies remain coherent. - Active zone of the fuel assembly (largest fraction of 'claddings' and 'fuel') Among some other changes not related to a specific assembly geometry, the updated FICAR-12ft-v3 workbook takes into account the axial distribution of burn-up, whereas in the first versions of FICAR, a hypothetical

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uniform axial burn-up distribution was used. To take into account a more realistic axial distribution, (de Wouters, 2005) states correction factors for each assembly type to be applied to the results (i.e. the radionuclide inventories) of the first versions.

These correction factors are determined only for the initial enrichment and burn-up used in the v0-workbooks. The impact of initial enrichment and burn-up on the correction factors was investigated by recalculating these correction factors for different initial enrichment and burn-up. For this, the FICAR-12ft-v3 workbook was used. As proposed in (de Wouters, 2005), the inventory for a uniform axial burn-up distribution was calculated by setting cells A2 to A71 of the worksheet 'fitting' equal to 1.

The exercise shows that the standard deviation of the different correction factors is low for all nuclides, generally lower than 1%. It is therefore decided to apply the correction factors for the 8ft and 14ft assemblies independently of the used initial enrichment and burn-up (of course, after cancelling out the correction factors for the 12ft assemblies that are implicit to the FICAR-12ft-v3 workbook).

- ERU fuel actinide inventory

The actinide spectrum of spent ERU fuel is slightly different from that of spent ENU fuel, due to the higher initial inventory of U-233, U-234 and mainly U-236. Since the FICAR- 12ft-v3 workbook is not suited to calculate the radiological inventory of spent ERU fuel, a comparison was made between the adapted FICAR-12ft-v3 workbook and the FICAR-8ftv0 workbook. All parameters (initial enrichment, burn-up, isotopic half-lives,,…) were set alike and the correction factors for the axial burn-up distribution were applied on the results of the FICAR-8ft-v0 workbook.

Table 2 shows the ratio of the actinides activity in spent ERU fuel to that in spent ENU fuel at unloading from the reactor. As expected, the activities of U-233, U-234 and U-236 are higher in the spent ERU fuel, as are the products of U-236 activation (Np-237 and Pu-2383) and the daughter nuclides of the U isotopes. The activities of the higher actinides are generally lower than in spent ENU fuel.

To take into account the impact of the ERU assemblies on the average inventory of the 8ft assemblies, it is decided to multiply the activities of the underlined nuclides in Table 2 by 3,3 in the calculation of the ERU assembly inventory. This is not conservative for Th-229 and Th-232, but their initial activity is of low importance for long term safety (on the long term, the activity of these RN is dominated by the initial activity of their mother isotopes).

Table 2: ratio of actinides activity in spent ERU fuel vs. spent ENU fuel (at EOL)

Ra226 3,24 U238 0,98 Am242m 1,00 Th229 3,65 Np237 2,69 Am243 0,97 Th230 3,22 Pu238 2,90 Cm242 0,96 Th232 4,49 Pu239 1,02 Cm243 0,95 Pa231 3,10 Pu240 1,01 Cm244 0,97 U233 2,98 Pu241 0,99 Cm245 0,93 U234 3,29 Pu242 0,97 Cm246 0,94 U235 1,01 Pu244 0,97 Cm247 0,95 U236 3,08 Am241 0,99 Cm248 0,98 3.1.3.2 Verification of the adapted FICAR-12ft-v3 workbook: comparison with inventories calculated with FICAR-v0 and FICAR-v4.3 workbooks Two series of checks have been carried out to confirm that the adaptations lead to acceptable variations compared to the basic Tractebel calculations (when using the same half-lives, impurities and taking into account the axial burn-up profile).

The first one is a simple comparison with the results obtained with the FICAR-8ft-v0 and -14ft-v0 workbooks, similar to the one made in (de Wouters, 2005, Appendix E) for the 12ft workbooks. The results are presented in annex 1a.

The most important deviation is for Tc-99 in the cladding, due to the supplementary activation production chain added to version 3.

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In (de Wouters, 2005, Appendix E), the many deviations that appear for activation products were explained by the different activation cross section used in both versions: in version 3, they were extrapolated from those established at 4,15% and 3,2% enrichment instead of using those at 4,15% enrichment. Since the initial enrichments in the FICAR- 8ft-v0, -12ft-v0 and -14ft-v0 workbooks are 4,25%, 4,5% and 3,8% respectively, one 3 Through decay of U-237 and Np-238 activation products, respectively. would expect a similar but less pronounced deviation for the 8ft. assembly (since 0<(4,25-4,15)<(4,5-4,15)), and a deviation in the opposite direction for the 14ft. assembly (since (3,8-4,15)<0<(4,5-4,15)). This is indeed the case. The approach for the actinide inventory of spent ERU fuel introduces some conservatisms for the concerned nuclides, except Th-229 and Th-232, as described above. Other notable differences can be observed for Cm-isotopes and Eu-155. Those are not explained as yet. A second check is performed by Tractebel. In the past, a version 4.3 of the FICAR workbook was developed (O/N doesn't dispose of this version). Tractebel used this version to recalculate a few spectra calculated by O/N with the adapted FICAR-12ft-v3 workbooks. The agreement was said to be 'excellent': the typical deviation was 3%, the average of the deviations was zero. The deviation on 90% of the isotopes was less than 5%, for only 2%, the deviation exceeded 10%. The results are presented in annex 1b. Both checks illustrate that the adapted FICAR workbooks can reliably be used for the inventory calculations. 3.1.3.3 Impact of the adaptations to the FICAR-12ft-v3 workbook: comparison with previously calculated inventories In order to evaluate the effect of the differences in methodology, as well as perform an extra check on the correctness of the implementation of the methodology, the previously calculated spectra were recalculated with the adapted FICAR-12ft-v3 workbooks described above, but using the compositions and impurity levels as used for the calculations of the spectra in DCT2.2. For each of the 56 calculated radionuclides and each assembly type and component the ratio of both results were calculated. The ratios for the 8ft., 12ft. and 14ft. UOX average assemblies are given in Annex 2. It has to be noted that in the previous calculations, some adaptations were made to the results for specific nuclides in order to resolve (party unexplained) differences between the calculations with the first and the new version of the FICAR tool. Given the satisfactory results (including explanations) of the comparisons in the previous paragraph, this approach is not retained in the current calculations. These adaptations were thus cancelled out when determining the activity ratios. - Correspondence and differences for all assembly types It is immediately clear that the general correspondence is good: most radionuclides have an activity within 5% of their value for the total assembly in DCT2.2 (52 out of 56 for 8ft. and 12ft. UOX and 51 for 14ft UOX). The four differences that are found for all three assembly types (Se-79, Ag108m, Sn-126, Am242m) are due to the different half-lives used for the conversion of mass to activity (see §3.1.2). In the case of Se-79, a safety factor of 10 was previously used as well, to take into account the uncertainty on the half-life. When the ratios are corrected to make them comparable, good similarities are found (both on assembly and component level). - Correspondence and differences for the 14ft. assembly

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The spectrum of the 14ft. assembly shows some deviations from DCT2.2 that are not present for the other assembly types. These are described hereafter. The most important parameter affecting the activation product build-up in the non-active part is the distance separating the component from the fuel region. Therefore, separate cross-sections were defined in the first version of the FICAR tool for the different assembly types. However, the role of the assembly geometry has not been taken into account in previous calculations: all calculations were performed with the FICAR-12ft-v3 version and the results were corrected for the total mass of each component. This results in a lower activity (by 15-20%) than the one calculated in DCT2.2 for 11 of 13 calculated nuclides in the structures (for Se-79 and Ag-108m this is after the half-life correction described above).

This difference in methodology also explains the differences in Ni-59, Ni-63 and Tc-99 activity in the claddings. Since Ni-59 and Ni-63 are mainly produced by activation of the nickel and Tc-99 by activation of the molybdenum present in Inconel, the higher relative mass of Inconel in the 'claddings' part of the 14ft. assembly compared to the 12ft. assembly should be taken into account. The same can be said for the Zr-93 and Nb-94 activity in the 'structures', which unlike the other 11 calculated nuclides do not originate from the most abundant material in the structures (stainless steel), but from respectively Zircaloy and Inconel. Correcting the ratios for this difference results in ratios close to 1 for Ni-59, Ni-63 and Tc-99 in the claddings and a ratio similar to those of the other isotopes in the structures for Zr-93(4) and Nb-94.

The high Co-60 ratio for the fuel is explained by an error in applying the correction factors for burn-up distribution in the previous calculations.

- Correspondence and differences for the 8ft. assembly

The considerations made for the 14ft. assembly in the previous paragraph, are valid for the 8ft. assembly as well. Since the mass of the structures of the 8ft. assembly differ only slightly from the 12ft. assembly, the effect is small for most radionuclides. Correcting the ratio for Nb-94 in the structures to take into account the different masses of Inconel, leads to a ratio of 1,2. Given the small contribution of the structures to the total Nb-94 activity in an average 8ft. assembly (±1%) and the fact that the adapted FICAR-12ft-v3 workbook gives the same results for the structures as the original FICAR- 8ft-v0 workbook, the remaining deviation is not further investigated.

3.1.4 Be-10 and Mo-93 inventory

As mentioned in §2, the FICAR tool doesn't allow to calculate the Be-10 and Mo-93 inventory. Therefore, an effort was made to find suitable activities per assembly component to be used in further calculations. From reports by or for Sandia National Laboratories (Naegeli, 2004), US DOE (Carter *et al.*, 2012), NDA (Pöyry Energy, 2010), SKB (SKB, 2010) and NIREX (Electrowatt-Ekono, 2003), the data presented in Table 3 was extracted. On the basis of these activities, covering values were selected as presented in the last row. These activities will be added to each spectrum calculated further in this note, regardless of initial enrichment, burn-up or cooling time at which it is established. Thus, no difference is made for these nuclides between the average and maximal fuel assembly spectra. The activities in the structural materials and cladding as provided by the NDA and SKB reports are for 12ft. assemblies and can thus easily be converted to 8ft. and 14ft. assemblies.

4 Since there is no Zircaloy in the 14ft structures, the weighted average of the impurity levels times the activation cross section, expressed per unit mass were compared.

Table 3: Be-10 and Mo-93 activities per assembly component

Be10 Mo93 source

Fuel type

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and BU

Total

assembly

Struct.

mat. Cladding Fuel matrix Total

assembly

Struct.

mat. Cladding Fuel matrix

Bq/tHM Bq/tHM Bq/tHM Bq/tHM Bq/tHM Bq/tHM Bq/tHM Bq/tHM

UOX70 3,97E+05 6,69E+07 SNL

UOX60 3,42E+05 1,09E+09 DOE

UOX60 4,17E+05 5,32E+04 6,44E+03 3,57E+05 1,04E+09 9,93E+08 0,00E+00 4,38E+07 NDA

UOX44 5,35E+08 4,48E+07 SKB

UOX57 6,20E+08 5,92E+07 SKB (5)

UOX57 9,33E+08 8,72E+07 SKB (5)

MOX35 4,63E+08 3,43E+07 SKB

MOX45 6,90E+08 5,62E+07 SKB

UOX 'high' 0,00E+00 6,26E+05 0,00E+00 8,00E+07 NIREX

MOX 'high' 0,00E+00 6,72E+05 0,00E+00 6,11E+07 NIREX

selected 1,11E+06 1E+05 1E+04 1E+06 1,1e+09 1E+09 0E+00 1E+08

3.1.5 Calculation of the average spectrum for UOX-assemblies

In order to calculate an average radiological spectrum for each assembly type, a series of calculations was performed. For each assembly subgroup (i.e. the groups as defined by Synatom, further subdivided according to cladding type and type of UOX (ENU vs. ERU)), three radiological spectra were calculated using the adapted FICAR tool: one for the typical, one for the maximal and one for the minimal initial enrichment. In all cases, the declared average burn-up was used, as well as a 4 year irradiation time6. Then, in a conservative manner, the maximal activity of each nuclide was retained for the structural parts7, the cladding and the fuel matrix of each subgroup. As a last step, the average spectrum for the assembly type was calculated as the weighted average of each subgroup. All spectra were calculated at 10 years after unloading from the reactor.

3.1.6 Calculation of the maximal spectrum for UOX-assemblies

To determine the maximal radiological spectrum for each assembly type, first the impact of burn-up and initial enrichment was investigated. Applying a higher burn-up leads to higher activities of all activation and fission products, except for Pm-147 (at higher enrichments) and the part of Ag-110m that is produced by activation. Also the activities of most actinides increase with burn-up, except for the nuclides mentioned in Table 4. As explained in the table, the lower impact of these nuclides on the long term safety when applying a higher burn-up, is very limited or 5 Both tables C-11 and C-12 in (SKB, 2010) give spectra for spent UOX assemblies with 57 GWd/tHM burn-up.

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6 This is a fixed parameter in FICAR. The original CASMO/ORIGEN2/MCBEND calculations have all been made considering constant power over 4 years irradiation, without reactor shut downs between cycles. The impact of this simplification is minor for long-lived critical radionuclides, but can be significant for nuclides with short halflives (up to Cs-137). The impact of these simplified histories on short term (few decades) thermal load should be assessed when calculating evolution of the thermal power.

7 The enrichment of the fuel doesn't play a role in the activation of the non-active part, so the three spectra are equal for the structural parts. compensated by the higher activity of other nuclides. U-235 is the only exception to this, but its lower activity is inherent to a higher burn-up. The lower impact of these nuclides on the operational safety (dose rate, heat output) when applying a higher burn-up, is largely compensated by the higher activity of other relevant nuclides.

Table 4: Impact on long term safety of nuclides with higher activity for lower burn-up

Pu-239, Am-242m, Pm-147

The differences on the activity remain limited (within a half percent).

U-238

The lower U-238 activity is inherent to a higher burn-up. The difference remains however limited (within a few percent).

Ra-226, Th-230, Pa-231 The initial activity is of low importance for long term safety (on the long term, the activity of these RN is determined by their mother isotopes).

U-233, U-234

Mostly important as mother isotopes of Th-229 and Ra- 226, respectively. On the medium/long term, the activity of Th-229 and Ra-226 is still higher than for lower burnups thanks to the higher initial activity of their other mother isotopes (essentially Pu-241 for Th-229 and Pu-238 for Ra-226). On the very long term, the Ra-226 activity is determined by the secular equilibrium with U- 238.

U-233 is also a fissile nuclide, but its long term inventory is defined mainly by the initial inventory of its mother isotopes (Np-237, Am-241, Pu-241). Am-241

On the long term, the activity of Am-241 is still higher than for lower burn-ups thanks to the higher initial activity of Pu-241 (at EOL+10y, the activity of Pu-241+30xAm-241 increases with higher BU).

U-235

The U-235 activity inherently decreases with burn-up. Its residual activity at EOL contributes to the Pa-231-activity on the long term.

Ag-110m

The Ag-110m production by activation maximises at low IE and intermediate BU. Its activity is however of no importance on the long term (half-life < 1y). It is further observed that for a given burnup, a higher initial enrichment leads to lower activities for most of the activation products, some of the fission products (Ru-106, Pd-107,..) and most of the higher weight actinides, while the activity increases for the other nuclides. For some nuclides (Pu-238, Pu-241, Eu-155,..), their behaviour might change with burn-up.

With respect to the cladding, the M5/Zirlo composition is used since it has a higher Nb content than the other zirconium alloys. It is thus decided to use the maximal burn-up of 55 GWd/tHM and the M5/Zirlo cladding composition for the calculations of the maximal spectra of the UOX-assemblies, while

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varying the initial enrichment. The exact values for the initial enrichments used are all typical, minimal and maximal enrichments of the subgroups belonging to the assembly type. Finally, the maximal activity of each nuclide was retained for the 'structures', the 'claddings' and the 'fuel' of each assembly type.

For the 8ft. assemblies, the effect of the use of ERU fuel is taken into account by multiplying the activities of Ra-226, Th-229, Th-230, Th-232, Pa-231, U-233, U-234, U-236, Np-237 and Pu-238 by 3,3 as proposed in §3.1.5. This is done regardless the initial enrichment (thus also for initial enrichments outside the range of the subgroup for ERU fuel).

However, for heat production considerations, this spectrum might be overly conservative, especially since the last ERU fuel assembly was discharged in 2009 (de Limelette, 2017d). Therefore, a maximised spectrum for ENU fuel is also calculated, as well as a maximised spectrum for ERU fuel (by taking only into account the relevant initial enrichments).

3.1.7 Calculation of the spectrum for MOX-assemblies

Given the large differences in calculation of the spectrum of MOX-assemblies compared to UOX-assemblies, an adaptation of the FICAR-12ft-v3 workbook to MOX assemblies seems ill-advised.

A sole spectrum will therefore be calculated using the first version of FICAR, i.e. the 'FICAR-12ft-MOX-7.7%-50GWd' workbook, where the radionuclide half-lives and the material composition and impurities are adapted in the same way as described in sections 3.1.2 and 3.1.1 respectively. The 'correction factors for axial burnup distribution' are applied on the results, as proposed in (de Wouters, 2005). Additionally, two other corrections were made. Firstly, a correction factor of 6,62 was applied on the Tc-99 activity in the cladding to take into account the production of Tc-99 from Mo-99 decay by the chain Mo-99 → Tc-99m → Tc-99, which was ignored in the first version of FICAR. The exact same was done in the previous calculation of the MOX-inventory. Secondly, the formula to calculate the Ag-108m production by activation of Ag in the fuel was added to the worksheet8.

The impurities in the MOX fuel matrix used are as shown in Table 5. The cells in yellow were taken from an UOX assembly composition in the FICAR tool. The cell in red was taken from the SF-COMPO database (NEA, 2016).

8 The formula is present in the original FICAR-12ft-MOX workbook for Ag activation in other materials and is completely analogous for activation in the fuel. This is confirmed by the presence of this formula in the FICAR- 12ft-v3 workbook.

Table 5: MOX impurity contents

MOX (wt%)

Aluminium 0,075 Silicium 0,075 Bore 0,00025 Titane 0,075 Bismuth 0,0004 Thorium 0,001 Calcium 0,075 Tungstène 0,01 Cadmium 0,00079 Zinc 0,02 Cobalt 0,0025 Carbone 0,01 Chrome 0,1 Chlore 0,0025 Cuivre 0,01 Fluor 0,0025 Fer 0,05 Azote 0,0075 Indium 0,002 Dysprosium 0,0031 Magnésium 0,075 Europium 0,0006 Manganèse 0,01 Gadolinium 0,0003 Molybdène 0,05 Samarium 0,0005 Nickel 0,05 Argent **0,00005** Plomb 0,01

3.2 Results

The above described calculations result in 9 different spectra:

- an average inventory for the 8ft. UOX assemblies;

- a maximal inventory for the 8ft. UOX assemblies;

- a maximal inventory for the 8ft. UOX-ENU assemblies for heat impact considerations;

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- a maximal inventory for the 8ft. UOX-ERU assemblies for heat impact considerations; - an average inventory for the 12ft. UOX assemblies; - a maximal inventory for the 12ft. UOX assemblies; - an average inventory for the 14ft. UOX assemblies; - a maximal inventory for the 14ft. UOX assemblies; - a (maximal) inventory for the 12ft. MOX assemblies. The inventories at 10y after unloading the spent fuel assemblies from the reactor are presented in Appendix 3. 3.3 Comparison with previously calculated inventories: impact on the safety assessments In this paragraph, the results as presented in §3.2 will be compared with the radiological spectra as present in the Data Clearance Table 2.2 in order to assess the impact of the revised calculation on the safety assessments. All differences in inventory should originate from one or both of following possibilities: 1) differences in the calculation methodology: impurities (see §3.1.1), half-life (see §3.1.2), adaptations made for specific nuclides in previous calculations or adaptations made to the FICAR-12ft-v3 workbook (see §3.1.3); 2) differences in the used information on the initial enrichments and burn-ups (i.e. the definition of the groups of assemblies) and the number of assemblies allocated to each assembly group, or the number of assemblies with a M5/Zirlo cladding (high Nb impurity). - Specific differences for all UOX assembly types Some of the most apparent differences originate from the different half-lives used in both calculations to convert the mass of the nuclide to its activity, and the use of a safety factor for the Se-79 activity in previous calculations (see also §3.1.3.2). This results in a significant reduction of the Se-79, Ag-108m and Sn-126 activity (by approximately 80%, 70% and 60% respectively). On the other hand, it leads to a 10% rise in Am-242m activity, and subsequently, a similar rise in Cm-242 activity. The changes in the used impurities leads to a 50% decrease in Cl-36 activity in the fuel matrix (and thus a similar decrease in the overall assembly), a ±20% rise in Mn-54 activity in the cladding. The higher Ag impurity in the fuel matrix slightly counteracts the decrease due to the different half-life used for Ag-108m. Nb-94 in the cladding is mainly produced by activation of niobium impurities. Since the Nb-94 activity in DCT2.2 was calculated considering all cladding material as M5, there is also a significant reduction in Nb-94 activity9. Generally, the differences in used initial enrichments and burn-ups leads to slightly lower activities. Large deviations are however found for the larger mass actinides (generally when the atomic mass is 242 or higher). This can be ascribed to the strong non-linear behaviour versus burn-up of nuclides that are produced by subsequent neutron capture and the different grouping (i.e., distribution of initial enrichment and burn-up among the assemblies) that is used in both calculations. Other apparent decreases are for H-3, Kr-85, Ru-106 in the cladding. - Correspondence and differences for the 8ft. assembly Apart from Se-79 and Sn-126 for which the half-life was adapted, there is an excellent correspondence for the fission products between the previously calculated inventory and current one.

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There is a small decrease in activity of the activation products, which reaches maximum 10% on the overall assembly (except for Cl-36, Nb-94 and Ag-108m, as explained before). A few nuclides show a decrease up to 20% in a specific component of the assembly. Mn-54 have a higher activity in respectively the structures and the cladding due to a higher impurity content used in the current calculations.

With respect to the actinides, there's a ±30% rise in activity for those nuclides that are more abundant in spent ERU fuel. As explained before, there is a rather large decrease (10-45%) for the larger mass actinides. For the remaining actinides, the correspondence is good.

- Correspondence and differences for the 12ft. assembly

The fission product activity is generally a few percent lower than in the previous inventory (apart from Se-79 and Sn-126, that are a lot lower). This is also the case for the activation products, except for Cl-36, Nb-94 and Ag-108m whose activity decreased significantly, and Mn-54 due to the higher iron impurity in the cladding.

As for the actinides, apart from the larger mass nuclides and Am-242m and Cm-242, the correspondence is good. A 9% rise in U-235 can be seen due to the different initial enrichments and (generally lower) burn-ups used. This also results in a 8-10% decrease in Th-229 and Pu-238 activity. All other actinides stay within 5%.

9 This is a reduction compared to DCT2.2. However, for safety calculations, this overly conservative Nb-94 activity was corrected by dividing it by 4 (it was assumed that only about ¼ of the SNF assemblies was cladded with M5 or Zirlo).

- Correspondence and differences for the 14ft. assembly

As explained in §3.1.3.2, the activities of most isotopes in the structures decreased by 15-20% due to the different calculation methodology. For the reason explained in the same paragraph, the Ni-59 and Ni-63 activity in the cladding rose by respectively ±30 and ±15% (for Tc-99, this effect was compensated by the lower average burn-up).

The fission product activity is generally 5-15% lower than in the previous inventory (apart from Se-79 and Sn-126, that are a lot lower) due to the lower average burn-up.

For the actinides, some larger decreases can be observed due to the different burn-ups used (Th-229, Np-237, Pu-238, Cm-246, Cm-247 and Cm-248). However, the Pu-242, Am-243, Cm-243 and Cm-244 activities rise as a consequence of the low minimal enrichment (1,6wt%).

- Correspondence and differences for the MOX assembly

Some of the differences are similar to those general for the UOX assemblies. This is the case for the significant reduction of the Se-79 activity (half-life and safety factor), the reductions of the Ag108m and Sn-126 activity and the rise in Am242m and Cm-242 activity (half-life), the 50% decrease in Cl-36 activity in the fuel matrix (Cl impurity in the fuel) and the rise in Mn-54 activity in the cladding (Fe impurity in the cladding).

In the previous calculations, a correction factor of 500 was applied to take into account the activation of Ag in the fuel matrix. Using the exact formula results in a multiplication of the activity in the fuel by ±556 and thus slightly counteracts the decrease due to the different half-life used for Ag-108m.

The doubling of the Zr impurity content in stainless steel results in a 18% rise in Zr-93 activity in the structures. Some small differences in used half-lives lead to several minor differences, e.g. a 4% rise in Eu-155 activity and a 5% and 3% decrease in Cm-243 and Cm-247 activity respectively.

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However, a minor change in the used half-life of Am-241(10), leads to as much as a 12% rise in Np-237 activity at EOL+10y. This consequently results in a 4% rise of U-233 activity. Globally, we can conclude that the current calculations lead to a lower average activity in spent fuel assemblies, mostly thanks to the lower average burn-ups communicated by Synatom. The largest decreases in activity for specific nuclides however stem from corrections in half-life and impurity level, a.o. for the mobile Cl-36 and Se-79. The largest increase in activity is for Nb-94, due to a misjudgement of the fraction of assemblies cladded with M5/Zirlo for previous safety calculations (see footnote 9). The most important increase in actinide inventory is for those nuclides affected by the use of ERU in 8ft. assemblies. 10 In the previous calculations, a half-life of 432,2y was used for the conversion of mass to activity, and a halflife of 433y for the decay, while in the current calculation 432,808y was used for both. **4. Spent fuel and reprocessing waste inventory in** **the case of a mixed scenario** 4.1 Methodology The Synatom letter of 29 March 2016 (Synatom, 2016b) also provides information on the fuel assemblies that might be selected for reprocessing in case this would be resumed. However, the grouping of the assembly types that is used here is different from that of the total assembly fleet: there is only one 8ft. assembly group, combining assemblies from all ‘total fleet’ groups. For the 12ft. and 14ft. assemblies, there are two groups defined. In both cases, the first group contains only low burn-up assemblies from the first ‘total fleet’ group, while the second group combines assemblies from the first three of four ‘total fleet’ groups for the 12ft. assemblies, or from all three ‘total fleet’ groups for the 14ft. assemblies (thus also from the first group!). A more limited number of properties are associated with each group: only initial enrichment range, number of assemblies and average burn-up are given. No information is given on the average initial enrichment, maximal burn-up, distribution of cladding types, loading periods or FGR. In (Synatom, 2016a), the total number of ERU/mixed RepU assemblies irradiated in Doel 1 and 4 that are presently planned to be reprocessed, could be found. With the assumption that the distribution between the 8ft. and 14ft. assemblies is the same as for the total assembly fleet, the 8ft. assembly group can be split in two subgroups. One subgroup contains the ERU assemblies, with enrichment range and cladding as for the corresponding ‘total fleet’ group, but average burn-up as for the ‘to be reprocessed 8ft. assemblies’ group. The other subgroup equals the initially defined group, but with a reduced number of assemblies. Average spectra for both the assemblies selected and not selected for future reprocessing will be calculated using these groups, as will be explained in §4.1.1 and §4.1.3. The radiological inventory of the assemblies selected for reprocessing will then be converted to spectra for future CSD-V and CSD-C waste packages (§4.1.2). The calculation of the maximal spectra will be discussed in §4.1.4. 4.1.1 Calculation of the average spectrum for to be reprocessed assemblies The calculation methodology for the to be reprocessed assemblies is very similar to that for the total fleet. For each assembly subgroup (i.e. the groups as defined by Synatom, further subdivided according to cladding type and type of UOX (ENU vs. ERU)), three radiological spectra were calculated using the adapted FICAR tool: one for the maximal and one for the minimal initial enrichment, and one for the average initial enrichment of the corresponding ‘total fleet’ subgroups. In all cases, the declared average burn-up was used, as well as a 4 year irradiation time.

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Then, in a conservative matter, the maximal activity of each nuclide was retained for the structural parts, the cladding and the fuel matrix of each subgroup. As a last step, the average spectrum for the assembly type was calculated as the weighted average of each subgroup. For subgroups that exist both in a Zr-4/PCA-2b and a M5/Zirlo cladding version, the highest possible number of assemblies with M5/Zirlo cladding was taken. In the case of a resumption of reprocessing, all MOX fuel assemblies will be reprocessed. The corresponding radiological inventory is thus the same as calculated in the previous chapter. With regards to the decay time at the moment of reprocessing, two cases were considered: - Reprocessing of the assemblies at 8 years after unloading from the reactor. This corresponds to the value recommended in Andra's "Dossier 2005" (Lagrange, 2005). - Reprocessing of the assemblies at their average cooling time after unloading from the reactor (between 12 and 35 years), as communicated by Synatom (de Limelette, 2017c). This is less conservative for short-lived nuclides, but slightly more conservative for Am-241 (which mainly determines the heat output after Cs-137 and Sr-90 decay). A third option would be to use a chart by AREVA that relates burn-up, cooling time and incorporation rate (i.e. #CSD-V/tHM, see also §4.1.2) (Synatom, 2009). However, this chart is potentially not valid for future reprocessing processes. Also, this would lead to a case intermediate to those described above, so it's added value would be limited. It is therefore decided not to pursue this third approach. 4.1.2 Calculation of the average spectrum for future CSD-V & CSD-C With the results from §4.1.1, the total radiological inventory of the assemblies selected for reprocessing can easily be calculated. This inventory can then be converted to an average spectrum per CSD-V and CSD-C, taking into account the estimated number of these waste packages (1000 CSD-V (de Limelette, 2017c) and 675 CSD-C (Synatom, 2016b), equivalent to incorporation rates of 0,91 CSD-V/tHM and 0,61 CSD-C/tHM) and the carry-over fractions for each radionuclide from the different assembly components to the two waste streams. The determination of these carry-over fractions is based on several reports: - The carry-over fractions from fuel matrix to CSD-V (except for U and Pu) are provided in Cogéma note NT/0083 53/VEL/03.00001 Rév. 01 (Cogéma, 2003). For H-3 and Kr- 85, conservatively 0,1% was taken instead of 0%. - The carry-over fraction from cladding and structures to CSD-V was based on the maximal mass of shearing fines in CSD-V waste packages mentioned in the same note. For the to be produced CSD-V, this amounts to 4 kg/CSD-V x 1000 CSD-V / 365 tonnes cladding+structures = 1,1%. For the already produced CSD-V, this becomes 4 kg/CSD-V x 387 CSD-V / 228 tonnes cladding+structures = 0,7%. - The U and Pu recovery fraction (i.e., the fractions of the U and Pu mass that are effectively recovered) has evolved over time, from 99% (design recovery efficiency) (Broudic, 2008) to over 99,9% (CEA, 2016). A fraction of the reprocessing losses is dispersed in the CSD-V and CSD-C waste. Since neither the evolution in time of the recovery fraction, nor the distribution of the reprocessing losses are known in detail, the carry-over fraction from fuel matrix to CSD-V for U and Pu was set to 0,1%. This value is conservative for future vitrified waste. As will be shown in §5.4, this value is also conservative for the returned CSD-V waste packages.

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- The carry-over fractions from fuel matrix to CSD-C are based on (Gue *et al.*, 1986) and (Hélie, 2004). For H-3, the highest value is taken. For the fission products, an average value of 0,2% is taken. The activation products are conservatively assumed to have the same carry-over fraction (Hélie, 2004). For the actinides, carry-over fractions to CSD-C between 0,01% and 0,1% are reported. Conservatively, the same value as for fission and activation products was therefore chosen. Two sets of results are thus obtained, according to the two cases with different decay time at the moment of reprocessing as described in $4.1.1. For long term safety, no important differences between the two cases are expected. For heat impact considerations, the timely profile of both spectra will differ. In the case of a longer decay time before reprocessing, the heat output of a CSD-V canister will be lower initially, but will decrease more slowly with time and eventually surpass that of the case with a shorter decay time before reprocessing. 4.1.3 Calculation of the average spectrum for not to be reprocessed assemblies For the assemblies that are not selected for future reprocessing, no separate information was given. Thus, to calculate the radiological spectra of unreprocessed assemblies, one has to subtract the radiological inventory of the to be reprocessed assemblies from the 'total fleet' inventory. Since this first inventory was calculated to be conservative for the reprocessing waste, subtracting this from the initial (conservative) 'total fleet' inventory, might lead to an underestimation for the unreprocessed assemblies. Therefore, the calculation described in §4.1.1 was repeated with two differences, leading to a deliberate underestimation of this inventory. After calculating the three spectra per subgroup, the minimal activity per nuclide and per component was retained. Secondly, all cladding was assumed to be Zr-4/PCA-2b. FUEL MATRIX **0,1%** of H-3, Kr-85 **0,1%** of U and Pu **1%** of I-129 **10%** of C-14 **100%** of other RN CSD-V CLADDING **100%** of all RN CSD-C TRUCTURES **100%** of all RN **80 %** of H-3 **0,2%** of other FP&AP **0,2%** of actinides **0,7/1,1%** of all RN All spectra were calculated at 10 years after unloading from the reactor. Finally, the total inventory (of to be reprocessed assemblies) per assembly type was subtracted from the total inventory of the 'total fleet' of this assembly type, and divided by the number of not to be reprocessed assemblies of this type, which consequently leads to a (conservative) average spectrum for the not to be reprocessed assemblies. 4.1.3.1 Discussion This way of working obviously leads to the 'double counting' of a part of the activity. The most impacted radionuclides are Nb-94 (due to the cladding type unknowns), U-235 and the higher mass actinides (whose production is more influenced by the initial enrichment than other nuclides). For all other nuclides, the activity counted twice is less than 10% of the total inventory of that nuclide (reprocessed and unreprocessed assemblies combined) for the 8ft. and 12ft. assemblies. For the 14ft. assemblies, this is a lot higher due to the combination of high enrichment variability (as opposed to the 8ft. assemblies) and the large fraction of assemblies selected for reprocessing (as opposed to the 12ft. assemblies). No additional information is available to further refine this methodology and reduce the conservatisms. For the sake of the safety assessment within SFC-1, which is a methodological safety case, the current method is deemed sufficient. For heat impact calculations (related to the design of the supercontainer, the design of the repository, near field THM considerations or the (far field) aquifer temperature), the impact of this 'double counting' of activities will be limited to the CSD-V, more

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specifically to the heat production by Cm-244 decay. It should be noted that the contribution of Cm-244 to the total heat output decreases quickly with time. If nevertheless these studies show a problematic overestimation, a review of the methodology described in this note shall be considered. A possible solution might be found in a Cm-244 limitation in one CSD-V waste package, due to its fissile properties. However, the Cm-244 limitation on the previously produced CSD-V waste packages will not be applicable on the future CSD-V (de Limelette, 2017b).

The heat output of the average unreprocessed assemblies in the mixed scenario is similar to that of the average assemblies in the direct disposal scenario, so no impact is expected here.

4.1.4 Calculation of the maximal spectrum for not to be reprocessed assemblies and future CSD-V & CSD-C

4.1.4.1 Maximal spectrum for not to be reprocessed assemblies

Since no details are available on individual assemblies selected for reprocessing, no distinction is made between the maximal spectra for the unreprocessed assemblies in the case of a mixed scenario or in the case of a direct disposal scenario.

4.1.4.2 Maximal spectrum for future CSD-V

To estimate the maximal radiological spectrum of the to be produced CSD-V and CSD-C waste packages, we cannot rely on AREVA's production specification, since these will be revised for the CSD-V. A maximum alpha activity at 10 000 years after production of 2,3GBq/g is foreseen in the new specification (de Limelette, 2017a). With the radiological vector calculated in the previous paragraph, this would lead to an unrealistically high activity: the maximum would be a few hundred times the average. Therefore, it is proposed to use the data from both Belgian and German past CSD-V productions. A maximum-over-average ratio can be calculated for a number of waste properties: total beta/gamma activity (±1,3), total alpha activity (±1,5), Nd content (±1,4), thermal output at production (±1,3) and for declared radionuclides (between 1,15 and 7). The highest maximum-over-average ratio for medium and long lived fission and activation products (T1/2 >10y) is 1,66. For the U and Pu isotopes, this ratio lies between 3,08 and 4,69 while for the minor actinides it is limited to 2,73. Only taking into account those nuclides with a significant impact on the heat production, this becomes 1,22 for the fission and activation products (Sr-90 and Cs-137) and 1,64 for the actinides (Am-241, Am-243 and Cm-244).

Based on this information, ratios of 2 for the fission and activation products, 5 for U and Pu and 3 for the minor actinides are used for establishing a maximal spectrum for safety assessments. Furthermore, it is proposed to use the ratios of 1,3 for the fission and activation products and 1,7 for the actinides to establish a maximal spectrum for heat impact considerations. 4.1.4.3 Maximal spectrum for future CSD-C Maximum-over-average ratios can also be calculated for the CSD-C waste properties (based on Belgian waste only): total beta/gamma activity (±2,0), total alpha activity (±1,7), thermal output at production (±2,1) and for declared radionuclides (between 1,6 and 41). The highest maximum-over-average ratio for medium and long lived fission and activation products (T1/2 >10y) is 3,89, while for U and the transuranic elements this is 4,56. Ratios of respectively 4 and 5 are therefore applied on the average spectrum to calculate the maximal spectrum of to be produced CSD-C waste packages.

The thus calculated CSD-C inventory passes the AREVA guaranteed parameters for total long-lived (T1/2 >50 years) alpha activity, total alpha-Pu activity, Pu-241 and Cm-244 activity. It should be noted that this maximal inventory does not correspond to a realistic waste package: this maximal spectrum combines the maximal activity of each individual nuclide and should thus cover all waste packages that will be produced in the future11.

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4.2 Results

4.2.1 Unreprocessed spent fuel assemblies

The above described calculations result in 3 different spectra for the not to be reprocessed spent fuel assemblies:

- an average inventory for the unreprocessed 8ft. UOX assemblies;

- an average inventory for the unreprocessed 12ft. UOX assemblies;

- an average inventory for the unreprocessed 14ft. UOX assemblies.

These average inventories are presented in Appendix 4a, at 10y after unloading the spent fuel assemblies from the reactor. The corresponding maximal inventories are identical to those presented in the previous chapter (§3.2) and are not repeated.

4.2.2 CSD-V & CSD-C

The average and maximal inventories of the to be produced CSD-V and CSD-C waste packages were calculated for two considered cases:

- reprocessing of the assemblies at 8 years after unloading from the reactor;

11 Of course, uncertainties on the input data and calculations in this note on the one hand, and the waste characterization by the producer on the other hand, still have to be taken into account. This however falls outside the scope of this note.

- reprocessing of the assemblies at their average cooling time after unloading from the reactor (between 12 and 35 years), as communicated by Synatom.

This results in 10 different spectra, 5 for each case:

- an average inventory for the CSD-V waste packages;

- a maximal inventory for the CSD-V waste packages;

- a maximal inventory for the CSD-V waste packages for heat impact considerations;

- an average inventory for the CSD-C waste packages;

- a maximal inventory for the CSD-C waste packages.

The inventories are presented in Appendix 4b. For the first case, these are established at 10y after the unloading of the reprocessed spent fuel assemblies from the reactor. For the second case, these are established at the moment of reprocessing (thus 12 to 35 years after the unloading of the reprocessed spent fuel assemblies from the reactor).

4.3 Comparison with previously calculated inventories

In the Data Clearance Table 2.2, a radiological spectrum is given for future CSD-V and CSD-C waste packages. These spectra have been defined based on a full reprocessing scenario, but do not take into account the MOX-assemblies. Thus, all differences between these spectra and those calculated in this note, should originate from one or more of the following possibilities:

1) differences in the calculation methodology: impurities (see §3.1.1), half-life (see §3.1.2), adaptations made for specific nuclides in previous calculations or adaptations made to the FICAR-12ft-v3 workbook (see §3.1.3);

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2) differences in the used information on the initial enrichments and burn-ups (i.e. the definition of the groups of assemblies), the number of assemblies allocated to each assembly group and the inclusion of the MOX-assemblies; 3) differences in cooling time before reprocessing for the 2nd case with a 12 to 35 year decay time before reprocessing (8 years in the previous one); 4) differences in incorporation rate (#CSD/tHM) or carry-over fractions. 4.3.1.1 Comparison with radiological spectrum for CSD-V in DCT2.2 For the previous calculations, an incorporation rate of 0,6 CSD-V/tHM (as based on the recommendation in (Synatom, 2007)) was used instead of 0,91. This leads to overall ±35% lower activities in the current calculations. For some nuclides, this is counteracted or reinforced by other differences. The most important difference is for Nb-94: due to the inclusion of the shearing fines activity (which was neglected in the previous calculations), its activity is raised by a factor 200. For the Pu, Am and Cm isotopes, the low minimal initial enrichment of the assemblies selected for reprocessing and the inclusion of the MOX-assemblies lead to significantly higher activities (up to a factor 4). This effect is stronger for the higher mass isotopes (with atomic mass 242 or higher). This is even further fortified for Pu-240, due to the Cm-244 decay. For a series of other isotopes (namely C-14, Cl-36, Ca-41, Mn-54, Co-60, Ni-59, Ni-63, Ru-106, Pd-107, Ag-108m, Ag-110m, Sn-126 and Sb-125), the same effect is visible, but to a lesser extent (in all cases, the ratio remains below 1). In the case of a longer cooling time before reprocessing, some other effects are visible. The Am-241 activity is about 50% higher than in previously calculated inventories. Since U and Pu are separated during reprocessing, the U-233 and Pu-240 activity in the CSD-V are mainly determined by ingrowth from mother isotopes. If compared at the same time after the unloading of the assemblies, the U-233 and Pu-240 activities are much lower in the case of later reprocessing. With time, this effect diminishes. Other differences are due to different half-lives used (Se-79, Sn-126, Ag-108m, Am- 242m) or the lower Cl and higher Ag impurity in the fuel (Cl-36 and Ag-108m respectively). 4.3.1.2 Comparison with radiological spectrum for CSD-C in DCT2.2 Contrary to the case of the CSD-V, an incorporation rate of 0,8 CSD-C/tHM (as based on the recommendation in (Synatom, 2007)) was used in the previous calculations, compared to 0,61 here. Also, some different carry-over fractions were used from fuel to CSD-C: 100% of H-3, 1% of Pu-isotopes and 0,5% of other FP, AP and actinides. The lower incorporation rate used for the current calculations leads to overall ±30% higher activities. In combination with the lower carry-over fractions, there is a reduction of the fission product activity (by a factor 2) and the lower mass actinides. For the higher mass isotopes (starting from Am-242m), the low minimal initial enrichment of the assemblies selected for reprocessing and the inclusion of the MOX-assemblies counteracts this, which leads to higher activities up to a factor 3. Other differences are due to different half-lives (Se-79, Sn-126, Ag-108m, Am-242m) or the fraction of M5/Zirlo cladding in the reprocessed assemblies, which was chosen more conservatively in the current exercise (Nb-94).

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Globally, we can conclude that the recalculated CSD-V inventory presents a lower average activity for all nuclides, except for the higher mass actinides and Pu-240. The largest differences in the CSD-C inventory are for the higher mass actinides and Nb-94 (´ ±5). **5. Inventory of produced reprocessing waste** In the 1980s and 1990s, 672 tHM of spent fuel was sent to Cogema's (now AREVA) reprocessing plant in La Hague, of which 40 tHM featured no return of waste to Belgium. Of the other 632 tHM, about 290 tHM originated from the Doel 1 and 2 reactors (8ft. 14x14 assemblies), while 340 tHM originated from the Tihange 1 reactor (12ft. 15x15 assemblies). In this chapter, the average and maximum inventories of produced CSD-V & CSD-C waste packages will be calculated and compared to the inventories declared by the waste producer. 5.1 Methodology 5.1.1 Calculation of average spectrum for produced CSD-V & CSD-C For the calculation of the average spectrum of the already reprocessed spent fuel assemblies, a similar methodology as described in previous chapters was followed. Different subgroups of the 8ft. and 12ft. assemblies were defined in Synatom note 09/151 (Synatom, 2009). From the mass balance, it can be derived that about half of the assemblies in the "mixed" subgroups (denominated "Tihange/Doel") originate from the Doel 1/2 reactors and the other half of the Tihange 1 reactor. Contrary to the previous chapters, we can differentiate the Tihange 1 12ft. 15x15 assemblies. However, the FICAR worksheets don't allow to take this specific geometry into account. Therefore, the FICAR-12ft-v3 worksheet (designed for 17x17 assemblies) will still be used to calculate the inventory of the reprocessed Tihange 1 assemblies. No variability on the initial enrichment was applied. Furthermore, it was assumed that all assemblies had Zircaloy-4 or PCA-2b cladding12. Also, an 6 year cooling time of the assemblies before reprocessing was used, based on the Cs-134/Eu-154 ratio (as proposed in O/N-note 2008-1900 (Boulanger, 2008)). Finally, the carry-over fractions to vitrified and compacted waste as presented in the previous chapter (Figure 2) were applied on the total inventory of reprocessed assemblies, after which the activities of both waste streams were homogeneously distributed among the produced waste packages (387 CSD-V and 432 CSD-C). 5.1.2 Calculation of maximal spectra for produced CSD-V & CSD-C To calculate maximal spectra for these waste packages, the same maximum-overaverage ratios as defined in §4.1.4 can be used. A comparison with the Cogema/AREVA specifications is possible in this case. For the CSD-V waste packages, the maximal Cs-137, Sr-90 and Cm-244 as-calculated activity (applying ratios for safety assessment) is higher than the limit from the specification (the "guaranteed parameters") by respectively 60, 69 and 37%. These nuclides are mainly of importance for their heat production. Applying the lower ratios for heat impact considerations (as defined in $4.1.4.2) leads to maximal spectrum that only just exceeds these limits. Therefore, no effort has been done to refine the calculation of the maximal spectra of produced CSD-V waste packages. For the CSD-C waste packages, the maximal Pu-241, total Pu and Cm-244 as-calculated activity is higher than the limit from the specification (by 77, 47 and 38% respectively), 12 M5 cladding was not used on an industrial level before 1999 (IRSN, 2008), while Belgian assemblies sent to reprocessing were all unloaded before 1990.

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as well as the total activity of alpha emitters with half-live > 50 years (by 57%). Since the maximal spectrum for produced CSD-C is lower than that for the to be produced CSD-C for all radionuclides, no effort has been done to refine its calculation. 5.2 Results The above described calculations result in 5 different spectra for the already produced CSD-V and CSD-C waste packages: - an average inventory for the CSD-V waste packages; - a maximal inventory for the CSD-V waste packages; - a maximal inventory for the CSD-V waste packages for heat impact considerations; - an average inventory for the CSD-C waste packages; - a maximal inventory for the CSD-C waste packages. The inventories are presented in Appendix 5, at 10y after the unloading of the reprocessed spent fuel assemblies from the reactor. 5.3 Comparison with previously calculated inventories As in the previous chapters, the results will be compared with the radiological spectra as present in the Data Clearance Table 2.2 in order to assess the impact of the revised calculation on the safety assessments. However, DCT2.2 contains no separate spectrum for the produced CSD-C, nor does it contain maximal spectra, so the comparison can only be made for the average CSD-V inventory. All differences in inventory should originate from one or more of the following possibilities: 1) differences in the calculation methodology: impurities (see §3.1.1), half-life (see §3.1.2), adaptations made for specific nuclides in previous calculations or adaptations made to the FICAR-12ft-v3 workbook (see §3.1.3); 2) differences in the used information on the initial enrichments and burn-ups (i.e. the definition of the groups of assemblies) and the number of assemblies allocated to each assembly group 3) differences in carry-over fractions. As for the future CSD-V, the most important difference is for Nb-94, due to the inclusion of the shearing fines activity. However, since none of the reprocessed assemblies had a M5/Zirlo cladding, its activity increase is limited to a factor 10. There is a significant reduction in Cl-36, Ag-108m, Sn-126 (by a factor 2) and Se-79 activity (by a factor 5), and a smaller rise in Am-242m and Cm-242 activity, that can be explained by the same reasons mentioned in §3.3. The spectrum in DCT2.2 was derived from a single calculation for a 8ft. assembly, with 3,5wt% initial enrichment and 33 GWd/tHM burn-up. The subgroups used for the current calculation show slightly lower initial enrichments (3,4wt% for the 8ft. assemblies, 3,3wt% for the 12ft. assemblies) and slightly higher burn-ups (34,3 GWd/tHM for the 8ft. assemblies, 35,3 GWd/tHM for the 12ft. assemblies). This obviously also leads to a lower U-235 activity. This also leads to notable higher activities for the larger mass actinides (generally when the atomic mass is 242 or higher) as a consequent of the strong nonlinear behaviour versus burn-up of nuclides that are produced by subsequent neutron capture. 5.4 Comparison with the inventories as declared by the waste producer The calculated inventory can be compared to the average declared inventory of the returned waste packages. Regarding the CSD-V, there is a good correspondence for the medium- and long-lived

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fission products Sr-90, Zr-93, Tc-99, Pd-107, Cs-135 and Cs-137. After correction for the used half-lives, Se-79 and Sn-126 are overestimated in the current calculation by ±35%.

Larger differences are observed for shorter-lived nuclides (up to a factor 5, but 45 for Co- 60). These nuclides are however of less concern for long term safety. The calculated U and Pu-activities are a factor 1,5 to 2 higher than those declared by AREVA. For Np-237, this is a factor 1,8; for Cm-245 a factor 1,3. The other declared Am and Cm isotopes are within 15%.

Since the activity in the CSD-C waste packages stems solely from contamination from the fuel matrix and activation of alloy elements and impurities in the structural materials, larger differences are to be expected. On remarkable difference is for Ag-108m (6 orders of magnitude) due to the fact that AREVA has not taken its production by activation of Ag impurities into account. Other notable differences are for difficult to characterize nuclides C-14, Cl-36 and Ca-41 (all overestimated in the current calculation). The other medium and long lived fission and activation products lie within a factor 3. Except for Cm-248 (0,77), the actinides are all overestimated with ratios varying between 1,04 and 100, the activity-weighted average of their ratios being 2.

Globally, we can conclude that the calculated inventories are slightly conservative, but reasonably compatible with the declared ones.

6. Conclusion

In this note, the methodology for the calculation of the radiological inventory of the spent fuel assemblies and the reprocessing waste (CSD-V and CSD-C) in both the ‘open cycle’ scenario and the ‘mixed’ scenario are described and the results are presented.

In order to perform the calculations, the FICAR-v3 tool was adapted to make it usable for 8ft. and 14ft. UOX assemblies. Checks were performed to validate the adjustments, with satisfying results. After a short literature study, covering values for Be-10 and Mo-93 activities in the different fuel assembly components were proposed.

Subsequently, using Synatom’s assembly grouping by initial enrichment and burn-up, average and maximal spectra were calculated for the 8ft., 12ft. and 14ft. UOX assemblies. Only a single spectrum for the 12ft. MOX assemblies was calculated.

Next the case of a mixed scenario, in which part of the spent fuel assemblies is reprocessed, was considered. Both the average and maximal radiological inventory of unreprocessed assemblies and of the CSD-V and CSD-C waste packages was calculated.

The results of the calculations are presented in Annex 3 for the direct disposal scenario and in Annex 4 for the mixed scenario. For each case, a comparison with the results from previous scoping calculations performed during the period 2010-2012 (i.e. those comprised in Data Clearance Table 2.2), was done in order to identify the largest impacts for safety assessments. Also, the radiological inventory of reprocessing waste from past reprocessing contracts has been calculated. The results are presented in Annex 5. The results were also compared with those from previous calculations, as well as with the activities declared by the waste producer.

4.3c How are disposal concept uncertainties managed?

The uncertainties were mainly addressed by a generic assessment of potential sites, at several depths in two given host rocks for which the R&D Belgian programme is well-advanced. The details of such an approach is given below:

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Introduction

Due to a lack of decisions regarding the potential host rocks and sites, but in order to benefit from the existing knowledge resulting from 40 years of R&D, it was decided to define hypothetical/generic sites[8] for the geological disposal in poorly indurated clay. Three reference depths have been arbitrarily set by the O/N general direction as working assumptions: 200m, 400m and 600m. The results of this brainstorming will serve as a basis for the techno studies (feasibility and cost assessment) and for the safety studies (performance assessment). **However the results provided here cannot be used as such and specific integration notes should be further established to precise the detailed parameters and the specific boundary conditions.**

Approach

The hypothetical/generic sites were defined based on DOV 3D geological model developed by VITO (dov.vlaanderen.be).

First horizontal slices were performed at 200m, 400m and 600m below sealevel (TAW) in order to highlight the areas where the reference clays occurs at the depths set as working assumptions[9] (See Section 3). The reference clays are the Boom Clay Formation and the Ypresian clays (corresponding to the lower part of the Tielt Formation and the Kortrijk Formation).

Based on a map presenting the isohypses (Contour lines of equal height of the considered geological formations – in this case the top of the formation), vertical slices were performed first parallel to the strike at -200 mTAW, -400 mTAW and -600 mTAW in order to have a proper insight of the surrounding rocks (above and below) for the specified depths and a possible lateral variability of the geological formations (See Section 4 for Boom Clay and Section 5 for Ypresian clays).

Then, cross-sections were performed perpendicular to the strike for the most significant variations in terms of spatial configuration in order to have a better description of the geological context around the hypothetical/generic sites (See Appendix).

The overall lithological description of the various geological formations were used to define rather synthetic way the succession of aquitard and aquifer layers (covering a range of spatial configurations that may correspond to the underground in northern Belgium).

As a result to this approach (not documented in details), six hypothetical/generic sites were defined for the two poorly indurated clays: BC-200-A, BC-200-B, BC-400, YC-200, YC-400 and YC-600.

- **Horizontal slices**

The horizontal slices at an elevation of -200 mTAW, -400 mTAW and -600 mTAW are given respectively in Figure 1, Figure 2 and Figure 3 on which the reference clays (Boom Clay and Ypresian clays) have been indicated. The legends for the other layers are given in Figure 4. These maps clearly highlight the presence of the clay layers at depth representative to the working assumptions. It is worth noting that the use of the 3D geological model is by nature entailed by the limitations of the model itself. A geological model is an interpretation of geological data obtained by various means and aiming at explaining their spatial distribution. As a matter of fact, the methodology followed to develop such a model is highly subjective and the techniques to be used have to be carefully selected based

[8] In the context of this note, a generic site is a simplistic description of the succession of aquifers and aquitards that may be encountered in Belgium where the two main poorly indurated clay layer are at depth similar to the working assumptions.

[9] As the northern part of Belgium is generally flat, it was assumed that these slices are representative for our working assumptions

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on the geological terrains to be modeled – i.e., a monocline basin is not mapped with the same techniques as a highly deformed basin.

In this report the HCOV[10] Code is also used to further describe the aquifers and aquitards.

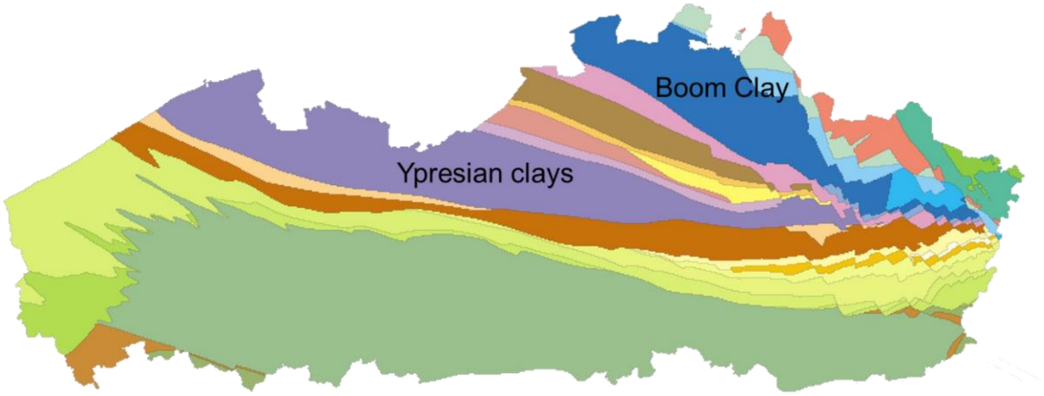

Figure 1: Horizontal slices at -200mTAW

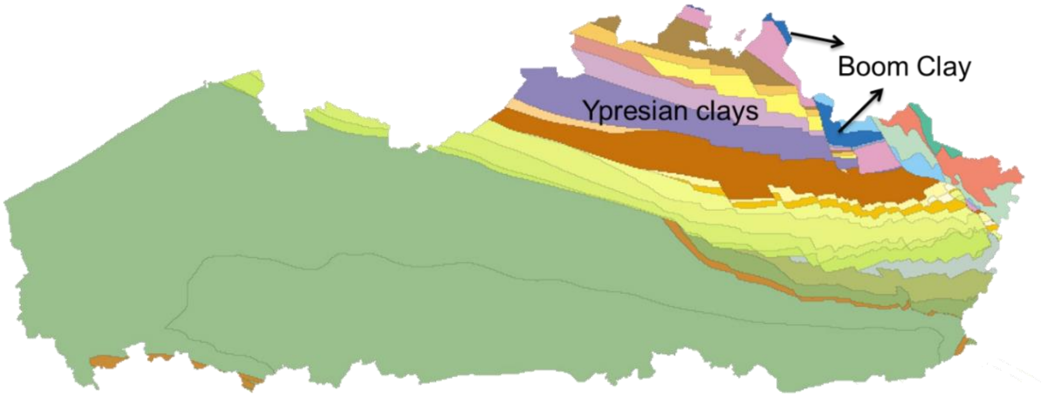

Figure 2: Horizontal slices at -400mTAW

[10] *Hydrogeologische Codering van de Ondergrond van Vlaanderen* (See https://dov.vlaanderen.be/dovweb/html/3hcov.html#codering)

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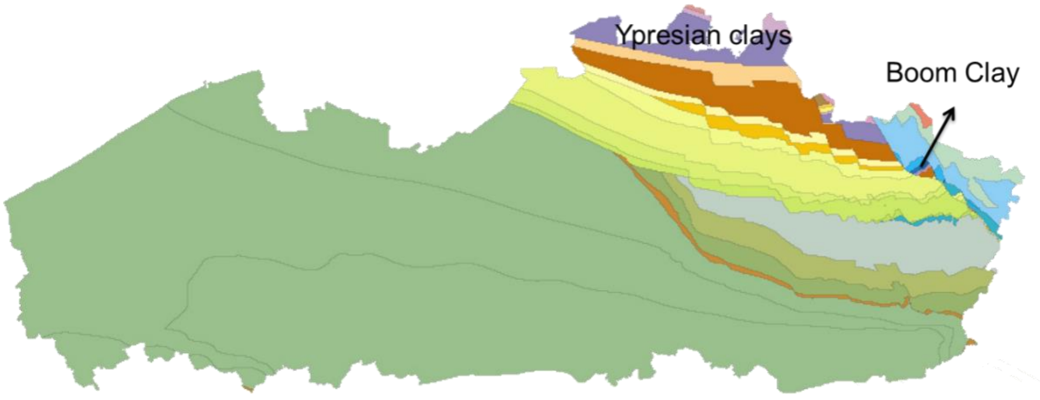

Figure 3: Horizontal slices at -600mTAW

Figure 4: legend of the different layers for the horizontal and vertical slices.

Generic sites - Boom Clay

- Isohypses Boom Clay

The isohypses for the top of Boom Clay are presented in Figure 5.

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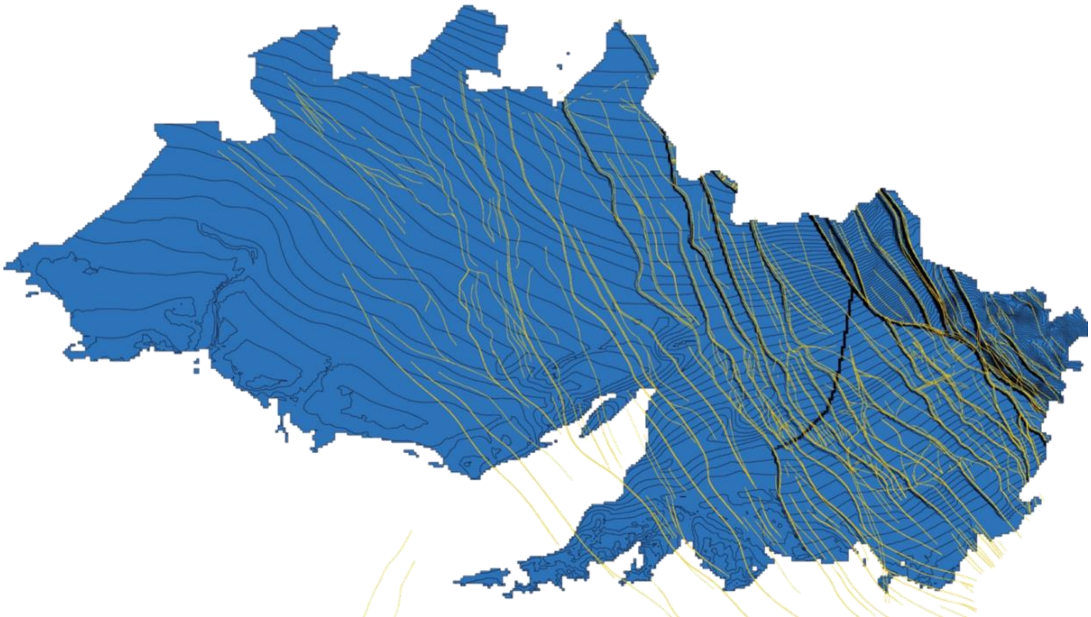

Figure 5: Isohypses for the top of Boom Clay.

- Boom Clay at 200 m

The vertical slice parallel to the strike of the mid-plane of the Boom Formation at -200 mTAW is presented in Figure 6. The Boom Clay has a relative constant thickness (about 100 m). The layers above the Boom Clay are also different (i.e. on the left of the figure (closer to the sea) and on the right side of the figure). It is also worth noting that the salinity of the deeper aquifers are expected to vary (more salinity closer to the sea).

Two generic sites were defined: The generic site BC-200-A (See Figure 7) and the generic site BC-200-B (See Figure 8) with a higher salinity and with an aquitard at the surface.

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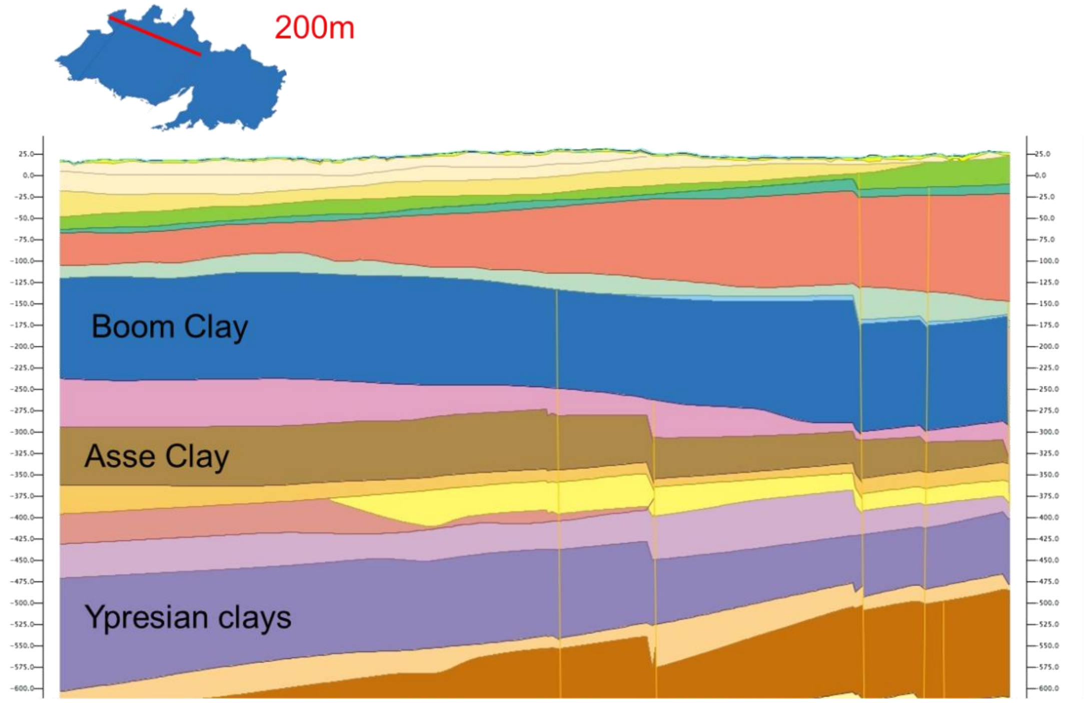

Figure 6: Vertical slice parallel to Boom Clay strike at -200m TAW based on GEO 3D model VL@DOV (Remark: Asse is only a part of the brown layer)

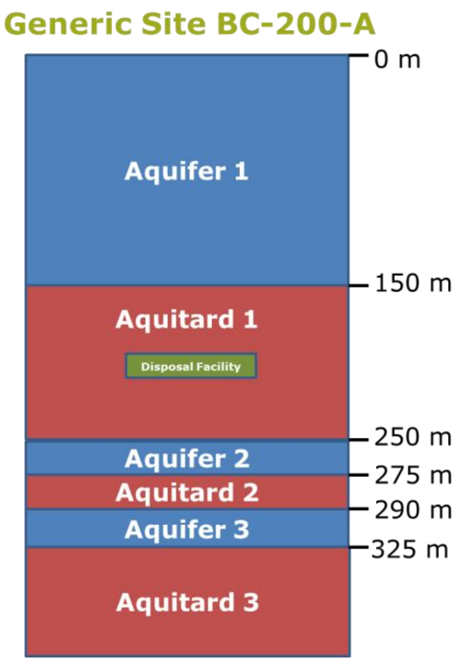

Figure 7: Generic Site BC-200-A

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For the generic site BC-200-A, the aquitards 1, 2 and 3 correspond respectively to Boom Clay (HCOV0300), Asse clay and Ypresian clays. The aquifer 1 corresponds to CKS-0200_GWL_1 and is composed of HCOV0230; HCOV0240; HCOV0250.

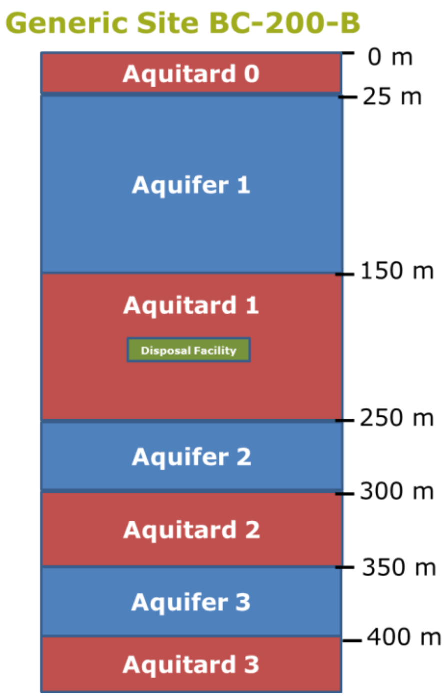

Figure 8: Generic Site BC-200-B

For the Generic Site BC-200-B, the aquitard 1, 2 and 3 correspond respectively to Boom Clay, Asse clay and Ypresian clays. The aquitard 0 corresponds to CKS-0220_GWL_1 at least in the Meuse basin (HCOV0220). The aquifer 1 corresponds to CKS_0200_GWL_2, at least in the Meuse Basin.

- Boom Clay at 400 m

The vertical slice parallel to the strike of the mid-plane of the Boom Formation at -400 mTAW is presented in Figure 9. On the right side of the Figure, a step is noticed due to the presence of a fault. Hence only the left side of the Figure is considered. The Boom Clay has a relative constant thickness (about 100 m). The layers above the Boom Clay are quite similar.

One generic site is defined: The generic site BC-400 (See Figure 10). The Aquitards 1, 2 and 3 correspond respectively to Boom Clay, Asse clay and Ypresian Clays.

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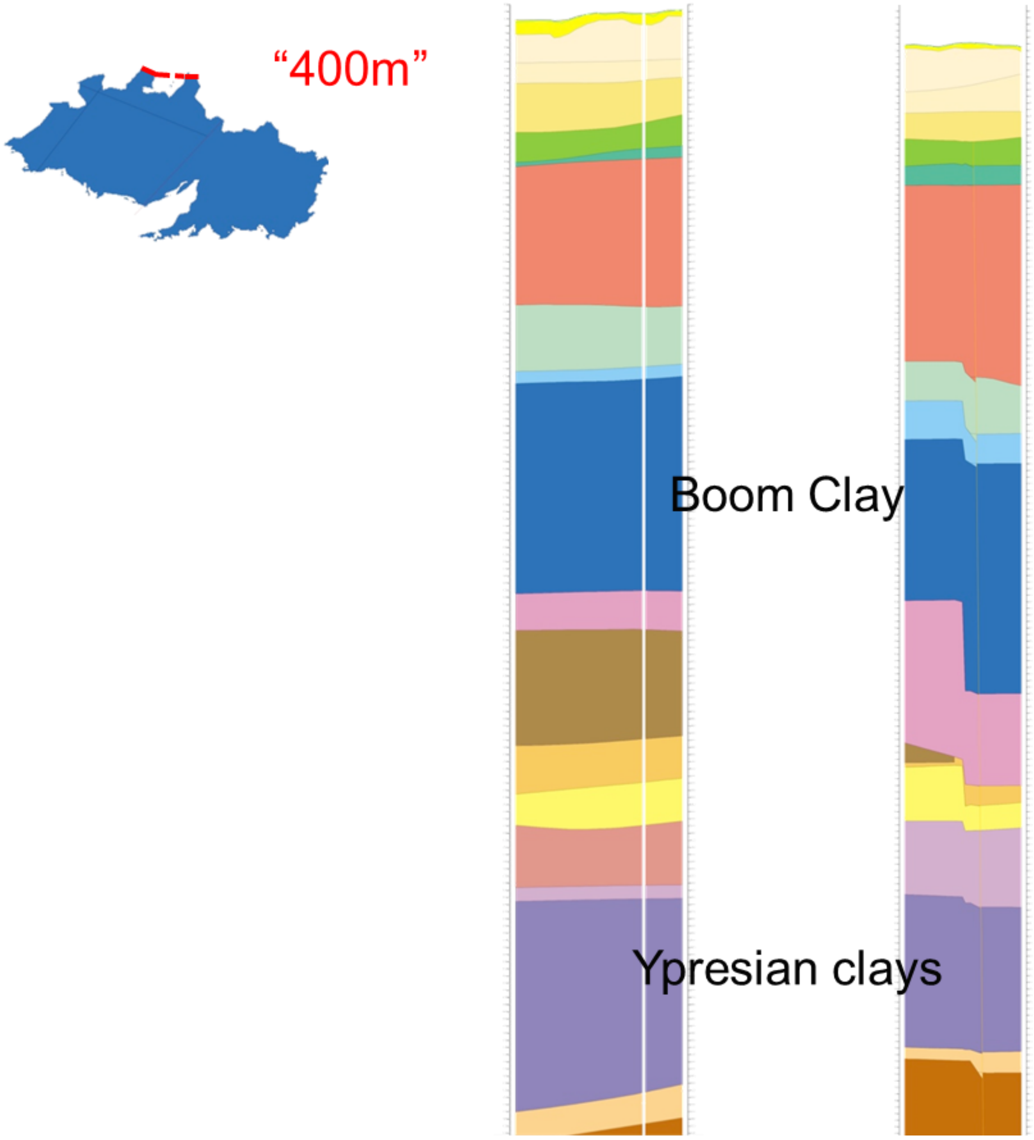

Figure 9: Vertical slice for Boom Clay at -400 mTAW based on GEO 3D model VL@DOV

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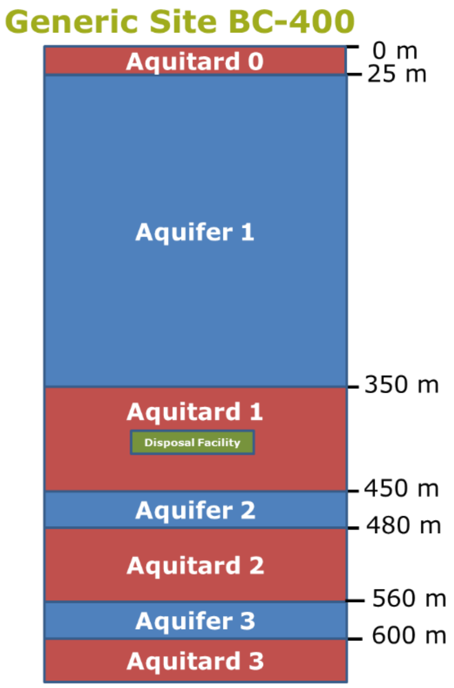

Figure 10: Generic Site BC-400

For the Generic Site BC-400, the aquitard 1 (HCOV0300), 2 and 3 correspond respectively to Boom Clay, Asse Clay and Ypresian Clays. The Aquitard 0 (CKS-0220_GWL_1) corresponds to the impermeable sediments of the *Klei-zand complex van de Kempen*. Note that the measured values of the salinity of aquifer 1 (CKS_0200_GWL_2) are always below 100mg/L for aquifer 1.

- Boom Clay at 600 m

The vertical slice parallel to the strike of the mid-plane of the Boom Formation at -600 mTAW is presented in Figure 11. Due to the very small thickness (about 30 m) of the Boom Clay no generic site was defined.

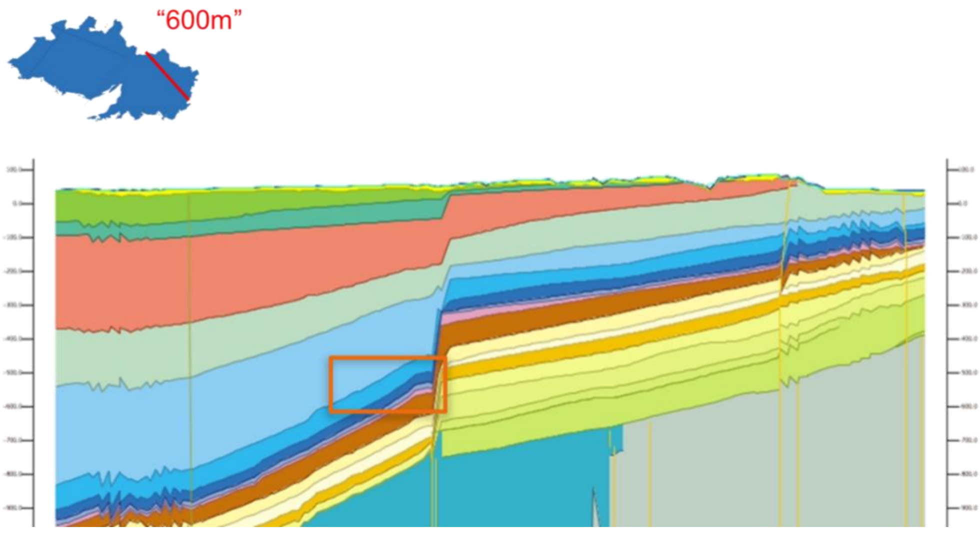

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Figure 11: Vertical slice for Boom Clay at -600 mTAW based on GEO 3D model VL@DOV

- **Ypresian clays**
  - Isohypses Ypresian clays

The isohypses for the top of geological formations included in the Ypresian clays are presented in Figure 12 (Tielt Fm) and Figure 13 (Kortrijk Fm).

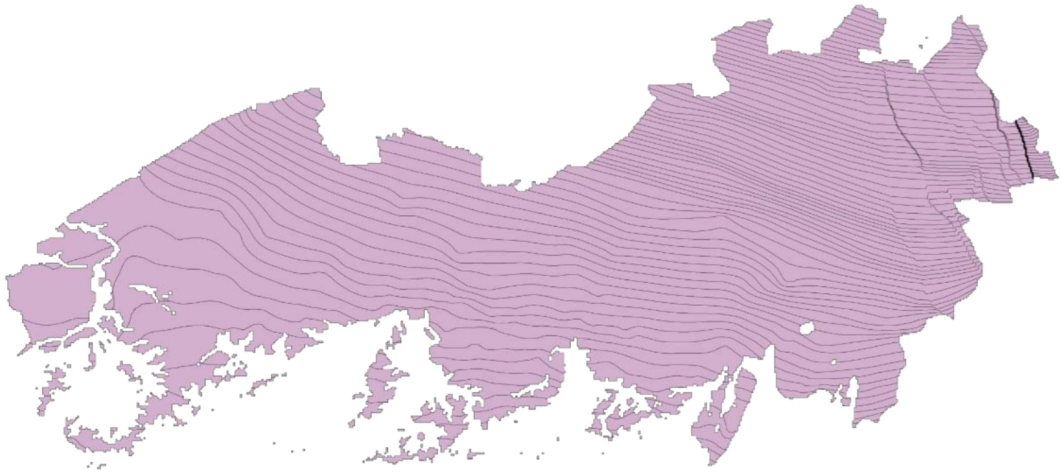

Figure 12: Isohypses of the top of the Tielt Fm)

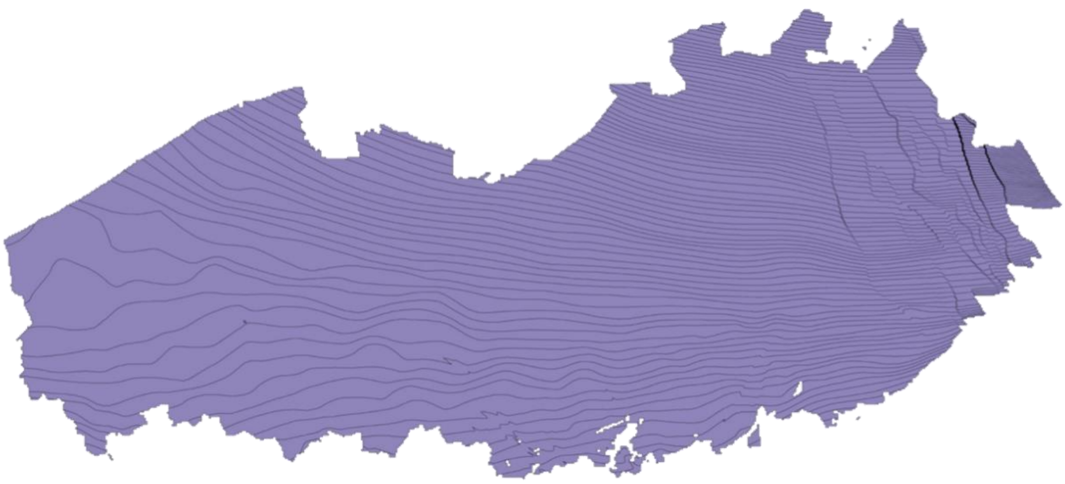

Figure 13: Isohypses Ypresian clays (Kortrijk Fm)

- Ypresian clays at 200 m

The vertical slice parallel to the strike of the mid-plane of the Ypresian clays at -200 mTAW is presented in Figure 14. The Ypresian clays have a relative constant thickness (about

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125 m). The layers above the Ypresian clays seem to be similar from West (left side of the figure) to East (right side of the figure). However this is not the case in reality. First of all, a number of layers disappear when going to the east, secondly, the stratigraphy of this part is under discussion, amongst others because of erosion surfaces, gullies etc.

One generic site is defined: The generic site YC-200 (See Figure 15). However given the lateral variability of the stratigraphy, it is more complicated to give the HCOV code.

The aquifer 1 corresponds to KPS_0120_GWL_1&2; KPS_0160_GWL_1,2,3; CVS_0160_GWL_1; CVS-0400_GWL-1. To the east, also HCOV0300 is present and east of the Schelde, the codes are different (CKS-0200_GWL_1 and BLKS__0400_GWL_2S). The aquifer 2 corresponds to CVS-0600_GWL_2 or BLKS_0600_GWL_2, which is including HCOV0800, where present. The aquifer 3 corresponds to CVS_0800_GWL-2 and is comprised in BLKS_0600_GWL_2 east of Schelde.

The aquitard 1 corresponds to the Bartoon aquitardsystem (HCOV0500). The aquitard 2 corresponds to the Paniseliaan aquitardsysteem (HCOV0700) and the aquitard 3 corresponds to Ypresian clays (HCOV0900). For the upper thin aquifer a high salinity is expected (~30 g/L), close to the sea.

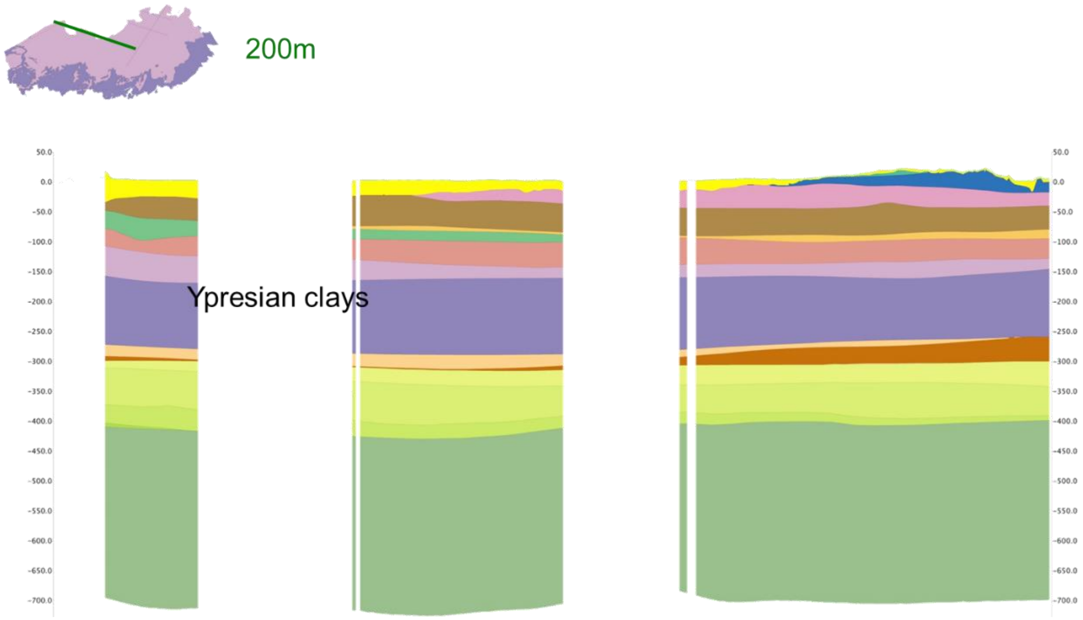

Figure 14: Vertical slice for Ypresian clays at about -200mTAW based on GEO 3D model VL@DOV

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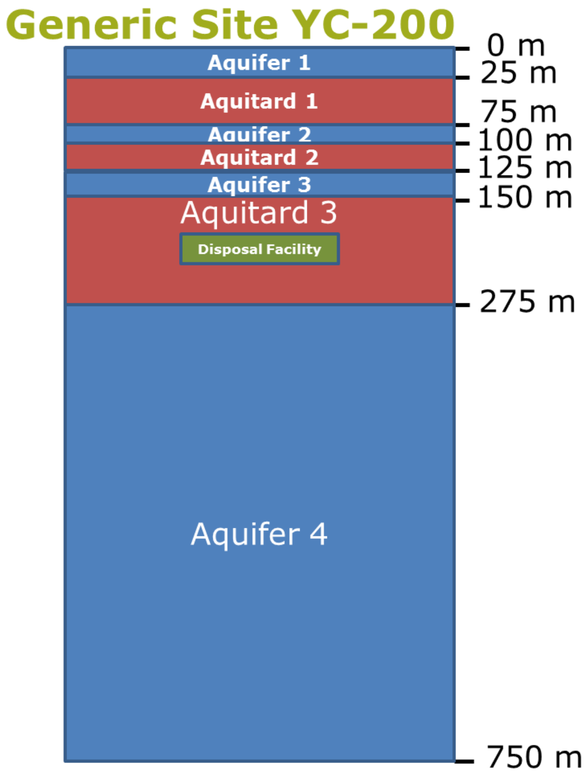

Figure 15: Generic Site YC-200

- Ypresian clays at 400 m

The vertical slice parallel to the strike of the mid-plane of the Ypresian clays at -400 mTAW is presented in Figure 16. The thickness of the Ypresian clays varies from about 75 m to about 150 m. The layers above the Ypresian clays presented small variations.

One generic site is defined: The generic site YC-400 (See Figure 17). The aquitard 1 corresponds to HCOV0300 (Boom Clay), the aquitard 2 corresponds to HCOV0500, the aquitard 3 corresponds to HCOV0700 and the aquitard 4 corresponds to HCOV0900 (Ypresian clays).

The aquifer 1 corresponds to KPS_0160_GWL_3. The aquifer 2 corresponds to CVS_0400_GWL_1 or BLKS_0400_GWL_2S. The aquifer 3 corresponds to CVS_0600_GWL_2 or BLKS_0600_GWL_2, including HCOV0800, where present. The aquifer 4 corresponds to CVS_0800_GWL_2 west of schelde, otherwise included in BLKS_0600_GWL_2.

For the upper aquifer (aquifer 1), a high salinity is expected (~30g/L) where close to the sea. In other aquifers, the concentration is lower and is increasing with depth and for the aquifer directly on top of the host rock (aquifer 3) a salinity of maximum 10g/L is expected.

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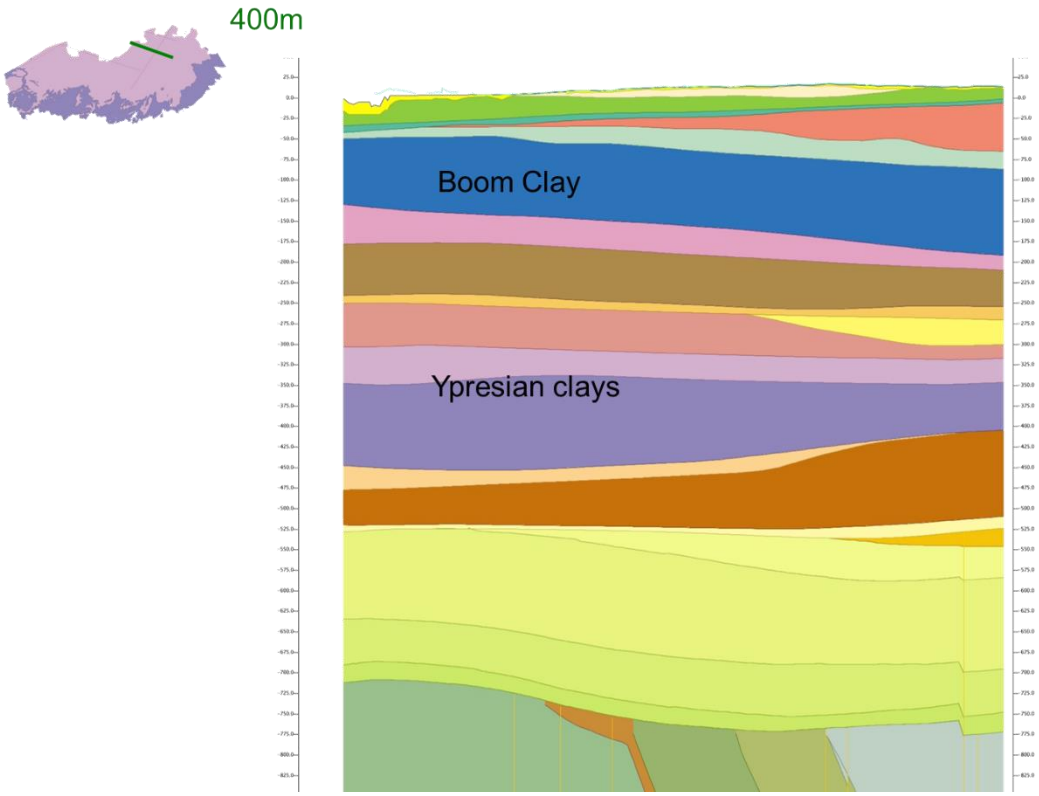

Figure 16: Vertical slice for Ypresian clays at 400m based on GEO 3D model VL@DOV

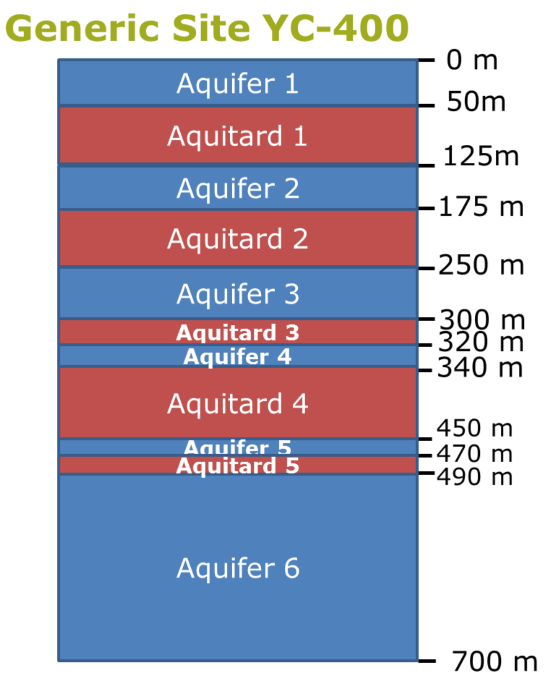

Figure 17: Generic Site YC-400

- Ypresian clays at 600 m

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The vertical slice parallel to the strike of the mid-plane of the Ypresian clays at -600 mTAW is presented in Figure 18.

One generic site is defined: The generic site YC-600 (See Figure 19). The aquitard 1 corresponds to Boom Clay (HCOV0300); the aquitard 2 is HCOV0500; the aquitard 3 is HCOV0700 and the aquitard 4 (HCOV0900) corresponds to Ypresian Clays.

Aquifer 0 corresponds to CKS-0220_GWL_1, comprising aquitard 0. The aquifer 1 corresponds to CKS_0200_GWL_2. The aquifer 2 is equivalent of BLKS_0400_GWL_2S, but belonging to the Meuse district. The aquifer 3 is equivalent of BLKS_0600_GWL_2S, but belonging to the Meuse district, which comprises HCOV0600, HCOV0700 and HCOV0800. The aquifer 4 is HCOV0800.

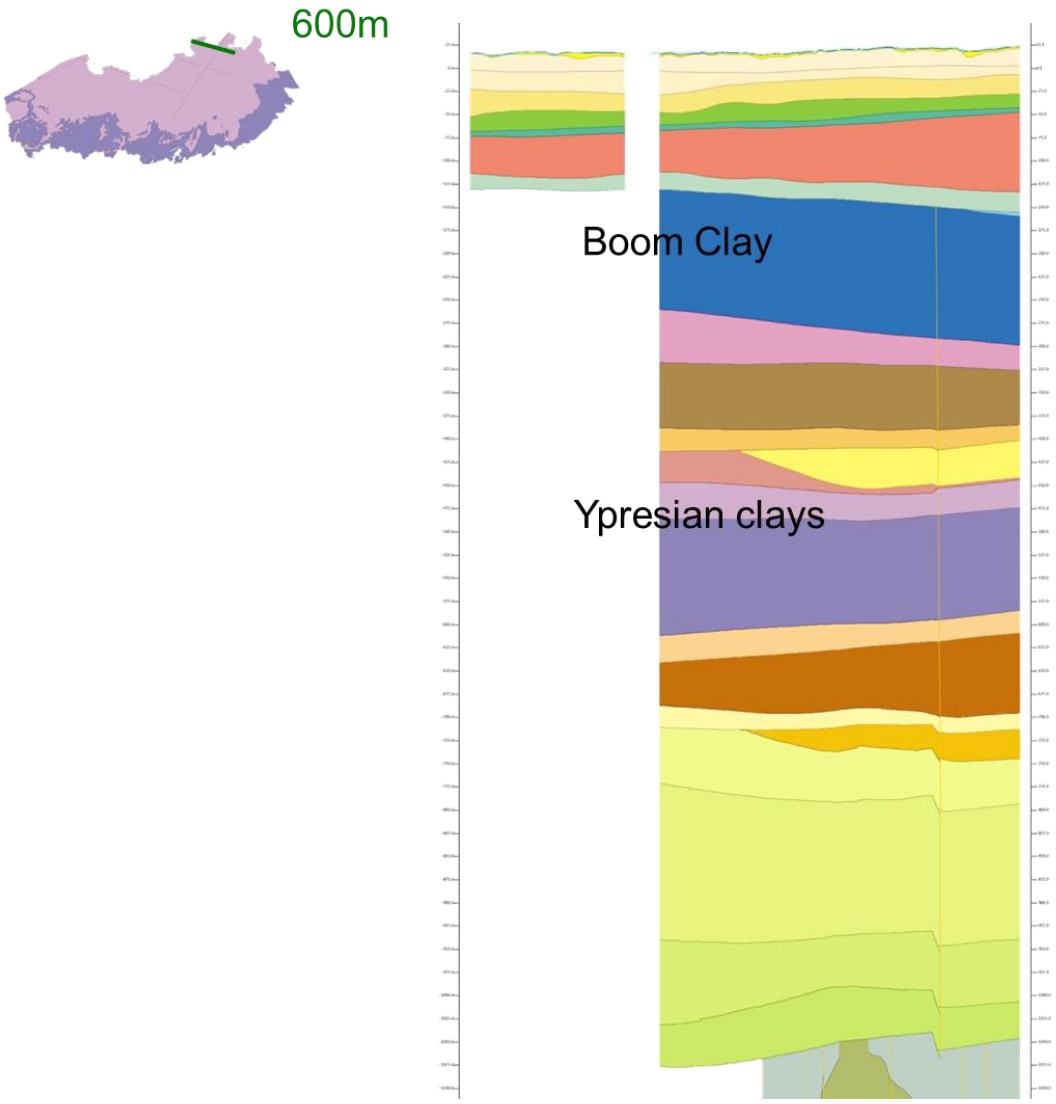

Figure 18: Vertical slice for Ypresian clays at 600m based on GEO 3D model VL@DOV

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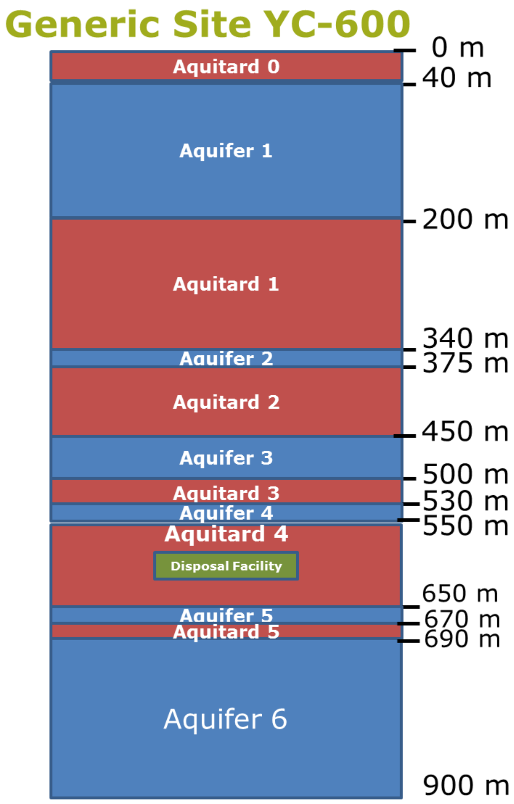 **Figure 19: Generic Site YC-600**
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
Some of the answers can already be found at the question 4.2., including the development of scenarios.
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
Yes
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
I don't think reversibility or retrievability will change anything to such situation. R&R only address the operational period (and eventually the institutional control phase) but are completely unrealistic beyond such timeframes. The uncertainties concern the ultra-long-term for which no certainty exist by definition. The expected evolution of the system assumes stability over time and flips the uniformitarianism hypothesis

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4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
I don't think R&D could change this horizon of prediction. Perhaps it is more efficient to work on the public perception.
4.3f How are uncertainties in the understanding of key processes managed?
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
i. Data Clearance Processes The data clearance process complements the processes for the derivation of the safety relevant parameters (Section 3.3.2, Figure 3.10) and for the qualification and validation of experimental data (Section 3.3.3, Figure 3.13). It focusses on the approval and update of the parameter values that are derived from these processes and their use in safety assessments and exploratory calculations. The objectives of the data clearance can be summarised as follows: to provide a centralised source of approved data to support the derivation of parameter values and ranges, as well as other aspects of the safety and feasibility case to enable systematic updating and versioning of the data so that changes can be made in an orderly, quality-assured and traceable manner to ensure that parameter values used in exploratory calculations and in the safety assessment are consistent with approved values and their ranges to provide information sources and tools for inspecting data that are tailored to the users' needs The data clearance process is an essential process for key safety calculations, but also a necessary process to follow in the course of the preparatory safety assessment and the performance of the related exploratory calculations. It ensures that the results of the early calculations form a reliable basis for guiding the development of the programme and that they are based on consistent and traceable input parameters and it allows inclusion of exploratory calculations in the formal safety phase without having to re-execute them on the grounds of data inconsistency. The data clearance process developed by ONDRAF/NIRAS is shown in Fig. 3.14 and is described in detail in (ONDRAF/NIRAS TR 2012-23E). The process is consistent and meets the requirements on traceability and consistency of the data used as well as of compliance to the quality assurance and the qualification, verification and validation defined by FANC (FANC/AFCN 2010). The main instrument of data clearance is the data clearance tables (DCT). They incorporate the parameter values to be used in the safety calculations including a large quantity of design data relating to the primary waste packages and the disposal system design, all available in a single place. Data traceability is enhanced through their systematic organisation and layout, and automatic data searching is facilitated by using a systematic parameter naming convention. Through versioning they "freeze" this information and ensure that all calculations corresponding to one version of the DCT are internally consistent. DCTs provide the link between raw data and quality-assured, cleared model parameters. They enable periodic, controlled updates of data through a systematic versioning process and recording of updates/changes in a history log within the DCTs.

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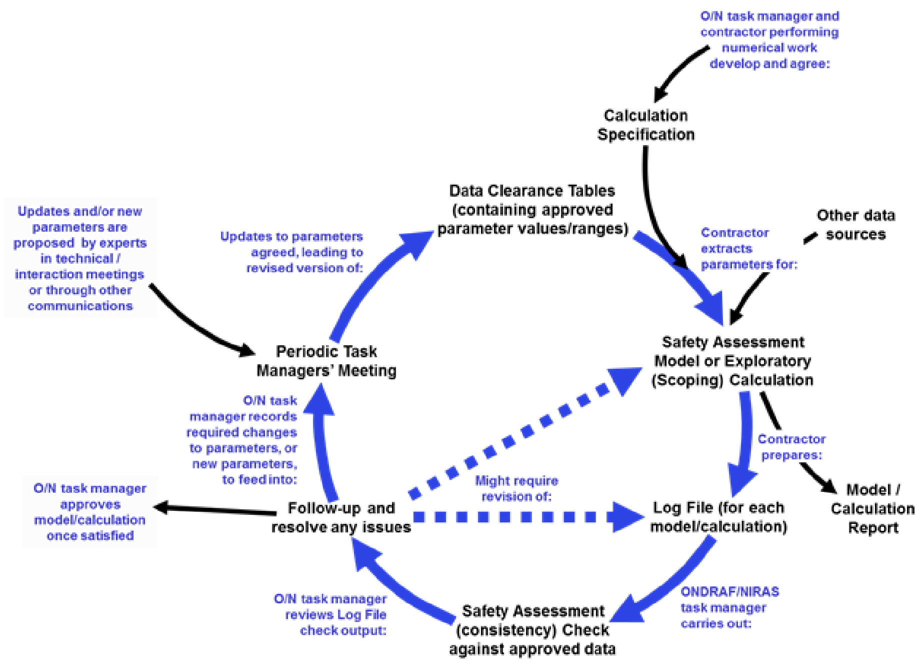

Figure 3.14 - The data clearance process

The process shown in Fig. 3.14 is consistent with the process of implementation of models and carrying out calculations discussed in Section 3.4.1, but the emphasis here is the "data" used in the calculations and the management of their use. The cycle starts with the calculation specification, which is prepared by the contractor on the basis of the validated and approved data (parameter values/ranges) in the last version of the DCT. Following the approval by ONDRAF/NIRAS the calculations are performed and the results are delivered in the form of a report to the task manager. In addition, the contractor provides the log file, which records the actual parameter values used for the calculation, and allows the task manager to check the consistency with the approved values, identify any open issues and, if necessary, repeat the calculations. A number of tools, further discussed in Section 4.4, are defined to ensure that:

the data used in a calculation are consistent with those described in the data clearance tables

any open issues with respect to the data are identified and are resolved, or the approach to resolve them is discussed and agreed in the appropriate groups

any changes are agreed upon, traced and implemented to the new versions of the DCT

The results of the calculations as well as the progress in RD&D activities in general are discussed in the Task Manager's meetings and can lead to an update of certain parameter values or ranges. A new parameter value is considered for the data clearance table if it is justified by multiple evidences and this justification has been peer reviewed internally or externally (depending on the importance of the update) and is validated by safety assessors (data user) and phenomenology/technology experts (data provider). It is expected that the new value will not be temporary or short-lived, rather it will be "stable" during a series of calculations. Updating of a DCT is thus a systematic and thorough process normally implemented only a few times within a year.

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- Data Clearance Flow Chart

Figure 4.9 is an alternative representation of the data clearance process shown in Section 3.4.4. It focuses on the interfaces between key components of data clearance, and highlights key aspects of when, and how, these components should be used.

The data clearance process begins when an organisation or individual extracts parameters from the latest version of the DCTs for use in a safety assessment model or exploratory calculation. The parameters to be extracted from the DCTs will depend on the scope of the numerical work to be performed, as set out in an approved calculation specification developed and agreed by the ONDRAF/NIRAS task manager and the individual or group performing the work. The person performing the model/calculation may also need to utilise data from other sources besides the DCTs, in order to have all of the parameters needed, either because a parameter has not yet been incorporated into the DCTs (see below), or because a decision has previously been made by ONDRAF/NIRAS that the parameter does not need to be included in the DCTs.

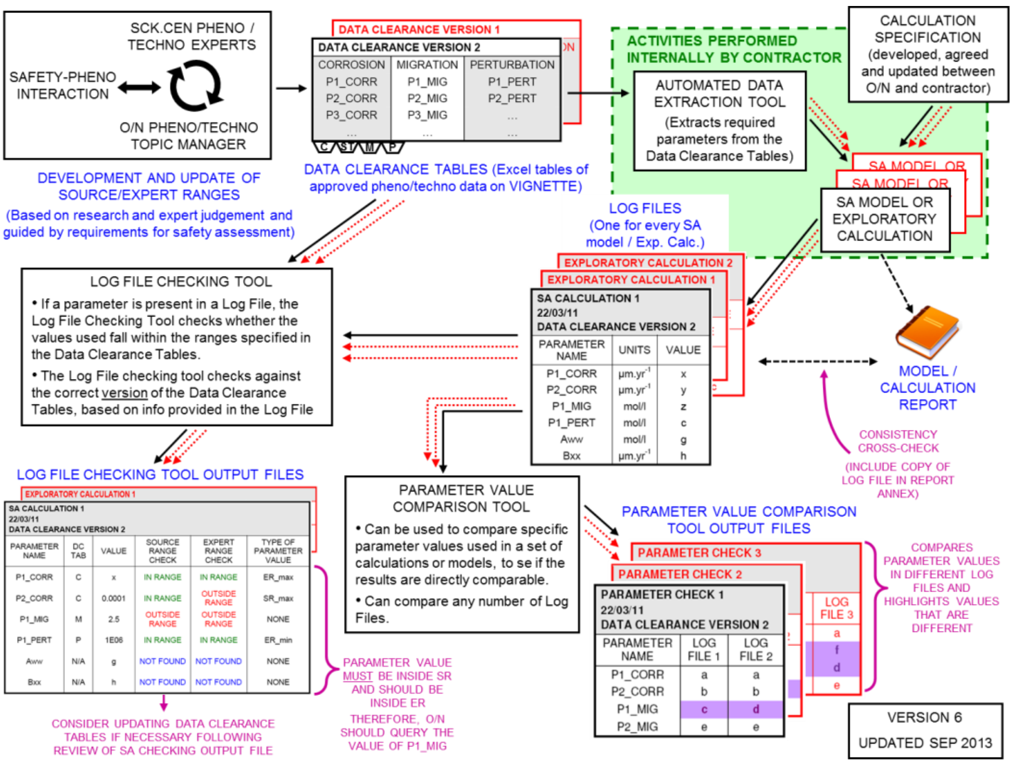

Figure 5.20-Detailed flowchart illustrating key steps in the data clearance process. This flowchart is sometimes referred to as the "Data Clearance Components Map" (ONDRAF/NIRAS TR 2012-23E).

Once the calculations are performed, in addition to the calculation report, as part of the data clearance process it is required that a Log File, recording the parameter values that were used, is submitted. The ONDRAF/NIRAS task manager cross-checks the parameter values used in the associated model/calculation against the approved values/ranges in the DCTs using the *Log file checking tool.* The check is typically carried out by the task manager who asked for the model/calculation to be performed and has the best understanding of which parameters should be selected to be consistent with the objectives of the study and associated assumptions.

The output file from log file checking tool shows whether parameter values utilised fall inside or outside the approved ranges/values documented in the DCTs and identifies when specific types of

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values are utilised, such as the upper or lower limit of an approved range, or the best estimate value. The task manager, using his or her expert judgement, can determine whether the value utilised is appropriate and acceptable for the calculation/study and must record the decision for each parameter in the space provided in the output file. During this process queries can arise that can be normally grouped as follows: i) parameter values used are within approved ranges, but the ONDRAF/NIRAS task manager does not consider that the most appropriate parameter or parameter value has been used for the calculation in question; ii) parameter values used fall outside approved ranges or the parameter cannot be found in the DCTs. Although the second type does not automatically mean that a calculation has been performed incorrectly, the task manager should follow-up his or her queries with the individual or group performing the calculation/model, as well as with those responsible for developing the data clearance system, and/or other ONDRAF/NIRAS task managers, to determine the reason why an Out of Range or Not Found result has been obtained in the cross-check and whether the calculations needs to be repeated with a different set of values. Reviewing the outputs of a Log File check may lead to identification of parameters which need to be added to the DCTs, or parameter values/ranges which need to be updated to reflect the latest understanding. When this occurs, the task manager should request that the required updates to the DCTs are approved at the "LTRD&D meetings" (see Section 4.1.1), which provide the forum for group discussion of proposed updates to the DCTs and for informing all task managers of changes and updates made. An issue to be considered in these discussions is whether such changes have any effects on interdependent parameters. An important issue to consider at task managers' meetings is the potential impact of proposed changes to the DCTs on the validity of numerical work that has already been completed. Sensitivity of a model/calculation to the value of a particular parameter may necessitate the re-running of such models/calculations periodically, to evaluate the impacts of parameter changes on the associated outputs. However, for pragmatic reasons, it is not a prerequisite that all models/calculations are updated immediately following every revision to the DCTs. Analysis of Log Files using the *Parameter Value Comparison Tool* (see below) enables ready identification of models/calculations that might be affected by changing a parameter value. ▪ Data clearance tables and checking tools **Data Clearance Table (DCTs)** DCTs contain all necessary information for parameters managed through data clearance, including parameter names, values, units, approval date, source reference and context information. They are designed to: enhance the traceability of data, through systematic organisation and layout enable periodic controlled update of data through a systematic versioning process and recording of updates/changes in a history log within the DCTs facilitate easy identification of relevant parameters through use of a systematic parameter naming convention that facilitates automatic searching Parameters are included within the data clearance system once they are identified as an important input for safety assessment and/or exploratory calculations, and once an appropriate value and/or range for the parameter has been agreed, approved for use and documented in a suitable reference source. In most cases, a group of subject experts, led by an O/N task manager work together (typically in a series of "Safety Assessement-Pheno Interaction Meetings") to agree appropriate parameter values, based on evidence available in the scientific literature, and based on expert judgement. Whereas the pheno experts have to provide the values for the parameters as close as

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possible to their experiments and what they think to be the reality, the safety assessors derive ranges for the resulting safety parameters in order to capture the potential remaining uncertainties and to apply the necessary conservatism required by the SA calculations. Once ranges of values are suggested by the safety assessors, the pheno experts have to check the consistency of these ranges and the underlying assumptions against their specialist knowledge. If the ranges proposed for safety assessment seem to be acceptable in the sense that they do not misrepresent the scientific results (taking into account the attendant uncertainties), then the values are approved by the experts and added to the data clearance table, Typically two types of ranges are defined for each parameter, to capture the various uncertainties associated with a parameter value (see also Section 3.3.2)

the source range - the range of values outside of which the parameter value is very unlikely to lie, considering current knowledge.

the expert range - the range of values within which experts expect the parameter value to lie. This is intended to be a more realistic range of parameter values than the source range and is thus expected to be narrower

The DCTs take the form of a Microsoft Excel spreadsheet, organised into various topic areas, each of which is presented on a separate worksheet (tab) in the spreadsheet, and has an associated ONDRAF/NIRAS task manager. A large quantity of information is included in the DCTs; for example Version 2.1 (September 2012) contains over 2,500 parameters.

Table 1 summarises the topic areas used in the DCTs, together with their scope and the responsible task manager at ONDRAF/NIRAS. Broadly speaking, these topic areas focus on different components of the disposal system, and are organised moving from the centre of the disposal system outwards (i.e. from the waste itself, through the various engineered and natural barriers, to the biosphere).

Table 1 - Topic areas included in the DCTs.

Topic area name	Worksheet (tab) name in DCTs	Scope of topic area
Inventory	Inventory	Radionuclide half lives, decay heats, activities and chemo-toxicity characteristics of components of the category B&C waste inventory.
Primary Waste Packages	Primary_WPs	Number and dimensions of primary waste packages
EBS Design (formerly referred to as "Feasibility")	EBS_Design	Parameters relating to the design of the EBS, as developed under ONDRAF/NIRAS' "Techno" work programme.
Characteristics of the EBS	EBS_Characteristics	Parameters relating to properties of the EBS that are utilised in safety assessment models and/or exploratory calculations
Source Term	Source_Term	Release rates of radionuclides from different wastes (and associated parameters).

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Corrosion	Corrosion	Corrosion rates for metals present in the waste and disposal concept.
Migration in the engineered barrier system (EBS)	Migration_in_the_EBS	Parameters used to evaluate migration of radionuclides through the EBS.
Migration in the disturbed zone (DZ)	Migration_in_the_DZ	Parameters used to evaluate migration of radionuclides through the DZ.
Perturbations	Perturbations	Parameters relating to the anticipated impact of the repository on the surrounding environment.
Migration in the Boom Clay	Migration_in_the_BC	Parameters used to evaluate migration of radionuclides through the Boom Clay.
Characteristics of the Boom Clay	Geosynthesis_Boom_Clay	Properties of the Boom Clay. Includes parameters relevant to the potential impact of the surrounding environment on the repository.
Characteristics of the surrounding aquifers	Geosynthesis_Aquifer	Properties of the aquifers surrounding the host rock.
Biosphere	Biosphere	Biosphere dose conversion factors applicable to the various release pathways and receptors considered in safety assessment.

Within each topic area, information relating to each parameter is systematically tabulated and includes:

The parameter name.

The units applicable to the parameter values reported.

The parameter values. In most cases, the source range, expert range and best estimate for a parameter value are recorded separately. An exception is parameters related to the primary waste packages, EBS design and biosphere topic areas, where fixed values are defined.

A "valid from" date

A description/comment relating to the parameter. This can include any contextual information needed to understand the origin, scope and/or applicability of a parameter.

The source reference for a parameter value.

Log File checking tool

The Log File checking tool works by comparing the parameter values reported in a Log File with the values/ranges recorded for the same parameter in a specified version of the DCTs. This is normally

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the most recently released external version of the DCTs, although the Log File checking tool can also be used to check a Log File against any previous version of the DCTs. It therefore has the flexibility to confirm whether a model/calculation is initially valid, and whether it retains its validity as parameter values are revised to reflect evolving understanding and as the DCTs are updated (which might require some models/calculations to be re-run). Each time a check is performed an output file is generated, which records, for each parameter reported in the Log File, whether the parameter value is: • IN RANGE or CONSISTENT with the range or fixed value (respectively) specified for the parameter in the DCTs. • OUT OF RANGE or NOT CONSISTENT with the range or fixed value (respectively) specified for the parameter in the DCTs. • NOT FOUND, which indicates that the parameter is either not included within the DCTs, or that there is some inconsistency between the DCTs and the Log File in the way that the parameter is recorded (for example, a parameter name that does not conform to the convention described in Section 5). The output file indicates when either a range check or a fixed value check is not applicable for a particular parameter, depending on the types of parameter value information provided in the DCTs. It also records whether the parameter values reported in a Log File are actually equivalent to specific values of the approved ranges recorded in the DCTs, such as the source range or expert range maximum or minimum value. This provides additional information to aid the task manager in evaluating whether appropriate parameter values have been selected for the model/calculation in question. The output file includes space for the task manager to record whether he/she approves the values used for each parameter in the model/calculation, based on the results of the check. **Parameter value comparison tool** The parameter value comparison tool works by consolidating the parameter values reported in a series of Log Files into adjacent columns within a single output file. This makes it straightforward to identify whether a specific parameter has (or has not) been used in each of the associated models/calculations, and whether the same parameter value was used in each case. The tool highlights instances where a different value is reported for a particular parameter in the Log Files checked. There is no limit on the number of Log Files that can be compared at once using the parameter value comparison tool, provided two or more Log Files are selected (although the tool can take longer to run for a large number of very long Log Files). In due course, the tool may be used to ensure consistency across key numerical work forming part of the SFC1 submission, but, for the time being, it has no formal role in the data clearance process, and can be used by anyone involved in supporting development of SFC1, either within ONDRAF/NIRAS or its supporting organisations. The checking tools have been developed using readily available software and have a simple and easy-to-use graphical user interface (or front-end) to assist the user in efficiently entering the required data into the spreadsheet to perform the checks. Fig. 4.11 shows the user interface for the LOG File checking tool.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)

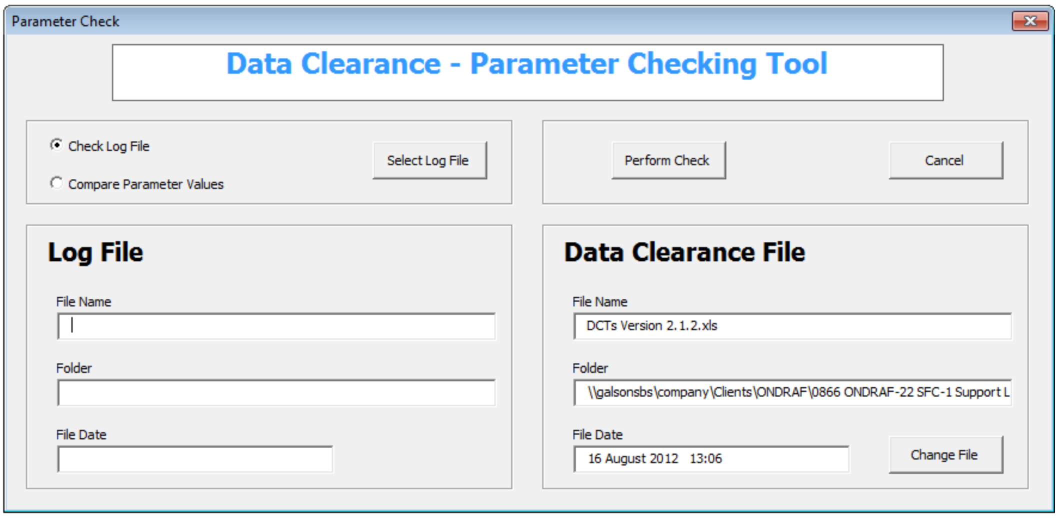

Figure 5.21- User interface for Log File checking tool

The information in the log file to be checked is entered in the text fields in the left part of the window, in the "Log File" frame. The 'Data Clearance File' frame also displays three text fields: *File Name*, *Folder* and *File Date,* that can be selected by pressing the change file using window explorer. The default value is the most recently completed version of the DCTs.

- Practical Organisation of the Data Clearance Process (Vignette)

A range of files is used and generated as part of the data clearance process, and it is crucial to ensure that these files are organised and stored systematically, and that they are readily accessible to everyone who needs to use them. Two areas on VIGNETTE have been reserved for the organisation of files and folders relating to data clearance:

1) A sub-folder within the Safety-Pheno Interaction area entitled "SFC 1 Data Clearance", which is accessible to the majority of ONDRAF/NIRAS staff and contractors. Data clearance files stored here include:

external versions of the DCTs, including past versions

comments and feedback on external versions of the DCTs

the DCTs "Planned Updates" spreadsheet

documents responding to comments on the DCTs. These generally take the form of Word documents responding to each set of comments received, and are placed on VIGNETTE in the same sub-folder as the associated comments.

the LOG file checking and the Parameter value comparision tools

secondary data tables

the Data Clearance Manual

2) A sub-folder of the Total Quality Management Folder entitled "Internal Data Clearance SFC1". Access here is limited to ONDRAF/NIRAS task managers and external members of the data clearance development team. Data clearance files to be stored here include:

internal (development) versions of the data clearance tables, including past versions

log files for all safety assessment/exploratory calculations

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output files from Log File checks ▪ Roles and responsibilities in the Data Clearance process The responsibilities for carrying out the main steps involved in the data clearance process illustrated in Figure 4.10 are clearly defined and can be summarised as follows (associated responsible groups are shown in bold): **Data clearance development team (= safety team):** Prepare and maintain DCTs incorporating parameters consistent with the scope of data clearance and ensure that the DCTs are available for use by all parties undertaking numerical work in support of SFC1. **ONDRAF/NIRAS task managers and B&C safety assessment team:** Identify numerical work (models and/or calculations) that needs to be performed. **ONDRAF/NIRAS task manager:** i) review the proposed scope of work and follow up any queries with the supporting contractor, until the approach has been fully agreed; ii) check that the values reported in the Log File are consistent with those provided in the technical report and with the calculation/model objectives; iii) check that the parameter values in the Log File are consistent with those in the DCTs by performing a Log File check using the tool developed for this purpose; iv) follow-up and resolve any issues with the Log File with the supporting contractor. Where necessary, record any remaining issues to follow up at the next periodic task managers' meeting (e.g. addition of new parameters to data clearance) and forward these to the data clearance development team. **Supporting contractor:** i) prepare a calculation specification describing the approach to perform a required piece of numerical work, including proposed input data and sources; ii) perform calculation/model, extracting and using data from the latest DCTs where possible (and additional data/expert judgement if required), and prepare associated technical report; iii) prepare a Log File recording all parameters used in the calculation/model. **Data clearance development team (Safety assessment team):** collate outstanding issues and suggested revisions/updates to the DCTs raised by task managers. Hold periodic task managers meetings and agree updates to the DCTs (and any other components of data clearance); ii) perform updates and issue new version of the DCTs based on feedback received from users. Communicate changes to users; iii) provide guidance on following the data clearance process to all users/reviewers as needed.
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
As part of the safety assessment methodology (ONDRAF/NIRAS, 2009) and (ONDRAF/NIRAS, 2015), the FEP catalogue provides a tool for consistency and completeness checking during the development of the assessment basis. Such checks are a form of "internal independent review" of ongoing activities that can lead to changes in the Research, Development and Demonstration (RD&D) work. The FEP catalogue is also used for completeness checking at various points during safety assessment and forms part of the quality assurance of the assessment. The way in which the use of the FEP catalogue fits into the overall safety assessment methodology of the B&C programme is shown in Figure 22.

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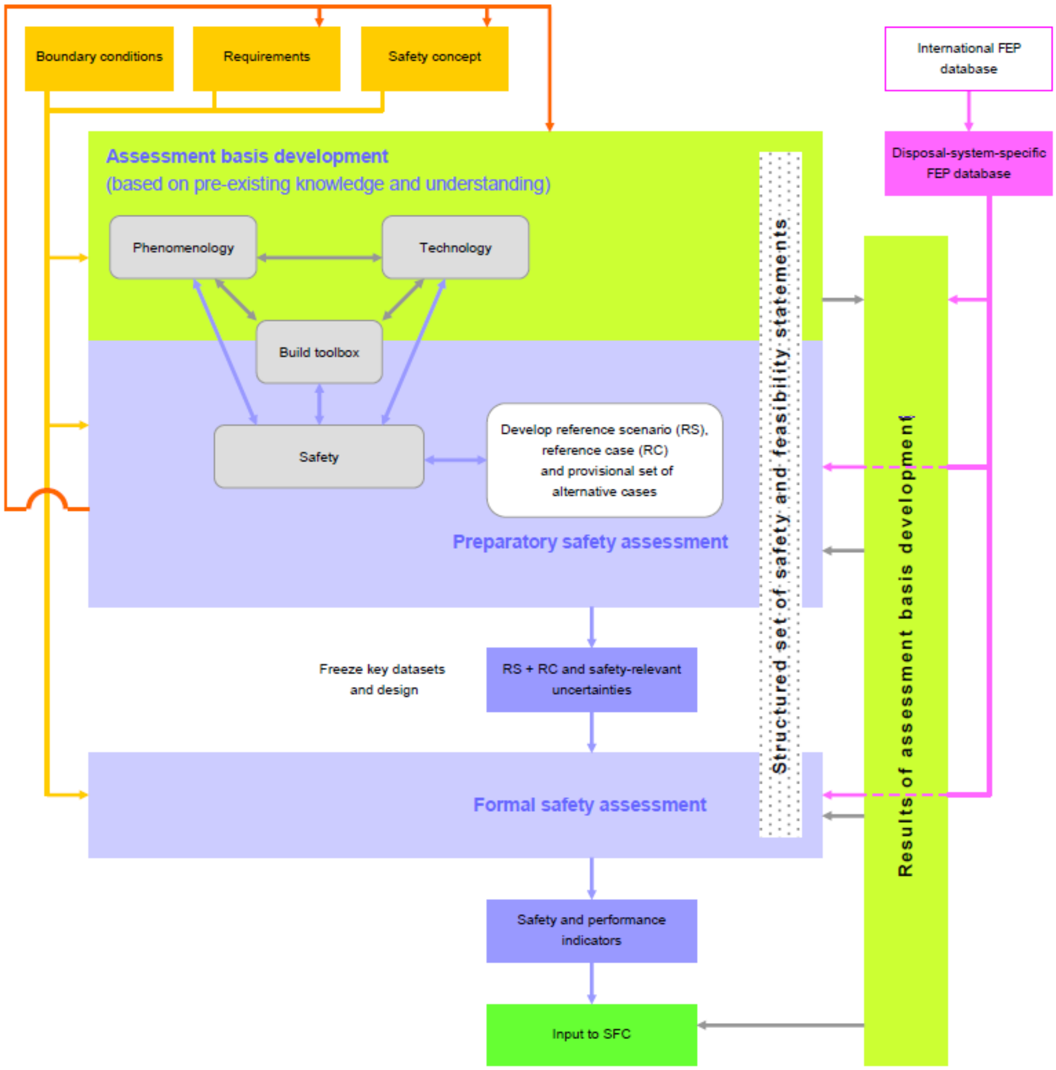

Figure 22 – The major steps followed in preparatory safety assessments and the use of the FEP catalogue as part of completeness checking. RS: reference scenario; RC: reference case [from (ONDRAF/NIRAS, 2015)].

Another use of the FEP catalogue is to identify any perturbing phenomena that may impact on the validity of the safety statements. The reference scenario and the altered-evolution scenarios are derived from a systematic examination of the perturbing phenomena and associated uncertainties potentially affecting the validity of the safety statements, and the upward propagation of these uncertainties from one statement to another, where safety statements are organised hierarchically in a top-down manner, starting with the most general (high-level) statements and progressing to increasingly more specific (lower-level) statements (ONDRAF/NIRAS, 2009) and (ONDRAF/NIRAS, 2015).

As well as using FEPs to gain an understanding of the evolution of the disposal system, storyboards can also be used as a tool to provide an integrated overview of expected system evolution [see figures in (ONDRAF/NIRAS, 2008)]. As an example, Figure 23 summarises the expected sequence of hydraulic, thermal, mechanical, and chemical events and processes, during the peak thermal phase for a supercontainer, for a design where the stainless steel envelope is initially perforated.

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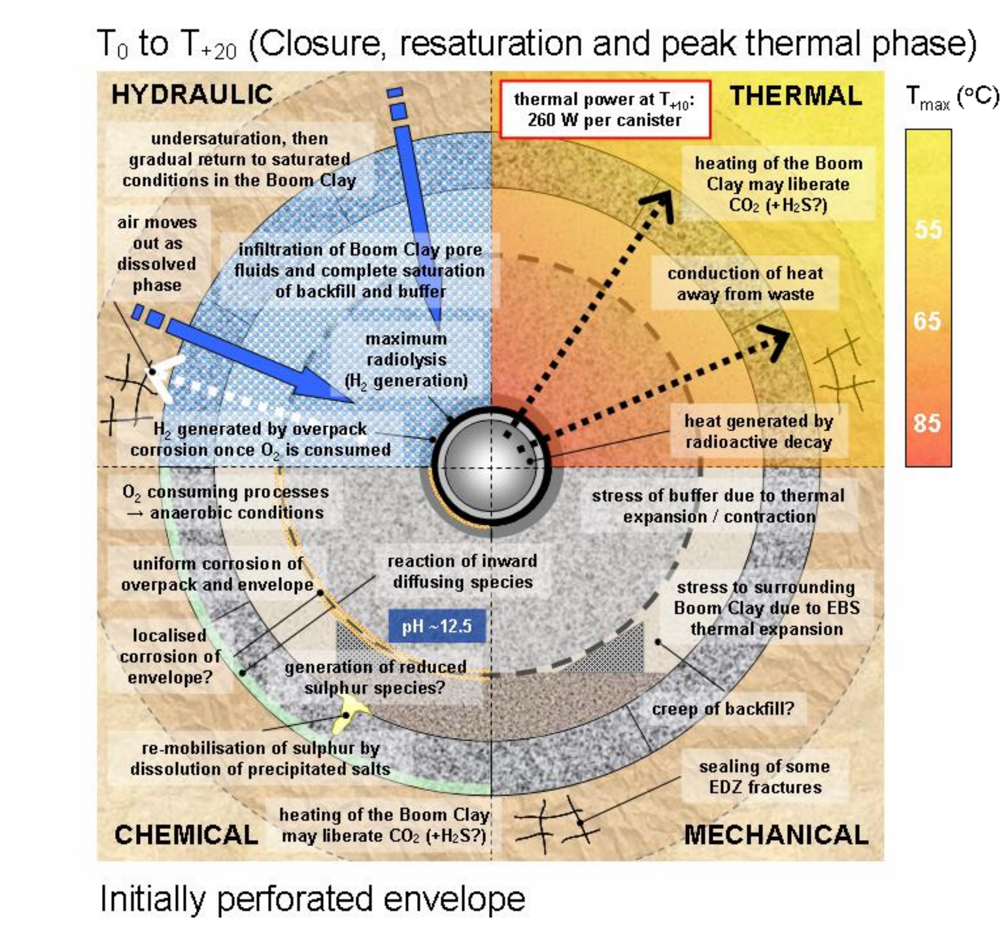

Figure 23 – Transverse cross section through a disposal gallery showing key processes and events occurring during the peak thermal phase, spanning the first 20 years after closure [from (ONDRAF/NIRAS, 2008)].

- The 2018 Update of the FEP Lists

This project, running from 2016 to 2018, aimed to update the ONDRAF/NIRAS FEP lists provided to the NEA in 2013, both for use within the ONDRAF/NIRAS programme and to provide to the NEA as part of ongoing work to upload project-specific FEP lists into the NEA's newly developed web-based database. The update takes account of both updated project information and changes to the structure of the NEA FEP list.

The two separate FEP lists, focusing on geosynthesis and supercontainer EBS FEPs respectively, were retained.

- Implementation of Completeness Check of Scenarios and Calculation Cases

As already mentioned in Section 3.3.2, completeness checks are conducted during preparatory assessments and during formal assessments as part of their quality assurance. In particular, during the preparatory phase, a provisional set of scenarios and calculation cases is confirmed and consolidated, with particular attention being given to ensuring no potentially safety-relevant perturbing phenomena and uncertainties have been overlooked. Key tools for the development and completeness checking of scenarios and calculation cases include the safety (and feasibility)

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
statements, a database of features, events and processes (FEPs) and storyboards illustrating the phenomena occurring within specific compartments of the disposal system under consideration. The safety statements (especially the lowest-level leaf statements), storyboards illustrating the understanding of the evolution of the system on the part of the safety assessors in each scenario, as well as other tools and methods, e.g. PROSA (ONDRAF/NIRAS, 2001), are useful to focus discussions on possible omissions with phenomenological experts. The FEP database also can be used directly to check for the omission of any specific FEPs from the safety statements and storyboards, which can then be rectified if necessary, and also that all possible interactions between safety relevant FEPs have been considered. The use of the FEPs to check the completeness of the safety statements is described in Section 4.5.1. Section 4.5.2 discusses the use of storyboards. Finally, the application of PROSA is described in Section 4.5.3. ▪ The FEP - Safety Statement Mapping Methodology A methodology for determining the completeness of the safety statements using the nea fep database (NEA 2000) has been developed and implemented. An overview of the methodology is given in Section 3.3.2, Figure 3.6. Further details are presented in the following paragraphs. The essential idea behind the methodology is that omissions in the set of safety statements may be highlighted by the existence of feps for which no corresponding safety statement can be identified. The objectives of a set of safety statements and a fep list are, however, different. This means that a direct comparison of safety statements and feps does not necessarily result in a one-to-one mapping between the two. Rather, there can to be several feps that are related to particular safety statements and several safety statements that are related to particular feps. The potential for these types of relationship has been taken into account in developing the methodology used for completeness checking. This methodology is illustrated in Fig 4.11. It comprises the identification of links or mappings between safety statements and feps, and a consolidation and analysis of these mappings to identify potential gaps or areas for development in the set of safety statements. Two separate mappings are undertaken are that aim to: identify feps corresponding to safety statements; and identify safety statements corresponding to FEPs. The consolidation phase of the methodology is concerned with the presentation and analysis of the results from the mapping.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)

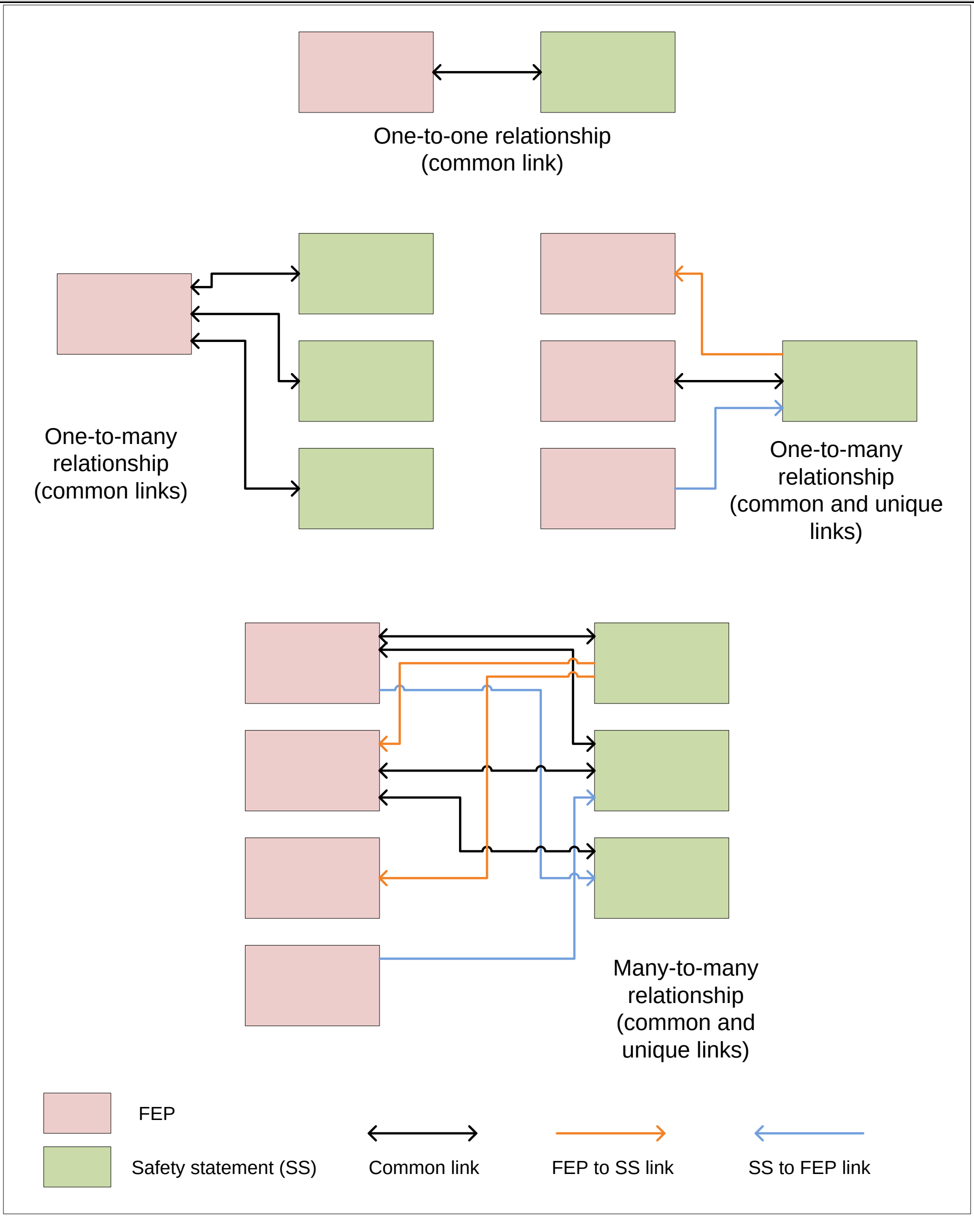

Figure 5.24-Illustration of the types of relationships identified between FEPs and safety statements.[11]

As noted previously, there are potentially "many-to-many" relationships between safety statements and feps, but the completeness checking methodology is not designed to identify all of these relationships. Although multiple relationships may be identified, the focus is on the identification of key links that reflect the principal aspect(s) of the fep or safety statement. Several such links may be identified for each fep or safety statement, but supporting or secondary links, reflecting minor aspects of the fep or safety statement, are not comprehensively identified. The identification of links between safety statements and feps is done primarily on the basis of the text descriptions, although the position of the safety statements within the hierarchy (which gives additional context and meaning to the statement) may also be taken into consideration. The categorisation of the feps is generally not

[11] From Galson report - to be provided by CDE

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
required for mapping purposes as the fep descriptions are comprehensive and also supported by explanatory information. There is an element of judgement in the identification of links in cases where a general fep or safety statement leads to large numbers of possible links. In order to reduce the potential impact of such judgements, the two mappings are best undertaken independently, without discussion or collaboration. This approach helps to reduce the possibility that key links are over-looked, and an analysis of the resultant mappings also allows any conflicting judgements to be identified and resolved. The possibility of key links being missed or mis-identified is also reduced by a systematic approach to the mapping. In the case of mapping safety statements to feps, the systematic approach requires that, for any particular fep, the safety statements are examined from the most detailed to the more general. The result of this approach is that general statements are only linked to feps where there no relevant detailed safety statement has been linked. In the case of mapping feps to safety statements, this approach means starting by identifying feps that correspond to the most detailed safety statements. This ensures a level of familiarity with the structure and scope of both the set of safety statements and the feps prior to mapping the more general statements. The results of the mapping are entered into a relational database that provides the basis for the consolidation and analysis and can be updated as the set of safety statements is developed. An excerpt from the database is shown in Fig. 4.13. The database is used to consolidate the two mapping and to generate a single set of linkages between feps and safety statements. This set includes both those links where the same linkage was identified in both mappings and those links that are unique to one mapping. Common links represent cases either where there is a one-to-one relationship between a safety statement and a fep, or where the two mappings have identified the same link from a set of one-to-many or many-to-many relationships. Where the links are unique, it is generally the case that the mappings have identified different elements of a one-to-many or many-to-many relationship. The focus of the completeness check is not, however, to establish a comprehensive set of links between feps and safety statements, but to identify whether the set of safety statements is complete with respect to the fep list. To support this aim, the database can be used to identify: safety statements for which there is no corresponding FEP, and FEPs for which there is no corresponding safety statement Hence, as well as gaps in the safety statements, the methodology can also highlight safety statements for which there are no corresponding feps. The identification of these is less significant in terms of completeness checking, but may be significant in terms of highlighting redundancy or other issues with the structure of the safety statements.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)

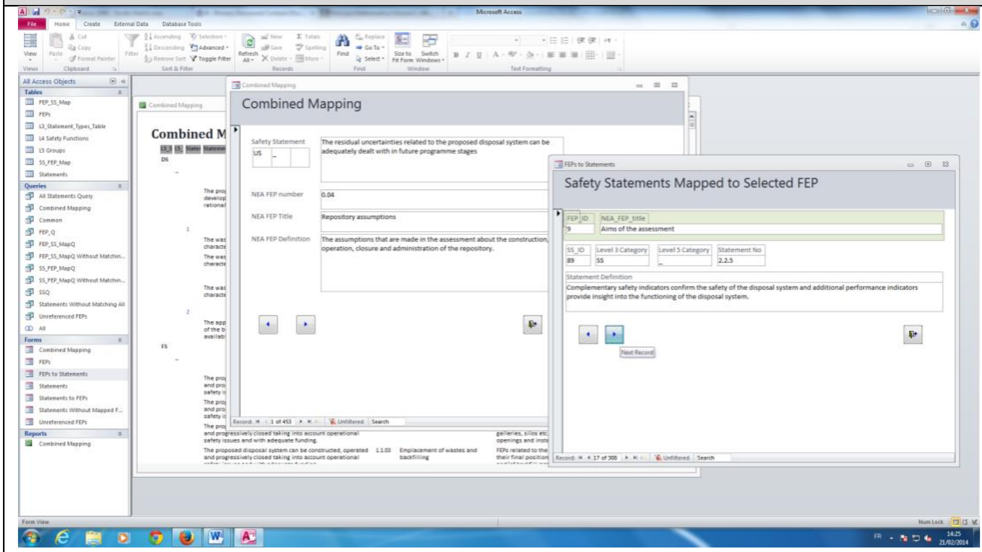

Figure 5.25- Excerpt from database built for completeness check FEPs against safety statements.

- The storyboards

Storyboards illustrate the phenomena - thermal, hydraulic, mechanical and chemical - occurring within specific compartments of the disposal system under consideration, for specific scenarios or calculation cases, as they evolve over time. An example of a storyboard is shown in Fig. 4.14. The figure shows a transverse cross section through a disposal gallery containing vitrified high-level waste and illustrates the key processes expected to occur during the thermal phase, when the temperature in the engineered barrier system is at its highest.

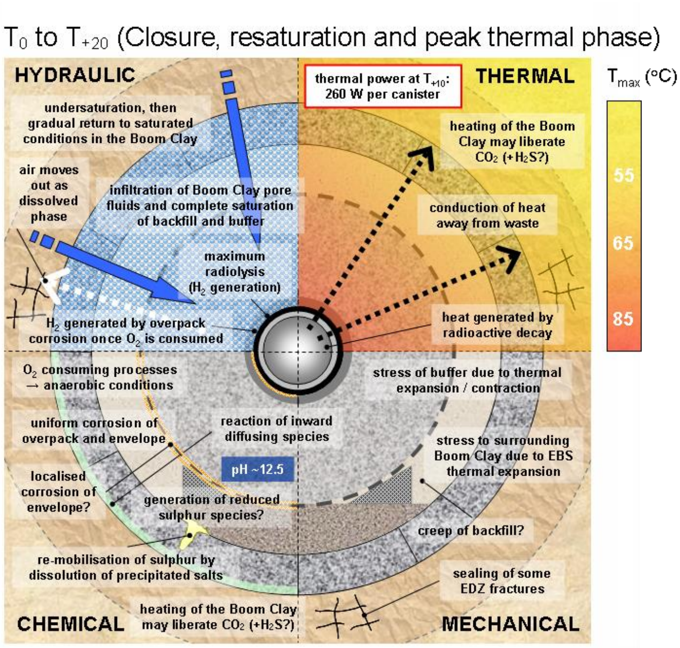

Figure 5.26- Storyboard illustrating THMC processes

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Like the safety statements, storyboards can be checked for completeness against the NEA FEP database, or other international and peer reviewed FEP lists, since these provide a comprehensive overview of all the processes and events that may occur in a disposal. The storyboards, however, incorporate additional information in that they illustrate the integrated understanding of the evolution of the system on the part of the safety assessors in each scenario, including interactions between FEPs. They thus provide a useful focus for discussions on possible omissions with phenomenological experts.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
At the level of our organisation (WMO), extensive R&D programmes can be carried out in order to get as much knowledge as possible to face different options regarding the choice of the host rock and consequently, the repository design. In parallel, the opposite exercise is performed, trying to find the most generic properties a system may have in order to capture the invariants that will be encountered in each case. Regarding the societal uncertainties, the WMO wan try to be at the origin of some initiatives to influence the decisional process.

Table A-9: RWM (UK) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 20 September 2019 Part 4 – 30 September 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Mike Poole	
1.1b From which country and organisation are you?	
RWM, UK	
1.1c Type of your organisation (WMO, TSO)?	
WMO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Safety assessment	
1.2b Please explain briefly your role in your organisation and your background.	
My background is Physics, my role includes post-closure performance assessment, supporting research, mathematical modelling and treatment of uncertainty.	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
To deliver a geological disposal facility for higher activity radioactive wastes and provide radioactive waste management services.	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
Early part of a site identification and selection process (Phase 1).	
Part 4. Strategies for managing uncertainties	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***
The main criterion in the UK regulatory guidance is a risk guidance level: “After the period of authorisation, the assessed radiological risk from a disposal facility to a person representative of those at greatest risk should be consistent with a risk guidance level of 10^{-6} per year (i.e. 1 in a million per year).” This represents a one in a million per year chance, to a member of a potentially exposed group at greatest risk, of a fatal cancer or serious hereditary effect. This risk guidance level does not apply to human intrusion scenarios, although the consequences in terms of dose of such scenarios are to be assessed. During the operational period, the effective dose resulting from any release of radioactivity from the facility must meet constraints on source-related dose and a site-related dose. Also, assessments of radiation doses to non-human organisms and the accessible environment are to be assessed. The main requirement re non-radiological hazards are that the developer “should demonstrate that the disposal system provides adequate protection against non-radiological hazards”.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
It is required that during safety assessments and justifications of the disposal facility, the Operator define “the procedures for analysis of uncertainties (of input data, models) and sensitivity of the assessment results to the values of input parameters and assumptions”, as well as “procedures for comparison of the results obtained with the safety criteria”. Comparison of the results of assessments must be performed taking into account uncertainties in the calculation results. (“General Safety Provisions for RW Disposal”)
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
The fact that there are inevitably significant uncertainties in the post-closure evolution of a geological disposal facility means that an iterative approach to their management is required, and this meshes well with a similar iterative approach to research and data acquisition activities such as a site characterisation programme. At each stage in such a process, results from a probabilistic safety assessment model can be used to inform to which parameters performance measures are most sensitive, and can therefore guide subsequent data acquisition activities in a meaningful way. Prior to identification of a disposal site in the UK, we have produced generic safety assessments to support a demonstration of how a safety case will be made for a disposal facility and to provide a baseline against which to assess waste package disposability. We will produce site-specific safety assessments at different stages of the licensing process as the disposal facility implementation process progresses.
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
The evolution of the disposal system will depend on many features, events and processes (FEPs). The identification and analysis of FEPs leads to a detailed description of the relevant factors affecting the performance of the geological disposal system. Uncertainties over future states of the disposal system, and uncertainty about human behaviour are best addressed by considering different scenarios. The assessment will be centred on a base scenario which describes the features of the disposal system at closure and the way in which that system is expected to evolve with time. Deviations from the base scenario, caused by FEPs that may or may not occur will be considered as variant scenarios. For a given scenario, there will exist data and model uncertainty. Strategies for handling data uncertainty tend to fall into the following five broad categories: 1. Demonstrating that the uncertainty is irrelevant, that is uncertainty in a particular process is not important to safety because, for example, safety is controlled by other processes. 2. Addressing the uncertainty explicitly, for example using probabilistic techniques. 3. Bounding the uncertainty and showing that even the bounding case gives acceptable safety. 4. Ruling out an uncertain FEP, usually on the grounds of very low probability of occurrence, or because other consequences, were the FEP to happen, would far outweigh concerns over a GDF performance (for example a direct meteorite strike). 5. Agreeing a stylised approach for handling an uncertainty. The preferred treatment of particular uncertainties may depend on the context of the assessment and the stage in the process of developing a GDF.
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
The UK regulatory guidance strongly suggests a probabilistic approach will be required as the main assessment model. Probabilistic models can give insights into which parameters are important but, for a model with many uncertain parameters representing a diverse range of physical and chemical processes, the situation can appear quite complicated. In many cases, however, large uncertainties in input parameters do not always translate to large uncertainties in risk – calculated performance measures such as risk may be insensitive to all but a few key parameters. It may be possible to bound the effects of certain processes using a deterministic approach, but care needs to be taken when combining this strategy with probabilistic modelling (discussed in the previous subsection) because making conservative assumptions for certain parameters, rather than explicitly representing the uncertainty, introduces bias into a model. The probabilistic approach ensures that many possible combinations of model parameters are considered. However, it can be a challenge to communicate the results of probabilistic calculations to those unfamiliar with such analyses. Therefore it is often helpful to include other presentations such as deterministic sensitivity analyses and 'what if?' calculations to improve the understanding and communication of the results. Any quantitative assessment will be supported by more qualitative arguments such as alternative lines of reasoning and use of natural and anthropogenic analogues.
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
It is expected that a register of key uncertainties, informed by performance assessment calculations, will be maintained across iterations of a safety case. This register may be used to inform future iterations of site characterisation activities and future research needs, with the aim of seeking to reduce those key uncertainties, or modifications to facility design to mitigate those key uncertainties.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
Largely covered in answers above, but updates to uncertainties in an assessment model due to newly acquired information should be undertaken as far as possible using methods consistent with a Bayesian approach, although it is recognised that for some parameters, an element of expert judgement will be required alongside more mathematical approaches.
4.2f Other information that you would like to add:
N/A
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***

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At the current generic stage of the UK programme to develop a GDF, the overriding uncertainties are high level and are related to the fact that we do not yet have a site. This means that estimates of the duration of stages of the programme have to be based on planning assumptions at this stage. Likewise, cost estimation for the GDF programme is also based on a series of planning assumptions, with alternatives being considered as ‘what-if’ cases.
4.3b How are uncertainties related to waste inventory managed?
At this stage of the UK programme, the uncertainty in the volume of waste for disposal is driven by possible changes to the assumptions that are made by ourselves and waste producers about what is to included, although eventually (at disposal) the volume inventory will be known. We currently considered a number of alternative inventory scenarios to explore the sensitivity of the inventory to these uncertainties and possible changes. The alternative scenarios are considered in turn in order to allow the impact of each to be more clearly understood. The radionuclide inventory associated with a particular volume inventory of waste for disposal is uncertain, and will remain so, due to uncertainties in the data that can realistically be provided by the waste producers.
4.3c How are disposal concept uncertainties managed?
The UK currently has a generic safety assessment, as we do not yet have a site for a disposal facility. We consider example geological disposal concepts appropriate for three possible types of host rock, higher-strength rock, lower-strength sedimentary rock and evaporite, for both low heat generating waste and high heat generating waste.
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
As noted in the answers to question 4.2, uncertainties over future states of the disposal system are best addressed by considering different scenarios. The assessment will be centred on a base scenario which describes the features of the disposal system at closure and the way in which that system is expected to evolve with time. Deviations from the base scenario, caused by features events and processes that may or may not occur will be considered as variant scenarios. The assessment of the base scenario will usually focus on a total system model, a probabilistic model of the whole system, in which parameters are assigned probability density functions which are a quantification of the uncertainty in the parameters. The points about very long timescales are considered in the answer to the next question.
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
Yes
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Noting that the UK regulatory guidance recognises uncertainties that cannot readily be quantified, it is worth considering at what timescale do these become more significant than those that can be quantified? An analysis of such system uncertainties can be used to define an appropriate timescale for probabilistic calculations of risk, that is a timescale during which all significant uncertainties can reasonably be explicitly represented. Specifically, at the point at which cycles of major climate change (including glaciations) become possible, significant unquantifiable uncertainties relating to the evolution of a disposal system exist. Beyond this timescale, which might be several hundreds of thousands of years, simpler, deterministic 'what-if?' calculations and reasoned qualitative arguments are recommended to illustrate possible system performance. For example, such 'what-if' calculations might include a reference case in which there is assumed to be no geosphere and biosphere evolution due to climate change (a continuation of the status quo), and other cases where specific example evolutions are postulated, perhaps based on knowledge of past climate evolutions. In this way, though there are significant unquantifiable uncertainties at very late times, the principles of long term safety of geological disposal remain demonstrable.
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
No. Increased research and development are not likely to reduce the kind of unquantifiable uncertainties associated with the very long timescales as discussed in the answer e-1 at all - that's the whole point of distinguishing such a timescale, it is the point at which uncertainty ceases to be quantifiable.
4.3f How are uncertainties in the understanding of key processes managed?
This may be managed by considering various different conceptual models. Also, this relates to the modelling hierarchy - as well as a total system model, there will be detailed process models developed of such processes. These then need to be abstracted into an appropriate representation in the total system model that is commensurate with the amount of uncertainty - it may be that this representation can be a significant simplification of the processes, or it may not, it depends on how significant the uncertainties are to performance measures such as risk.
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
There are a number of important issues here: 1. The need for a data management system that can ensure the quality of data at all levels in our performance assessment models. This may have a different nature for the higher level models, compared to what is needed for detailed data e.g. from site characterisation. At the moment the UK does not have a site. 2. There are likely to be various hierarchies of models through which data, and information about uncertainties, need to be propagated. In some cases this might be done mathematically, for example using models to provide upscaled parameters for a larger scale model e.g. for rock properties such as permeabilities. In some cases, there may be an expert judgement input to define probability density functions or bounding values for parameters of a total system model, given experimental data and results of more detailed process models. 3. A data management system will need to store metadata alongside the data itself, including provenance, sources of uncertainty etc.
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
We would envisage a cross check of FEPs against identified safety functions, and an audit showing which FEPs from internationally agreed lists are included in the models for the base and/or variant scenarios, and which are not, including justification.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
N/A
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
In terms of the quantitative part of the safety case, it is recommended that as far as possible, the evolution of specific uncertainties is managed mathematically with methods consistent with a Bayesian approach to modifying uncertainty in the light of new information. In qualitative terms, and for wider uncertainties that may change by nature rather than just quantitatively, it is recommended that a register of key uncertainties is maintained and updated from one iteration of the safety case to the next, so that progress in resolving or managing these can be demonstrated.

Table A-10: SKB (Sweden) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 30 September 2019 Part 4 – 30 September 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Claes Johansson	
1.1b From which country and organisation are you?	
SKB, Sweden	
1.1c Type of your organisation (WMO, TSO)?	
WMO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Management	
1.2b Please explain briefly your role in your organisation and your background.	
Senior specialist Waste and Decommissioning	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
SKB's mission is to take care of all spent fuel and low- and intermediate level in Sweden and especially from our owners the nuclear power plants.	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
For operational low and intermediate level SFR is under operation (phase 4). An extension for decommissioning waste for SFR is under the licensing process (phase 2). For spent fuel it is under the licensing process (phase 2). For the long-lived low and intermediate level waste it is in phase 1.	
Part 4. Strategies for managing uncertainties	
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration***	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.
It is stated in the legal frame work that uncertainties should be addressed, not exactly how.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
See e.g SKB report TR 14-01, that could be found on SKB:s website. www.skb.se
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
See e.g. report TR 14-01.
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
See e.g. report TR 14-01.
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).
Both probabilistic and deterministic methods are used, see e.g. report TR 14-01.
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
See e.g. report TR 14-01.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
See e.g. report TR 14-01.
4.2f Other information that you would like to add:
See e.g. report TR 14-01.
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
See e.g. report TR 14-01.
4.3b How are uncertainties related to waste inventory managed?
See e.g. report TR 14-01.
4.3c How are disposal concept uncertainties managed?
See e.g. report TR 14-01.
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
See e.g. report TR 14-01.
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
Yes
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
I dont have a proper answer to this problem.
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
I dont have a proper answer to this problem.
4.3f How are uncertainties in the understanding of key processes managed?
I dont have a proper answer to this problem.
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
See e.g. report TR 14-01.
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
See e.g. report TR 14-01.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
It is all the time on the agenda to work with uncertainties every time a new safety assessment is performed.

Table A-11: SÚRAO (Czech Republic) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 13 September 2019 Part 4 – 18 September 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Zdena Lahodová	
1.1b From which country and organisation are you?	
Czech Republic, SÚRAO	
1.1c Type of your organisation (WMO, TSO)?	
WMO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Safety assessment	
1.2b Please explain briefly your role in your organisation and your background.	
I work as a safety assessment technical specialist. I am mainly responsible for evaluation of source term for a deep geological repository. My background is a nuclear physicist. I studied at the Faculty of Nuclear Sciences and Physical Engineering.	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
Our mission is to provide for the safe disposal of radioactive waste in accordance with the requirements of nuclear safety and human and environmental protection. We manage radioactive waste repositories, coordinate preparation for the construction of a deep geological repository and verify that the waste to be disposed of meets the strict standards set by the State Office for Nuclear Safety.	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
DGR Phase 1 3 Operational radioactive waste repositories Phase 4 + Phase 5	
Part 4. Strategies for managing uncertainties	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***
The criteria are based on Decree No. 377/2016 Coll., on the requirements for the safe management of radioactive waste and on the decommissioning of nuclear installations or category III or IV workplaces and Decree No. 378/2016 Coll., on siting of a nuclear installation.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
The solution of uncertainties depends on the different fields and knowledge level.
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
Yes + sensitivity analysis, iterative procedures, comparison of results from different approaches, calculation, several models.
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Carry out an assessment of the evaluation of uncertainties by independent experts.
4.2f Other information that you would like to add:
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
4.3b How are uncertainties related to waste inventory managed?
4.3c How are disposal concept uncertainties managed?
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
Yes
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
Use historical data and development, analogue evidence.
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
Yes, in a progressive iterative way, focusing on the most important parameters
4.3f How are uncertainties in the understanding of key processes managed?
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***

Table A-12: Bel V (Belgium) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 4 October 2019 Part 4 – 30 September 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Frank Lemy	
1.1b From which country and organisation are you?	
Bel V (Belgium)	
1.1c Type of your organisation (WMO, TSO)?	
TSO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Safety assessment, Management	
1.2b Please explain briefly your role in your organisation and your background.	
Roles: - Review of safety cases for disposal facilities - Manager of the technical support provided by Bel V to the national safety authority (FANC) in the field of geological disposal Background: - Mining engineering - Engineering geology - Nuclear safety - Long-term safety assessment of disposal facilities	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
- A near-surface disposal programme is being implemented for the long-term management of LLW - There is currently no national policy for the long-term management of ILW, HLW and spent fuel. Nonetheless, a R&D programme on geological disposal has been running for more than 40 years.	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
LLW: Phase 2 ILW, HLW & SF: Phase 0
Part 4. Strategies for managing uncertainties
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***

The Belgian regulatory framework for RW disposal relies primarily on the following radiological protection and safety principles:

1) Radiological protection principle of application of dose limits
2) Radiological protection principle of optimisation of protection
3) Safety principle of defence in depth
4) Safety principle of demonstrability

Demonstrating safety implies substantiating in the safety case that each of these principles is properly applied through the stepwise implementation of a safety strategy. The application of these principles and the demonstration of conformity with these principles have several implications for the management of uncertainties.

1) Principle of application of dose limits

Demonstrating the conformity with this principle involves substantiating that the following criteria are met considering uncertainties on future evolutions of the disposal system and of its environment (including the biosphere):

- Dose constraints (and hence of the dose limits)
- Reference values for complementary safety indicators
- Reference value for the dose associated with penalizing scenarios and human intrusion scenarios (only for surface disposal)

Uncertainties associated with the quantification of the indicators of the potential radiological impact of the facility should be treated so as to ensure that this potential impact is not underestimated. In practice, this involves:

- The development of a scenario representative of the expected evolution of the disposal system
- The development of a set of scenarios bounding unexpected but possible evolutions of the disposal system and of its environment
- The use of conservative parameter values and hypotheses in these scenarios and in associated models

2) Principle of optimisation of protection

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Protection during the operational and post-closure periods has to be optimised considering prevailing circumstances (i.e. term used by ICRP) or boundary conditions of the programme (including aspects like the waste to be disposed of, available sites, available financial resources, regulatory framework, stakeholder conditions,...). The objective is to provide the highest level of protection considering prevailing circumstances by preventing and reducing, as far as reasonably achievable, future exposures. The optimization process is an iterative process, which is part of the safety strategy, i.e. the high-level approach for achieving safe disposal (including the basis for an overall management system, a siting, design and implementation approach, and a safety assessment methodology). It begins with the selection of the host formation. This process involves: • Ensuring compliance with dose and risk constraints • Identifying, assessing (in terms of benefits for safety and costs) and compare possible options for every safety-significant choice or decision. The benefits associated with possible options are assessed based on safety attributes reflecting, where relevant: - The potential radiological impact of the facility - The ability of the system to isolate and confine the wastes - The level of defence in depth provided by the disposal system (see hereunder) - The level of demonstrability provided by the disposal (see hereunder) Hence, benefits in terms of uncertainty management are one of the attributes that should be considered when applying this principle and hence when making decisions during the implementation of the disposal programme. **3) Principle of defence in depth** The objectives of defence in depth are (see IAEA safety glossary 2018): a) To compensate for human-induced events and component failures; b) To maintain the effectiveness of the barriers by averting damage to the facility and to the barriers themselves; c) To protect workers, members of the public and the environment from harm in accident conditions in the event that these barriers are not fully effective. This principle must ensure that safety is not improperly dependent on a single element of the repository, or on a single control measure, or the fulfilment of a single safety function or a single administrative procedure. Therefore, it has consequences in terms of design as well as control measures and procedures. Defence in depth is implemented primarily through the combination of a number of consecutive and independent levels of protection that would have to fail before harmful effects could be caused to people or to the environment. For disposal facilities, the following levels should be implemented: 1. Preventing deviations from normal operation and the failure of items important to safety such as the safety functions fulfilled by the different system components. This is done a.o. by reducing or avoiding as far as reasonably achievable sources of uncertainty having the potential to jeopardize safety (e.g. by modifying the location or design of the disposal facility). Control measures and procedures are also needed to prevent defects and damage to the disposal.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
2. Maintaining as much as reasonably achievable (by host rock/site selection and design) the performance of system components that perform a safety function when they are subjected to disturbances internal (e.g. waste-induced perturbations) or external (e.g. earthquakes) to the disposal system (i.e. robustness of individual system components). 3. Providing the disposal system with independent and complementary safety functions and components so as to maintain a sufficient level of protection safety following the failure of a safety function or system component that would be caused by an uncertain disturbing event or process. 4. Detecting deviations from normal operation, defects or damage to the disposal system so as to take corrective measures where needed (only effective until the end of phase 4). Operating limits and conditions determine the conditions that must be met to prevent situations that could lead to accidents, or to mitigate the consequences of accidents should they occur. The monitoring and inspection programmes for the systems and components should allow verifying that operating limits and conditions are met. 5. Preventing the progress of, and mitigating the consequences of, accidents that would result from failure of previous levels by preventing, through an emergency plan internal to the facility, accident sequences that lead to large release of radioactive material or early release of radioactive material from occurring (only possible before the end of the nuclear license). In this way, potential radiological risks for the public outside the site are still limited if an accident occurs in spite of all the previous measures. 6. Mitigating radiological consequences of a large release of radioactive material or an early release of radioactive material that could potentially result from an accident (only effective as long as an emergency plan external to the facility is available). The implementation of the defence in depth principle constitutes one of the key measures for managing uncertainties. **4) Principle of demonstrability** The principle of demonstrability requires: a) demonstrating that the disposal system is feasible with the required level of performance; b) using proven techniques (e.g. BAT). When new techniques are developed, their feasibility, control and reliability must be demonstrated before they are implemented. c) demonstrating that the performance level of the disposal system and that of its individual components will remain sufficient to ensure the protection of man and the environment, despite the reasonably foreseeable disturbances to which it might be subjected and contingencies associated with construction and exploitation d) managing uncertainties. Consequently, a systematic approach to managing uncertainties is considered as key in demonstrating confidence in the safety of a disposal facility. Hence, management of uncertainties needs to be integrated within the safety strategy.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
See answers to other questions which are based on: - Existing (draft) requirements and guidance of the Belgian regulatory framework

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
- international guidance and requirements: ○ WENRA Radioactive Waste Disposal Facilities Safety Reference Levels (2014) ○ Report on the European Pilot Study on the Regulatory Review of a Safety Case for Geological Disposal of Radioactive Waste (2016)
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
See answer to question 4.2.f for a generic answer to this question. The current situation of the Belgian programme is as follows: <u>Surface disposal programme (LLW):</u> A first version of the safety assessment was submitted by ONDRAF-NIRAS in the framework of the pre-licensing process (phase 2). A safety case including a safety assessment was then submitted in the framework of the licence application for the construction and operation of the facility. An update of the safety case is also required before starting construction. Then, regular updates of the safety assessment are also expected during the operation of the facility to take as-built properties, the characteristics of emplaced wastes, results from the R&D and monitoring programmes as well any changes to the design, state of knowledge or regulatory requirements into consideration. <u>Geological disposal programme:</u> In Belgium, there is at the moment no policy for the long-term management of ILW, HLW and spent fuel. In case disposal would be selected as the long-term management option for these wastes, one of the first steps of the programme will be to identify its different phases and the decisions associated with each of them. It is expected that a safety case including a safety assessment would be submitted the end of each phase of the decision-making process (See answer to question 4.2.f). These safety cases and safety assessments would have to support the decision associated with each phase.
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
Management of uncertainties needs to be integrated within the safety strategy followed by the implementer. Accounting explicitly for uncertainties and analysing their possible consequences are an essential part of any safety assessment. One part of safety assessments is to deal with the identification, characterisation and analysis of residual uncertainties that are relevant to safety, and investigation of their effects. Information about uncertainties and how they can be managed forms an important input for the decisions to be taken at each step in the development of the facility. The approach for managing uncertainties should define a management process for identifying, characterizing, assessing and, where appropriate, avoiding, mitigating or reducing them. Hence, the Belgian regulatory body identifies the following steps of an uncertainty management strategy (see Figure 1):

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)

1) Identification: Identification of uncertainties that need to be managed

2) Characterisation: Qualitative or quantitative description of identified uncertainties and identification of possible interdependencies

3) Analysis of safety-relevance: Assessment, e.g. through uncertainty/sensitivity analysis methods, of possible impacts of uncertainties on the results of the SA

4) Treatment: Propagation of safety-relevant uncertainties in the SA

5) Assessment of uncertainties on results: The assessment of uncertainties should allow:

- assessing the confidence in the performance and robustness of the disposal system and its components and in the radiological impact calculations;
- identifying the uncertainties that will need to be reduced, mitigated or avoided during subsequent iterations or phases (see Figure 1).

6) Avoidance, mitigation or reduction of uncertainties: This can be done by RD&D, data acquisition, further characterisation or reprocessing of the waste, site selection or characterisation, adapting the safety concept, construction methods and/or the design or adapting the management system (e.g. reduction of uncertainties on as-built properties by additional QA/QC measures)

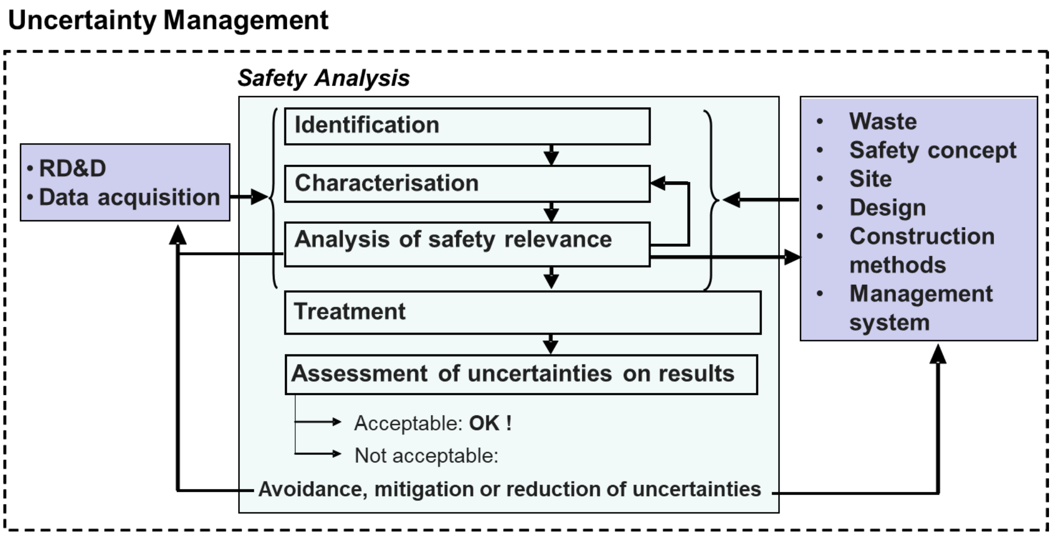

Figure 1. Elements of an uncertainty management strategy and associated activities.

4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).

Scenarios:

It is expected that uncertainties associated with the initial state and evolutions of the disposal system and of its environment are treated through the development of a set scenarios. Identifying and substantiating a set of illustrative scenarios helps to structure the safety case and is a valuable tool to identify where further work should be directed to avoid, mitigate or reduce uncertainties and to evaluate their effect. By this means, the link between safety assessment and safety strategy is maintained. A radiological impact assessment should include a representative number of different scenarios that can account for the range of possible outcomes.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
<u>Conservative vs. best-estimate approach:</u> The safety case is expected to include a conservative estimate of the impact of the disposal system on people and the environment based on a best-estimate description of the likely evolution of the system. This provides a starting point for developing the management of uncertainties. A distinction is made between "best estimate" and "conservative" choices of modelling assumptions and parameter values. A third category is also introduced, namely "penalising" choices. More specifically, the three categories distinguish between choices which are considered: - likely to reflect the behaviour of the real system ("best estimate"); - less likely to do so but are still within the range of conceivable possibilities, thereby being deliberately chosen so as to lead to an upper estimate of consequences ("conservative"); and - to bound all conceivable, including very unlikely possibilities and lead to calculated consequences more severe than any that could actually be realised ("penalising"). A key objective of the safety case is to obtain a thorough knowledge of the processes likely to take place in the disposal system and an adequate understanding of its long-term behaviour. This entails investigating the most likely performance of the system, leading towards a best estimate approach. However, for compliance with regulatory requirements it is usually necessary to show that the estimates of radiation dose or risk from the possible migration of radionuclides from a disposal facility are below or consistent with some reference criteria. It is then sufficient to demonstrate that an upper estimate of the release lies below the target value. Such considerations lead towards a conservative approach. A pessimistic approach may use a model or set of parameter values that do not refer to phenomenological knowledge, chosen to lead with certainty to an impact greater than anything possible. For example, a parameter value may be chosen that corresponds to a physical limit. The motivation for using such an approach might be to test the overall robustness of the disposal facility concept, to handle with certain processes that are poorly understood or with large uncertainties associated with very long time-scales. It should be recognised that there are limitations to making exclusive use of an overall best estimate approach and that some conservative assumptions leading to simplifications will always be necessary for some parts of the system (e.g. due to limitations of site investigations). In particular, where uncertainties are large the concept of a best estimate may have little meaning. In the framework of the step-by-step approach, there is a need for dialogue between the regulator/TSO and the implementer to clarify expectations on the matter at each decision step. <u>Probabilistic vs. deterministic assessments:</u> Scenarios can be assessed through probabilistic or deterministic approaches, each having benefits and limitations. Probabilistic and deterministic assessments have important but different contributions to make and are therefore seen as complementary. A mixed analysis approach combining both probabilistic and deterministic assessments is thus recommended. <u>Uncertainties that can not be quantified:</u> Some uncertainties are difficult to quantify or bound, and are less amenable to the above methods, particularly in cases where the range of possibilities is very wide or uncertain. The evolution of the biosphere and the nature and timing of future human actions, for example, become highly speculative even over relatively short timeframes. Where such uncertainties may be considered to have a significant effect on the safety case, measures to investigate, address and mitigate these uncertainties as well as evaluate their impact on safety should be implemented. Such measures

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include the use of safety and performance indicators complementary to dose and risk, and the use of stylised approaches (e.g. to model the biosphere and for human intrusion scenarios) that are broadly conservative with respect to any consequences for safety or the environment.
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
The implementer has to assess the suitability of the host rock, surrounding environment and engineering components in particular to demonstrate the feasibility, the performance and the robustness of the disposal system with regard to the safety functions. Features, events and processes that can affect the performance of the system and its components should be identified and effects on the system behaviour and robustness should be assessed. The implementer demonstrates that methods and materials of excavation and construction are feasible and reliable. In all these respects, the projected performance of the site and engineered components is expected to be confirmed and important uncertainties remaining at the particular stage of the project are identified and plans presented for managing them. Performance assessment, whose role is to assess the performance of the system or subsystems using performance indicators, is a valuable tool for identifying where further work should be directed to avoid, mitigate or reduce uncertainties. This is a means by which the link between safety assessment and safety strategy is maintained. A register of significant uncertainties should also be provided. Additionally, the safety case(s) issued at each phase of a disposal programme are expected to provide a description of the management system which should include a description of the information that will be recorded and how it will be recorded. The information management system should enable investigations of options considered and results of these investigations to be traced through the process.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
Additionally, the safety case(s) issued at each phase of a disposal programme are expected to provide a description of the management system which should include a description of the information that will be recorded and how it will be recorded. Considering the implementation of the principle of optimisation of protection, the information management system should enable: • investigations, assessments and comparisons of options considered • the results of these investigations, assessments and comparisons as well as resulting decisions to be traced through the process.
4.2f Other information that you would like to add:
The approach to the management of uncertainties is a part of the safety strategy. Within a step-by-step approach to disposal facility development, information about uncertainties and perspectives on how they can be managed form an important input for the decisions to be taken at each step.

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The views of Bel V on the different measures that should be taken to manage the evolution of uncertainties and the possible occurrence of new uncertainties are provided in the answer to question 3.2.b (see part 3 of the questionnaire) How much uncertainty can be accepted at a given step depends on the decisions to be taken at that step. The way uncertainties are managed is thus expected to evolve throughout the different programme phases (see Report on the European Pilot Study on the Regulatory Review of a Safety Case for Geological Disposal of Radioactive Waste (2016)): Phase 0: Policy, framework and programme establishment: During this phase, the implementer is expected to consider potential sites and design options, to establish the safety strategy and to carry out preliminary assessments. At this stage of development these assessments will be based on assumptions and generic data, and taking into account prognosis of waste characteristics to be disposed of. At this stage of the project, the safety case will present the safety strategy and the way it will be met. Key aspects related to the safety strategy, namely to optimization and description of the design concept, need to be addressed. The management system and the approach to performance assessment, radiological and non-radiological impact assessment, as well as uncertainty management should be set out and explained, even though these aspects are likely to evolve in subsequent phases of the project. The assessment strategy at this stage should outline the basic approaches and tools that are expected to be applied to model the individual components of the disposal system and the disposal system as a whole, and to demonstrate the safety of the system with reasonable assurance. In particular, the assessment strategy should provide an indication of how the different aspects of safety assessment will be conducted. In particular, the implementer is expected to address: • The proposed methodologies to be adopted; • Approaches to scenario development; • Model development; • The treatment of uncertainties; • The role of sensitivity analysis, through safety assessment. At this stage it will not be possible to provide a detailed description and assessment of the facility. Consequently, it should be recognized that it will not be possible to provide the evidence necessary to demonstrate long-term safety, nor will it be possible to demonstrate the practicability of the design. However, at the end of this phase the implementer should demonstrate that: • the key factors important to safety have been identified; • adequate host formations and sites with respect to the safety strategy are potentially available; • the design concept integrates properties and characteristics of the host rock, engineered materials and waste. The safety case should aim specifically to address the identification of areas where knowledge is lacking or uncertainties are high and the establishment of priorities for further work in the next phase as well as proposals for the preferred approaches and options, particularly in respect of the development of the design, research and data acquisition, scenario development and modelling. Phase 1: Site evaluation and site selection:

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During this phase, the implementer identifies and confirms potentially suitable host formations and sites that are compatible with the design concept and the safety strategy and characterizes these sites to the extent that a decision can be made on the preferred site. The safety case should contain an appropriate demonstration of safety that will enable one or more candidate sites, together with specific locations on those sites, to be selected for the disposal facility and to allow progression to the next phase of disposal facility development.

At this stage, it is important for the implementer to carry out an assessment in order to support decisions related to the selection of host formations and sites. The safety assessment, considered as generic at the conceptualization phase, evolves to an indicative impact assessment consistent with the development of the design and the level of detail of the site characterization. Any uses of the results from the safety assessment must be balanced with the associated level of uncertainty.

The safety assessment should address:

- How the proposed methodologies adopted will be implemented;
- The performance indicators;
- The radiological criteria;
- The development of scenarios;
- The treatment of uncertainties and sensitivity analysis.

At this stage it is very important for the implementer to identify the key uncertainties and to establish as far as possible that they can be managed. Inability to manage the key uncertainties adequately once a site has been selected is a key risk for the project. The implementer must assess the ability of the disposal system and its components to fulfil its expected role.

This will primarily consist of identifying the perturbations that might affect the disposal system and its components, these being of internal (thermal, chemical, mechanical, radiological,...) or external (intrusion, climate change, seismicity, …) origin. This assessment is likely to be subject to large uncertainties, because site data, the engineering design and R&D results from in situ tests can only be partial at this stage. Enough quantification of the expected phenomena must nevertheless be made so as to bring sufficiently convincing evidence that the proposed disposal system can withstand these perturbations without unacceptable loss of its containment and isolation capability. Considering the possible perturbations and their uncertainties, the implementer should carry out sensitivity analyses in order to assess the robustness of the system and of its components, and to assist in directing and updating the research programme and in developing the facility design.

At the end of this stage, the implementer aims at establishing that at least one design option presents good prospects of feasibility, in the sense that it relies on proven and/or demonstrable features and is able to accommodate uncertainties related to the expected performance of the various components of the disposal system. This is an important condition to enable the large resources needed for moving to the next phase.

Phase 2: Site characterisation:

During the siting phase, the implementer identifies and confirms potentially suitable host formations and sites that are compatible with the design concept and the safety strategy and characterizes these sites to the extent that a decision can be made on the preferred site. The safety case must contain an appropriate demonstration of safety that will enable one or more candidate sites, together with specific locations on those sites, to be selected for the disposal facility and to allow progression to the next phase of disposal facility development.

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At this stage, the implementer is expected to develop the safety case to demonstrate that the adopted design can be implemented and will provide assurance that the disposal system (disposal facility together with the host rock and its environment) will meet the safety requirements for a given site. The implementer should investigate operational and long-term safety and present the outcome in detail. The safety case should present that the disposal facility is optimized. In order to substantiate that these goals have been achieved, the safety case should be based, in particular, on a mature assessment of the engineering and performance of the disposal facility as well as a detailed description and substantiation of the area where the disposal facility will be implemented. Substantiating that uncertainties have been properly managed is also part of the safety demonstration. This implies a.o. that: • uncertainty ranges are assessed and recorded; • uncertainties important to safety are propagated in the assessment to analyse their possible consequences; • the implementer demonstrates that the assessment contains a sufficient level of conservatism implying that the methodology followed cannot lead to an underestimate of the radiological impacts. More generally, the implementer should show that the implementation of the safety strategy has led to the identification, treatment and, where possible, avoidance or reduction of uncertainties. The synthesis should also consider the limitations of currently available evidence, arguments and analyses, and should identify areas where knowledge is lacking or uncertainties are high and where further work is needed for the next phase. It should therefore highlight the principal arguments on which the implementer has come to a judgement that the planning and development of the disposal system has reached a stage allowing the regulator to grant a licence for construction of the facility. <u>Phase 3: Facility construction:</u> The implementer should update the safety case to show that the safety significant uncertainties identified when the construction licence was issued have been reduced where possible and that residual uncertainties do not undermine long-term safety and can be managed. Uncertainties should be taken into account when preparing technical specifications (operational limit conditions) for disposal. The assessment should review uncertainties important for safety to ensure that in this respect it is acceptable to start the operating phase and should demonstrate that remaining uncertainties important to safety (e.g. regarding rock mechanical stability, gas generation, feasibility of closure, …) have been taken into account in the facility's operational design specifications. The implementer should confirm that the safety case contains all updated information about the disposal system, based on knowledge and new data gained during the construction phase. The implementer should demonstrate that uncertainties related to new elements identified during the construction phase can be managed in the next phases. <u>Phase 4: Facility operation and closure:</u> This period marks the beginning of waste emplacement and continues up to (but not including) the time when the facility is full and decisions are made on when and how finally to close and seal the facility. Data about the geological environment of the disposal facility and about the facility as actually built and the waste as actually emplaced, as opposed to the prior intent, will be gathered progressively during this period. In addition, there is the potential for significant improvements over the period, both

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to the practical techniques used by the implementer and to the methods used for establishing the safety case. New information gathered over this period will be used to improve the safety case and update it periodically. The safety strategy will be updated to incorporate feedback from operations. The implementer should update the demonstration that the implementation of the safety strategy has led to the management of uncertainties. By the end of the operational phase, the integration of the safety arguments and evidence will need to be acceptably complete. Knowledge about key uncertainties needs to be in a final state for the purpose of making the safety case for the period after closure. The key objectives of the safety case will include the confirmation that the disposal system has been optimised, that every operations has been done as expected, that the disposal system behaves as expected based on monitoring and surveillance, and that remaining uncertainties can be managed. The implementer will: • need to provide final substantiation of the models used for calculation, and full assessment of the remaining uncertainties and of the residual margins in the calculations based on information already presented in the previous safety case, updated as necessary. • have to confirm that the assessment contains a sufficient level of conservatism implying that the methodology followed cannot lead to an underestimate of the radiological and non-radiological impacts. • need to confirm that throughout the whole process (including closure of the disposal facility), the objective of “optimization” has been adequately achieved and that the relevant uncertainties have been reduced or otherwise addressed to provide confidence in the safety assessment and its results. Phase 5: Post-closure The objective will be to confirm the safety assessment results and the compliance with the regulatory criteria after closure. This confirmation will more particularly aim at confirming the absence of any conditions (especially due to the closure phase) that could reduce the post-closure safety of the facility as assessed in previous phases. It will be based on confirming that all the activities (especially closure) have been performed following the planned requirements. The implementer should update the safety assessment established in the previous stage on the basis of feedback from closure operations and analysis of the data gained during closure (from in situ monitoring and surveillance of the disposal system). The implementer should present a confirmation of the expected performance of the disposal system. This will be based on an updated and integrated overview of the level of knowledge about the ability of each component of the disposal system and the ability of the overall system itself to fulfil their expected roles accounting for any perturbations already encountered and any further ones foreseen.
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
According to the Belgian regulatory framework, the risks linked to uncertainties on “prevailing circumstances” need to be identified and analyzed on a regular basis throughout the disposal

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programme. The goal is to identify measures to reduce and mitigate these risks during subsequent programme phases. The term "prevailing circumstances" is used by ICRP and is associated with the principle of optimisation of radiation protection. Prevailing circumstances constitute the boundary conditions of the programme (including aspects like the waste to be disposed of, available sites, available financial resources, regulatory framework, stakeholder conditions,...).
4.3b How are uncertainties related to waste inventory managed?
Measures to manage these uncertainties in the Belgian disposal programme for LLW include: • Conservative estimates of the radiological content of waste packages • Additional characterization work (both destructive and non-destructive methods) aimed at reducing uncertainties regarding the radiological and non-radiological content of waste packages • Multiple independent controls aimed at minimizing the possibility mistakes during waste acceptance • The consideration in the safety assessment of an alternative evolution scenario exploring the possible consequences of accepting waste packages that would include quantities of complexing agents that would be larger than the corresponding waste acceptance criterion • Verifications prior to waste emplacement that waste acceptance criteria at the level of the vaults and tumuli will be effectively met • considering margins in the radiological capacity of the facility specified in the license to account for uncertainties on the possible evolution of the waste inventory. However, any increase of the activity of the waste inventory considered in the safety case requires an update of the safety case to demonstrate that safety remains ensured.
4.3c How are disposal concept uncertainties managed?
Report on the European Pilot Study on the Regulatory Review of a Safety Case for Geological Disposal of Radioactive Waste (2016)): During phase 0, the implementer is expected to consider potential sites and design options, to establish the safety strategy and to carry out preliminary assessments. At this stage of development these assessments will be based on assumptions and generic data, and taking into account prognosis of waste characteristics to be disposed of. The key aspects related to the safety strategy, namely to optimization and description of the design concept, need to be addressed. At this stage it will not be possible to provide a detailed description and assessment of the facility. Consequently, it should be recognized that it will not be possible to provide the evidence necessary to demonstrate long-term safety, nor will it be possible to demonstrate the practicability of the design. However, at the end of this phase the implementer should demonstrate that the key factors important to safety have been identified and that the design concept integrates properties and characteristics of the host rock, engineered materials and waste. Only preliminary elements will be presented. The safety case should aim specifically to address the identification of areas where knowledge is lacking or uncertainties are high and the establishment of priorities for further work in the next phase as well as proposals for the preferred approaches and options to address the areas identified above, particularly in respect of the

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development of the design, research and data acquisition, scenario development and modelling. It should be shown that adequate host formations and sites with respect to the safety strategy are potentially available. During phase 1, the implementer should determine the basic characteristics of the host rock and surrounding environment of the candidate sites, as well as those of the potential construction materials of the engineered components. The implementer is expected to propose design options in such a way that the safety functions and performance expected for each component will be achieved for the site(s) under consideration. At the end of this phase, the implementer aims at establishing that at least one design option presents good prospects of feasibility, in the sense that it relies on proven and/or demonstrable features and is able to accommodate uncertainties related to the expected performance of the various components of the disposal system. This is an important condition to enable the large resources needed for moving to the next phase. In preparation for the application for licensing the construction of the disposal facility (phase 2), the implementer adapts the conceptual design to the site properties, specifies and substantiates the reference design of the disposal facility, sets out detailed techniques for excavation and construction. To deliver the authorization, the regulator will expect the implementer to present, as a reference solution, a complete design for the disposal facility (including design of the closure arrangements), which is shown to be safe. The regulator will expect the choices made in the design are optimized. The regulator will also expect the solution presented to be fully substantiated as feasible. If the techniques proposed are not commonly used under similar conditions in other industries, the substantiation is expected to be based on demonstration of these techniques under conditions representative of those the implementer expects to encounter during construction of the facility. The qualitative and quantitative criteria that have been considered in order to select the design among alternative options should have been developed. The methodology to assure the quality of design and the traceability of data should also be described. The evolution of the design to the selected reference option in the framework of an optimization process should be addressed and shown to be consistent with the safety strategy. Any change to the concept during subsequent phases will require an update of the safety case to demonstrate that safety remains ensured.
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
Identification, characterisation and analysis of the safety-relevance of uncertainties associated with the initial state and evolution of the disposal system and its environment: The following uncertainties need to be identified, characterised and analysed: • Uncertainties regarding the waste inventory: radiological content and safety-relevant physico-chemical properties (e.g. heat emission, chemical species having the potential to disturb engineered components or the host rock, presence of complexing agents,…) • Uncertainties regarding the processes and characteristics upon which safety functions and/or radionuclide transport rely • Uncertainties regarding events, processes or construction potentially affecting safety functions and/or radionuclide transport

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- Uncertainties regarding the effects of possible events, processes or construction contingencies on the behaviour of the disposal system and prevailing conditions
- Uncertainties regarding the biosphere and its evolution

Treatment of uncertainties associated with the initial state and evolution of the disposal system and its environment:

See answer to 4.2.c

Management of uncertainties on the initial state of the disposal system:

In addition to the treatment of uncertainties on the initial state of the disposal system in the safety assessment (through scenarios or the use of conservative parameter values accounting for e.g. possible undetected construction defects), the following measures need to be taken to ensure that these uncertainties are properly managed:

Technical feasibility

the safety assessment must also address the feasibility and reliability of the proposed construction methods and the technical feasibility of the proposed design options to demonstrate that as-built properties will be as assumed in the safety case.

This implies identifying aspects that rely on already proven techniques and those that are new and need future confirmation through experimental tests. For the latter, the implementer will be expected to provide arguments confirming that technical feasibility can be demonstrated through a qualification programme that can reasonably be carried out within the time planned for project development. Where such arguments involve large uncertainties, the implementer will be expected to consider design alternatives, based on technical options that have been demonstrated on the basis of extensive feedback from industrial experience.

Level 1 of defence on depth (see answer to question 4.1)

Uncertainties on the initial state of the system can be avoided or reduced by reducing or avoiding as far as reasonably achievable sources of uncertainty having the potential to alter the properties of system components contributing to long-term safety during construction and operation (e.g. by limiting the probability of fire, by developing control measures and procedures to prevent defects and damage during construction,…).

Level 2 of defence on depth (see answer to question 4.1)

Uncertainties on the initial state of the system can be avoided or mitigated by selecting (by host rock/site selection and design), as much as reasonably achievable, components which are robust with respect to disturbances that could potentially arise during construction and operation (e.g. fire, earthquakes,…).

Level 4 of defence on depth (see answer to question 4.1)

Uncertainties on the initial state of the system can be reduced or mitigated by detecting deviations from normal operation, construction defects or damages to the disposal system so as to take corrective measures where needed during construction, operation and closure. This includes:

- developing quality control measures during construction based on clearly defined conformity criteria;
- defining operating limits and conditions that determine the conditions that must be met to prevent situations that could lead to damages/accidents, or to mitigate the consequences of damages/accidents should they occur. The monitoring and

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inspection programmes for the systems and components should allow verifying that operating limits and conditions are met; • allowing retrievability of the waste packages (during a certain period of time to be defined).
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
No
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
4.3f How are uncertainties in the understanding of key processes managed?
According to the Belgian regulatory framework, a safety assessment should be based on sufficient knowledge and understanding of the disposal system in its environment. The implementer of a disposal programme should ensure that he has an adequate understanding of the characteristics of the facility and of its host environment as well as of the factors that could affect its safety after closure for sufficiently long periods of time. During the initial phase of concept development, the data collected and the level of understanding achieved must provide sufficient confidence to commit the resources required to proceed to the next phase of the programme. The level of understanding must then be sufficient to demonstrate that applicable regulatory requirements are met. The principle of demonstrability (see answer to question 4.1) implies that <u>processes on which safety functions rely</u> should be sufficiently understood such that a sufficiently realistic representation of the system behaviour can be provided in PA models. Remaining uncertainties are treated using a conservative approach in modelling (e.g. advection in the host rock is modelled considering a conservative hydraulic conductivity). Where simplifications are necessary, the implementer should give the reasons and substantiate the validity of the simplifications with respect to the intended use of the model. If uncertainty on process understanding is too high to provide such a representative modelling, it means that safety cannot rely on the process and the safety concept needs to be updated. For <u>processes which do not underly safety functions</u> (e.g. advection in aquifers), several assessment cases with different conceptual models or neglecting the process can be envisaged to treat associated uncertainties. In the latter case, it should be justified that neglecting the process leads to a conservative estimate of the safety indicators.

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In many cases, steps can be taken to avoid, mitigate or reduce uncertainties linked to the level of understanding of the processes governing the evolution of the repository system. This can apply whether or not the uncertainty concerned is amenable to quantification. As the project progresses, effort should focus increasingly on key safety-relevant uncertainties and the data and measurements needed to address them. Uncertainties can be sometimes reduced by acquiring more data from, for example, site characterization (including host-rock) and laboratory tests. In some cases, uncertainties can be managed by identifying and assembling multiple lines of evidence that support assessment assumptions or parameters, including, for example, evidence from natural analogues to support the longevity of engineered materials.
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
Quality of the data According to the Belgian regulatory framework, a safety analysis must be based on the state-of-the-art. Available knowledge relevant to the analysis should therefore be identified. The potential needs in terms of developing new knowledge should then be identified. Indeed, the level of knowledge to be achieved for a given subject must be determined taking into account its importance for safety. Using the best possible knowledge possible includes: • a reliable characterization of the disposal system and its environment; • verifying the reproducibility of the results of measurement and experiments conducted to identify and characterize the events and processes related to the disposal system and its environment; • justifying the non-consideration of a priori relevant knowledge; • identifying, where appropriate, the cause of disparate or contradictory data. In some cases, expert judgment may be used, for example, to elicit a value, a distribution of values, a model, a degree of uncertainty, etc. The process followed to establish an expert judgment must be formal, structured, traceable and transparent and should seek to minimize associated biases. *Treatment of uncertainties* According to the Belgian regulatory framework, the treatment of uncertainties in the SA has to be transparent and traceable. The strategy to treating (i.e. propagating) uncertainties has to be substantiated considering in particular: • the objectives of the assessment • the type and nature of the uncertainty • the quality of the data • the safety-relevance of the uncertainty • the considered timeframe • interdependencies with other uncertainties (correlations between parameters, unfavourable combinations of parameters, process coupling, …)

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4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?

Completeness of FEPs

According to the Belgian regulatory framework, a safety assessment should be based on sufficient knowledge and understanding of the disposal system in its environment. The implementer of a disposal programme should ensure that he has an adequate understanding of the characteristics of the facility and of its host environment as well as of the factors that could affect its safety after closure for sufficiently long periods of time.

This should allow a.o.:

- identifying and understanding the different characteristics and processes underlying the safety of the facility;
- identifying and understanding the possible behaviours of the disposal system;
- identifying potential transfer pathways and trajectories of radionuclides within the disposal system and its environment;
- ensuring that no event, process or construction-related contingencies that may affect safety has been omitted or inappropriately discarded.

he methodology for identifying safety-relevant characteristics, events, processes and construction-related contingencies should be developed taking into account the specificities of the concept and the site. Their completeness and relevance of considered characteristics, events, processes and construction-related contingencies should be substantiated. The exclusion of events, processes and construction-related contingencies should be justified on the basis of their low likelihood and/or of their low potential impact.

Completeness of scenarios

According to the Belgian regulatory framework, the appropriateness of the methodology used to develop scenarios should be substantiated. An appropriate methodology should provide sufficient confidence in the completeness of the scenarios and hence minimize uncertainties associated with the completeness of the characteristics, processes, events and contingencies linked to construction considered in the safety assessment (see answer to question 3.1).

It should therefore be substantiated that the used methodology systematically allows:

- to take into account all possible events, processes, construction-related contingencies, transfer and exposure pathways that can significantly influence system performance and/or the radiological impact of the facility;
- to ensure that all possible evolutions of the disposal system and of its environment are covered by the set of developed scenarios. The manner in which events, processes and construction-related contingencies are combined should be justified.

The possible evolutions of the disposal system and of its environment, covered by each scenario, should be identified.

The approach and criteria used to exclude an event, process or contingencies linked to construction or a combination of events, processes and/or contingencies should be justified.

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4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
According to the Belgian regulatory framework, uncertainties associated with the tools and methods used in the safety assessment (see answer to question 3.1) have to be managed. This implies that the methods and calculation codes used in the safety assessment are verified and validated. The verification and validation of the methods and calculation codes allow minimizing uncertainties associated with their use and hence building confidence in the results of the safety assessment. More specifically, the verification and validation of models aims a.o. to substantiate that: • mathematical models adequately represent the processes described in the conceptual model considering the purpose of modelling; • the calculation codes correctly resolve the equations of the mathematical models for the conditions described in the conceptual model; • the representation of the system being modelled is adequate by comparing model predictions with data from the real system or experimental data. For models used in a post-closure safety analysis, this usually involves comparing the results of specific process simulations with experimental data, field observations, and/or natural analogues.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***

Table A-13: TS ENERCON (Hungary) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

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Date:	Part 1 – 27 September 2019 Part 4 – 28 September 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Attila Baksay	
1.1b From which country and organisation are you?	
Hungary, TS Enercon Ltd.	
1.1c Type of your organisation (WMO, TSO)?	
TSO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Safety assessment	
1.2b Please explain briefly your role in your organisation and your background.	
Engineer-physicist, specialized in nuclear field. Expert qualification on the fields of radiation protection, radioactive waste management. I participate in tasks where the radioactive waste management, storage and disposal are in focus. I am also responsible for safety related calculations, radiation protection, criticality calculations, source term calculations, assessments of contaminant migration.	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
Hungary has one operating nuclear power plant with four units of VVER-440 reactors, situated in Paks. Near the NPP a modular, vault type interim storage facility for the spent nuclear fuel (ISFS) is situated, where the SNF is stored until the disposal. The country also has one training reactor situated in the Budapest University of Technology and Economics and one research reactor in the Atomic Energy Research Institute also in Budapest. Currently two waste disposal and storage facilities are in operation in Hungary: • The Püspökszilágy Radioactive Waste Treatment and Disposal Facility (RWTDF) has a total disposal capacity of 5040 m3. This site is Radon type disposal facility with interim storage facility and waste treatment capabilities. Now this facility receives radioactive waste from institutions only but in	

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the earlier period it received radioactive waste from the NPP as well. Currently the site is under a safety upgrade. • Hungary's other facility is the National Radioactive Waste Repository (NRWR) which is near Bátaapáti village and now it is partly in operation; its surface facilities are in operation and drums of compacted radioactive waste or containers containing mixed radioactive waste from Paks NPP can be puffer stored there. The underground disposal chambers are continuously under construction parallel with the operation of the facility. The first chamber was put in operation in December 2012. The NRWR is designed to accommodate all operational and decommissioning radioactive waste arising from Paks NPP. Disposal concept applied in the NRWR has been optimized, that resulted a more efficient way of radioactive waste disposal. The national strategy regarding the spent nuclear fuel is the direct disposal. There is an ongoing research project with the aim of finding suitable formation for the deep geological repository capable of receiving HLW and spent nuclear fuel from the NPP. Area around village of Boda, in the Boda Clay Formation seems to be suitable, the research concentrates here. Missions of the national program are: • operate disposal facilities in a safe way; • carry out a safety program for the near surface facility; • extension of the underground facility according to the needs; • finding suitable formation for the DGR for the HLW and SNF.
1.4 At what phase is/are the radioactive waste disposal programme(s)?
In case of L/ILW the waste disposal program is in the Phase 3 and 4, since there is a continuous extension parallel with the operation. In case of disposal of SNF and HLW the program is in the phase 1.
Part 4. Strategies for managing uncertainties
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***
Repository has to comply with the radiological criteria: the radiation exposure of any member of the public has to (significantly) lower than the site specific dose constrain, most likely: 0,1 mSv/yr. In cases of scenarios that were not taken into the design basis, the radiological risk is the criteria: has to be lower than 1E-05.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.

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4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
4.2f Other information that you would like to add:
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
During the construction phase the “Design as you go approach” had an effect that helped dealing with uncertainties.
4.3b How are uncertainties related to waste inventory managed?
There are areas where development is needed. For a long period deterministic values were used for the activities if the radionuclides. The chemical properties are not taken into account. Now stochastic approach for the source term is accepted.

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4.3c How are disposal concept uncertainties managed?
It has to be based on expert consensus. International screening is another tool.
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
In the level of safety case: • Generally safety assessments are using conservative approach when dealing with uncertainties. • Conceptual uncertainties are dealt with approaching them with expert consensus. • Parameter uncertainty is mostly dealt with using stochastic computational approaches: o retardation of radionuclides o diffusion, matrix diffusion o presence of conducting fractures (stochastic hydrogeological models are used) o failure rate of waste packages There are no accepted methods for mitigation of uncertainties.
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
Certaity cannot be gained but the level of uncertainty can be reduced. Understanding of the long term behavior of the waste packages are important.
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
Yes, methodical approach on each field: hydrogeology, geology, geophysics.
4.3f How are uncertainties in the understanding of key processes managed?
Only generally used approach in this case is the expert consensus.
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
Most common approach is to derive probability distribution functions for uncertain parameters, than choosing mathematical approaches that are capable to handle pdfs..

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
Only generally used approach in this case is the expert consensus.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
Effects of the parallel activities in the underground repository. No method is used for that so far.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
Uncertainties regarding the source term can be handled to a point by careful and methodical analysis of the operation of the waste producer.

Table A-14: EIMV (Slovenia) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 2 October 2019 Part 4 – 2 October 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Nadja Zeleznik	
1.1b From which country and organisation are you?	
Slovenia, EIMV	
1.1c Type of your organisation (WMO, TSO)?	
TSO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Safety assessment, Management	
1.2b Please explain briefly your role in your organisation and your background.	
I am senior researcher and responsible for RWM in organisation. I am physicist (MSc), Reactor Physicist (MSc), and have 25 years of experiences in RWM.	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
Currently, focus is to develop near surface disposal, but there are also some basic plans for establishment of HLW disposal (with SF).	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
The near surface disposal is at Phase 2 (licencing for construction). for HLW disposal is the Phase 0.	
Part 4. Strategies for managing uncertainties	
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration***	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.
The regulatory requirement are set in Slovene legal framework. For the operational period the limit are related to effective doses for workers (up to 20 mSv/year in normal operation, and 50 mSv/year provided that the average annual dose over any five consecutive years, including the years for which the limit has been exceeded, does not exceed 20 mSv). The limit of the equivalent dose for an exposed worker shall be: for eye lenses, 20 mSv per year or 100 mSv in any five consecutive years, subject to the maximum dose of 50 mSv in a single year; for the skin, 500 mSV per year where this equivalent dose limit shall apply to the dose averaged over any area of the area of 1 cm2, regardless of the total surface of the skin exposed to ionising radiation; for exterminates, 500 mSv per year. The sums of annual exposures received by an individual from the population from all approved radiation practices shall not exceed the limit values for exposure of the population. The effective dose limit for individual members of the public shall be 1 mSv per year. The equivalent dose limit is for ocular lenses of 15 mSv per year and for the skin is 50 mSv per year, the last marginal equivalent dose on any part of the skin of 1 cm2, regardless of the total surface of the skin exposed to ionizing radiation. Operator of repository shall establish dose constraints as an operative tool in the optimisation of occupational exposure of its workers and dose constraint for the population shall be set as a personal dose that a member of the public receives from the planned operation. For optimisation of radiation protection in emergency and existing exposure situations, reference levels shall apply, and are set to 100 mSv or 20 mSv respectively. For post closure phase the effective dose shall not impose a burden exceeding 0.3 mSv/year on a member of the public under the normal evolution of a disposal facility. In cases of alternative evolution of a disposal facility, the following measures shall be implemented, depending on the burden imposed on a member of the public: a) for up to 10 mSv/year, no disposal facility optimisation measures are required; b) for above 10 mSv/year, measures to minimise the probability of an alternative evolution of a disposal facility are required; c) for above 100 mSv/year, measures to minimise the consequences of the alternative evolution of a disposal facility are required. In addition, also other conditions are set for disposal facility: site characteristics, design, transport, environmental impacts, and others.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
There is a practical guidance adopted as support for the development of safety report where the following is proposed: “A key outcome of the safety assessment is the identification and assessment of uncertainties that could endanger the safety of the disposal. Particular attention should be paid to reducing uncertainty through improved site characterization, design, tests and experiments (laboratory or in the field) and the analysis of analogue natural or anthropological systems. Important decisions and results should be based on multiple, independent approaches. methods (Multiple Lines of Reasoning) and demonstrate that safety analysis is based on robust arguments and assumptions. The remaining uncertainties need to be evaluated, described and presented. Uncertainty analysis and their impact

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on disposal safety should be made. At least: uncertainties arising from post-closure disposal development scenarios; uncertainties arising from the models used in the preparation of safety analyses; uncertainties arising from the input data. Sensitivity analysis should also be made. This chapter should describe the outstanding issues and significant uncertainties surrounding the design of the safety analysis and establish a plan to eliminate or reduce them."
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
Safety assessments are foreseen throughout the development of RW repository. First such is part of the site selection process, and foreseen also uncertainty management. In the adopted practical guides the uncertainty management is required. Later of each of the licencing steps (EIA, construction licence, trial and operation, closure, post closure) a separate safety assessment is foreseen with also uncertainty treatment.
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
The uncertainty management include identification, assessment of importance and quantification, reduction (treatment) approach and needs for R&D.
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).
All this approaches could be used, but are not prescribed by the legal frames. Therefore many times IAEA related documents are used, like ISAM and ASAM.
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
The recording is set as mart of the management system of implementer. All key uncertainties which are identified through safety assessments are recorded, the best approach how do treat them is taken, also resulting in initiating research and development, design or other activities.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
The outcomes of uncertainties treatment lead to reduction or mitigation of uncertainties, or to new R&D activities.
4.2f Other information that you would like to add:

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
This part is treated not systematically as there is no scientific approach. In case of delays, basically they resulted in increase of resources - this is taken in account mainly with regular reassessment of funding needs. Socio-economic and political uncertainties are addressed case by case (for example, current decision of Croatia not to join the project). The new regulatory requirement (governance uncertainties) are addressed also by regulatory authorities which sets normally a kind of transitional period where the old requirements could be applied.
4.3b How are uncertainties related to waste inventory managed?
Different inventory data are used and new characterisation programs applied. Also, scaling factors are used with conservative inventories. The information is part of the safety report or reference documentations.
4.3c How are disposal concept uncertainties managed?
Generic safety assessment and report is part of the procedure in the site selection where different disposal options are assessed from nuclear safety and radiation protection.
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
Uncertainties of the properties of the barrier system and in the conditions prevailing in the system are modelled and evaluated as part of the safety assessment for post closure. For data uncertainties the parameter distribution functions are used in probabilistic assessments, uncertainties related to barrier performance are treated by defining different scenarios of disposal system evolution based on different assumptions about how the barriers provide safety functions when subject to the effects of uncertain events or processes, several alternative scenarios are used to analysed uncertainties with material quality or barrier performance. Very long period are treated also with different scenarios and also calculations without cut off. For questions where there should be more R&D to reduce the uncertainties, the programmes are developed and implemented.
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
Yes
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?

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Yes, one cannot deny such consideration, but it is precisely to provide a credible answer at the scale of hundreds of thousands of years that the concept of disposal has been oriented towards (much older) geological formations located in geodynamically stable areas… This problem is addressed by referring to geological stable areas for much longer times than the required million years. The residual hazards, independent of the geological context, such as human intrusion, climate changes of anthropic origin or erosion necessitate to account for large margins. These uncertainties are managed through so-called « stylized » scenarios.
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
For some aforementioned « stylized » scenarios (such as human intrusion), R&D seems not to be able to reduce drastically the uncertainties (aleatory type). For others (of epistemic type), R&D is needed at least for determining the values of the parameters to introduce in the scenarios.
4.3f How are uncertainties in the understanding of key processes managed?
The conceptual model uncertainties should be treated by using more relevant models to predict the reality. But first all processes should be very well understood.
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
Special knowledge management system should be applied which include the system, the data base and record keeping. Usually, implementer adopts certain KM system and assures it maintenance.
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
FEP are recorded, than screened and used to derive and justified scenarios. What -if scenarios should be used to assess the robustness and defence in depth. the appropriate group of experts have to be involved in screening process.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
As said the measures for reductions of uncertainties should be adopted. They depend on the types of uncertainties. For data/parameter uncertainties the approach could utilize: conservative/worst case approach, best estimate, sensitivity analysis, probabilistic calculations. Similar approaches could be used in scenarios and model uncertainties. In addition, also scenario analysis with description of alternative futures can be used, consideration of alternative conceptual models and collection of further data can be implemented, computer model should be verified, calibrated and validated. For other uncertainties, like political, societal or governance, the measures taken usually foresee what if and worst case approach.

Table A-15: IRSN (France) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 4 October 2019 Part 4 – 4 October 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Muriel Rocher	
1.1b From which country and organisation are you?	
IRSN, France	
1.1c Type of your organisation (WMO, TSO)?	
TSO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Safety assessment	
1.2b Please explain briefly your role in your organisation and your background.	
I hold a PhD in Tectonics from Paris VI University and Gaz de France. I'm in IRSN as a nuclear safety engineer since 2004, carrying out both research projects and safety assessments related to geological, geodynamical and hydrogeological issues, for shallow-surface and deep underground disposal facilities, and being involved in the development of the national guiding principles, notably for siting of such waste disposal facilities. I'm the deputy head of the unit of expertise and modelling of disposal facilities.	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
See the answer given by Andra Andra response (provided by DUMONT Jean-Noël): "Manage all the French radioactive wastes, of all kinds: monitor and maintain the near-surface Manche repository (in closure phase), operate near-surface repositories in Aube department, design and study repositories for HLW and LL-IntemediateW, and LL-LowLevelW."	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
See the answer given by Andra Andra response (provided by DUMONT Jean-Noël): "HLW and LL-IW: phase 2; LL-LowLevelW: phases 0 and 1; VeryLowLevelWaste: phases 2 and 4; other waste (near surface repositories Manche and Aube): phase 4"	

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Part 4. Strategies for managing uncertainties
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***
The French guidance referring to the safety of geological disposal is the ASN Guide for geological disposal (formerly BSR III.2.f - June 10, 1991) – Definition of design and construction objectives for the disposal of radioactive waste in deep geological formations, with a view to ensuring safety beyond the operating period of the repository (12/02/2008) The fundamental objective defined in this guide is the protection of man and the environment: • During the lifetime of the disposal facility (operation & long-term). After closure, safety is provided passively • Against risks associated to radioactivity and toxic chemicals • ALARA Focusing on the geological disposal, radioprotection criteria are the only quantified criteria given in the ASN guide: • During operation, current regulations apply for workers (Labour code) and for public (Public Health code) • After closure: - Reference situation for a period of at least 10,000 y (including disposal facility defects, progressive degradation of waste and engineered barriers, climatic variations, geodynamics, seismic activity). Dose limit: 0.25 mSv/yr. - Beyond this period, the uncertainties on the evolution of the disposal system's environment rise progressively… The release of radioactive substances does not lead to unacceptable dose levels. The aforementioned value of 0.25mSv/year will be retained as a reference while this check is made. - For altered situation, the individual exposure levels must be kept sufficiently low in relation to the levels which are likely to lead to deterministic effects, and ALARA should be applied.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
In the ASN guide for geological disposal mentioned above, a specific section (§6.7) is dedicated to uncertainty to take into account and sensitivity studies. This section mentions that uncertainties are due to: • parameter values, • lack of knowledge of some phenomena, • exhaustivity or not of phenomena that may have an impact taken into account,

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
• conceptual models and necessary simplifications used to create the models, • future events or future human activities. A deterministic and pessimistic approach is recommended by the guide, which specifies that: • safety demonstration must clearly identify how the on-site investigations, research program results, design provisions, hypotheses made for the evaluation and the sensitivity studies have allowed the appreciation of the uncertainties and to take them into account. • residual uncertainties will be evaluated, according to their type, in a qualitative or quantitative way • expert opinion may be used, but the traceability of these opinions must be established. • sensitivity studies must be carried out to detect the most important parameters and to justify the simplifying assumptions made.
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
In France, the mandatory regulatory steps regarding DGR development would be the following: - The Licence application, granted by a decree of the Council of State; - if granted, a commissioning for operation (mise en service), which would be restricted to a so-called “pilot phase” (Law n° 2016-1015 of 25 July 2016); - the commissioning for the complete repository, which would be given by ASN on the basis of the results of the pilot phase (Law n° 2016-1015 of 25 July 2016); - Periodic reassessment would be then submitted every ten years, as for any basic nuclear facility in France (L. 593-18 of Environment Code); - Finally, the closure of the deep geological disposal would be enforced by a future law (Law n° 2016-1015 of 25 July 2016). In addition, the Procedure decree n°2007-1557 offered the possibility for Andra to submit a so-called “Safety Options Dossier” (DOS) of their project for facility, before embarking on the regulatory licensing process in 2015. Before this, several safety assessments were produced by the implementer, Andra, and review by several technical experts, including IRSN but also international peer-reviewers by the IEER, by IAEA, review by National Expert commission CNE….
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
The first instinctive step of the uncertainty management would be the identification of the source of the uncertainty. The second step is the assessment of their potential impact on the safety case. The result of this assessment could be used to prioritize the R&D actions (see below). Depending on the stage of

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development of the disposal, a change of the design of the facility can be made to avoid the source of the uncertainty, if for example there is little hope that a R&D program reduces them. A R&D program could then be defined and implemented in order to reduce uncertainties. Such actions may result in better understanding of the uncertainties and/or in unveiling other uncertainties. Therefore, such R&D programs should be undertaken at quite early stages in the development of a disposal, to avoid a situation where unplanned uncertainties challenge its success at the stage of closure for example. In France, the uncertainty management strategy is primarily under the responsibility of Andra. However, IRSN has continuously to maintain its skills so as to carry out an informed review. For that, IRSN is developing its own uncertainty management process and carries out research activities, developed in consistency with conclusions drawn from the stepwise regulatory process that allows periodically addressing the remaining issues that must be dealt with to improve the safety demonstration. After each review of Andra's safety case, IRSN has to reevaluate its priorities in the R&D regularly, accounting for both the key safety issues identified and its limited resources in staff, time and funds.
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).
The approach promoted by the ASN Guide for geological disposal is greatly inspired form the international guidance (IAEA SSG-23, EU PAMINA project and NEA MeSA initiative…). It promotes a deterministic approach, probabilistic approaches serving as complements (i.e., see uncertainties under a different light). This results in the requirement of accounting for all situations that could happen, even if they are very uncertain. However, such situations are not labelled the same way depending on the likelihood of their occurrence. For example, as part of the safety analysis for the post-closure phase, the following situations are studied: • A reference situation which corresponds to the foreseeable evolution of the repository and the geological environment caused by certain or very probable events • So-called "altered situations" which correspond to the occurrence of uncertain but plausible events, either natural or linked to human activities, which take over from the reference situation and may lead to an acceleration in the migration of radioactive substances between the repository structures and the biosphere. With respect to the treatment of the uncertainties, the safety assessment is expected to take these situations into account in a deterministic way, as soon as they can be safety-significant; either directly or by inducing other uncertainties. The potential exclusion of some uncertainties on the basis that they would be not significant needs to be justified and documented. As previously stated (4.2.b), the safety assessment, when presented in a mature safety case at important steps of the disposal development, should present how all uncertainties are treated or being treated. In the case of uncertainties accounted for in the safety scenarios, an important topic that the safety assessment needs to tackle is the effect of the combination of the uncertainties. When relevant, combination of uncertainties should be accounted for in one scenario with appropriate hypothesis.
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.

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The relevant information and feedback, as well as technical difficulties and need for R&D, are collected and recorded by IRSN after each review for future use or decision to develop new R&D programs.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
Results of R&D programs are systematically taken into account in the review of updates of the safety case.
4.2f Other information that you would like to add:
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
The management of uncertainties in the schedule or of socio-economic uncertainties is the duty of Andra. However, important offsets in the project might lead to the challenge of maintaining IRSN technical skills as well as adequate financial and human resources.
4.3b How are uncertainties related to waste inventory managed?
Again, the definition of volumes, activities etc. are primarily under the responsibility of Andra. In conformity with ASN request, Andra defines a baseline waste inventory for Cigéo as well as an inventory including waste “in reserve” and several scenarios of inventory with spent fuel in case of partial or total abandonment of retreatment at various dates in the future. In its safety case for license application, Andra will have to demonstrate that Cigéo would be adaptable for receiving such inventories in reserve (for example, some low-level long-lived radioactive waste) or with spent fuel; this is one aspect of the concept of reversibility defined by ASN. Nevertheless, after licensing, any intent to derogate to the baseline inventory will require for Andra to submit a new safety case to ASN. On its side, IRSN evaluates the sensitivity of the results of performance calculations to variations of several types of data: kinetics of RN discharges, waste radiological inventory, types of waste (those in reserve or spent fuel…). IRSN also verifies the adaptability of Cigéo’s works (designs and concepts) to such types of waste.
4.3c How are disposal concept uncertainties managed?
IRSN assesses the robustness of the concepts considered by Andra through sensitivity analyses. For example, studies are carried out with our own tool (MELODIE) with the use of a parameterized architecture of the disposal plant (length of galleries, location of shafts…). These sensitivity analyses may also account for human factors during operational phase (defect in design or manufacture, human error…). The IRSN computation tool being different from the one used by Andra, IRSN’s models are first calibrated against Andra’s results, and then used to carry out sensitivity analyses. For instance, in its review report of the Safety Options Dossier in 2016-17, IRSN suggested ASN to recommend that Andra selects, in the file to support the DAC, a disposal design that provides a proved

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
redundancy function of seals of seabed-to-surface facilities, considering at least the following defense lines and their combination: (i) efficient seals of gallery, (ii) the distance between the disposal quarters and the basis of seabed-to-surface facilities, and (iii) the positioning of the seabed-to-surface facilities on hydraulic upstream of the disposal quarters. The latter will have to be justified by a study concerning the advantages and drawbacks of different options, vis-à-vis the operational and the long term safety. Such recommendation has been supported by ASN.
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
The approach recommended in France for developing scenarios is the one of 2008 ASN safety guide, described in §4.2c (deterministic approach eventually complemented with probabilistic studies, a base case scenario and alternate evolution scenarios…). The uncertainties in parameter values are generally accounted for by Andra through a deterministic approach. However, the evaluation of earthquake hazard, both for operational phase and post-closure phase is complemented with probabilistic approach by Andra in the Safety Options Dossier. IRSN evaluated this hazard also by complementing with probabilistic approach for operational phase. Regarding the numerical modelling of RN flows with the MELODIE computing code, IRSN experimented a stochastic method in complement to the deterministic approach and implemented a dedicated module in MELODIE. The ASN guide is applied by Andra for developing scenarios, with few variations, as described in its Safety Options Dossier: • definition of 2 situations associated with the domain of normal evolution: one reference scenario, corresponding to the to the best of Andra's ability, and one "envelope" scenario, corresponding to the specified requirements to the components for functioning of Cigéo... • Several alternate evolution scenarios: 3 of dysfunctioning of part or all of the sealing works, 2 of dysfunctioning of some waste packages; • Human intrusion scenarios • Several What-if scenarios: 4 postulating dysfunctionings of sealing works, one for the waste packages, one assuming the presence of a fault in the host rock. IRSN disposes of experience from its Tournemire URL and carries out its own sensibility studies on the basis of scenarios, sometimes different from those defined by Andra both in terms of parameters values and the scenario itself. Indeed, IRSN developed its own scenario catalogue. This IRSN catalogue has been established by postulating, component by component, the failure of the important components for safety (sealing works, waste packages,…).
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
Yes
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
4.3f How are uncertainties in the understanding of key processes managed?
For the key processes that are not completely understood yet, such as for example pore overpressure measured in the Callovo-Oxfordian rock or effects of gas flow in clayey rocks, the different imaginable explanations should be accounted for in different scenarios, and for each of them the impact on safety should stay acceptable. If this verification cannot be carried out (e.g. impossible to identify which situation is the most pessimistic, process potentially involving too many combinations of effects…) or if the impact on safety is not bondable for at least one scenario, one should return to R&D or modification of concepts to bypass the uncertainty.
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
Regarding the management of R&D results in IRSN, the amount of data acquired is not so large and the organisation of the team carrying out the R&D notably in Tournemire and the team of reviewers (including those developing scenarios, modelling of RN transport…) in a same department (and in a same location) favours their direct contact. The homemade scenario catalogue was developed through collaboration of both teams and is continuously feed with results of R&D from researchers. In the perspective of the implementation of Cigéo, the amount of data that will be collected during construction, through operational activities and monitoring may be considerable and the treatment of such collection, both for operating the facility (daily or in case of incidental/accidental situation) and for recording memory, may need developments in the use of big-data.
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
Andra's safety demonstration is rather developed on the basis of a « top-down » approach (events that may affect the components having a role in each safety function…) for developing its scenarios. There is no development of a complete FEP list, even if,of course, Andra verifies that all the observed key phenomena (in the host rock, the site…) are accounted for in its scenarios. The approach developed by IRSN to construct its own catalogue of scenarios is more or less the same: evaluation of the FEPs that can affect each component and selection of those having an effect on safety to develop the scenarios.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)

Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases

3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties.

3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.

Regarding the global strategy to deal with evolution of uncertainties with the development of the project, TSOs should deal with such evolution in developing a real synergy between research and expertise. For the WMOs, taking large margins is the basic strategy in the safety case.

As the emergence of new types of uncertainties is very likely to occur, it should be dealt with by taking very large margins during the first stages of development of the project, trying to account for the large variability of each parameter, even though the range of possible values could be hard to explain. During the process aiming at adjusting these safety margins, some phenomena explaining why the parameters were so variable might be discovered. Reducing the margins necessitates to understand these phenomena, which is not an easy R&D activity because it may reveal other even more complex phenomena hidden behind. Such imbricated phenomena generally implicate even smaller spatial scales (for example, from the rock formation scale to the rock pore scale and to the atomic scale).

[Example of variability of the porosity in the host rock or in an aquifer level of the site: initially, the reasons for such a variability are not exactly known; it can be due to the presence of recrystallized zones, of variability of the rock composition, of the presence of fractures… The space layout of this rock with be progressively better understood by reconstituting its geological history (sedimentation, compaction, tectonic events…).]

In order to reduce key uncertainties or deal with their persistence, R&D on complex phenomena on the one side, and modelling of RN migration on the other side, should play a significant role. R&D on host rock and material interactions as well as on other poorly understood phenomena mentioned above can be carried out in analog rock in URLs (Tournemire, Mont-Terri…) or on the field (for example, IRSN studies various properties in clayey rocks in Malta, southern Spain, SE France…) as well as on rock or water samples in surface laboratories.

[The Tournemire Underground Research Laboratory (URL), located in Southern France, is an old railway tunnel extended with galleries crossing the Toarcian claystone at 250m depth. Owning its own underground research laboratory allows IRSN to study directly a clay rock and underground conditions representative to the Callovo-Oxfordian layer studied in France to host Cigéo, where an independent research programme can be freely defined.

The LUTECE laboratory, located in IRSN premises at Fontenay-aux-Roses, complete the URL for, e.g, solid and aqueous analyses.]

The advantage of studying such an analogue rock in Tournemire or Mont-Terri is that their properties are almost the close to those of the potential host rock studied by the implementer in France or Switzerland. The difference in their properties allows though TSO to check that phenomena identified by the implementer also exist in these analogues or are site-specific, and to compare and explain their intensity.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
In addition, the studies of various mechanistic processes with numerical models help determining and quantifying whether safety margins are sufficient.

Table A-16: NRG (Netherlands) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 25 September 2019 Part 4 – 1 October 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Jacques Grupa	
1.1b From which country and organisation are you?	
NRG	
1.1c Type of your organisation (WMO, TSO)?	
TSO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Safety assessment	
1.2b Please explain briefly your role in your organisation and your background.	
Radioactive Waste and Radiological Protection Consultant	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
The programme mission is to develop a geological disposal for all radioactive waste in The Netherlands	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
Phase 0	
Part 4. Strategies for managing uncertainties	
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration***	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.
Only the basic radiation protection criteria are in place, since actual disposal is still more than 100 years away. However, there is at present no framework for risk regulation in the very long timescales relevant for disposal.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
Present guidance says that disposed waste must be retrievable. Further the waste must be isolated, managed/controlled and monitored at all times.
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
The present safety assessments should include a quantitative treatment of risks, so quantifiable uncertainties can be treated probabilistic.
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
Risk management procedures should be in place: . identify risks . reduce risks if possible and feasible . remaining risks should be acceptable, otherwise stop the operation. This can be achieved in e.g. an ISO 31000 risk management process.
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).
The present safety assessments should include a quantitative treatment of risks, so quantifiable uncertainties can be treated probabilistic. Alternative lines of reasoning are often not used.
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
See b)

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
See b)
4.2f Other information that you would like to add:
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
Generic choices are made, and the promise that once more information is availiable, the safety case 'cycle' will be repeated.
4.3b How are uncertainties related to waste inventory managed?
Generic choices are made, and the promise that once more information is availiable, the safety case 'cycle' will be repeated.
4.3c How are disposal concept uncertainties managed?
Generic choices are made, and the promise that once more information is availiable, the safety case 'cycle' will be repeated.
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
Generic choices are made, and the promise that once more information is availiable, the safety case 'cycle' will be repeated.
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
No
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
It will be very difficult to make any statement on anything related to humans on such a long tern and therefore that remains highly uncertain. For other, more nature/geology/natural or engineered barrier system it would be possible by doing more precise research. A better understanding of the system would eventually lead to less uncertainty although there is a limit. I do however think that reversibility of decision process and/or retrievability of the waste will increase the uncertainty as the system will become more complicated.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
4.3f How are uncertainties in the understanding of key processes managed?
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
Uncertainty in data can usually be confined in bandwidth analyses.
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
In terms of alternative scenarios.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
All concerns should be countered by defence-in-depth approaches (or multi barrier systems). For example, knowledge about the repository can be maintained longer when the knowledge is not only maintained on a national level, but when is shared between countries and generations.

Table A-17: SSTC NRS (Ukraine) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 23 September 2019 Part 4 – 26 September 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Oleksii Tokarevskyi	
1.1b From which country and organisation are you?	
Ukraine, SSTC NRS	
1.1c Type of your organisation (WMO, TSO)?	
TSO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Safety assessment	
1.2b Please explain briefly your role in your organisation and your background.	
Head of Laboratory for Safe Radioactive Waste Management, about 20-year experience in field of radioactive waste management. Expert reviews of safety cases and safety analysis reports on activities and facilities related to RW management (including disposal). Development of regulations and guidelines.	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
The mission is to ensure creation and functioning of the integral system for management (including disposal) of RW of all types and categories, both existing and planned to be generated.	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
For geological disposal - beginning of stage 1, for near-surface disposal - stage 4.	
Part 4. Strategies for managing uncertainties	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***
Radiological safety criteria: for operational period - dose limits for workers and dose quota for public; post-closure period - dose constraints for public; levels of acceptable and negligible risks. Consideration of radiological impacts on workers and public during operation (normal operation, emergency situations and accidents); radiological impacts on critical groups of public in post-closure period.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
It is required that during safety assessments and justifications of the disposal facility, the Operator define "the procedures for analysis of uncertainties (of input data, models) and sensitivity of the assessment results to the values of input parameters and assumptions", as well as "procedures for comparison of the results obtained with the safety criteria". Comparison of the results of assessments must be performed taking into account uncertainties in the calculation results. ("General Safety Provisions for RW Disposal")
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
Safety assessment is expected to be produced at the early stages of disposal facility development starting from disposal concept development and siting.
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
Identification of uncertainties – there are considered uncertainties of: input data; conceptual and mathematical models; evolution of engineered barriers; site characteristics for long-term period. Analysis, treatment of uncertainties – qualitative and quantitative analysis of uncertainties. For qualitative analysis, there are identified uncertainties that have significant impact on the results of assessment of long-term safety of the disposal facility and those that do not have such impact. For the uncertainties that have significant impact of safety assessment, there is performed quantitative analysis of their impact on the final results. There are identified uncertainties related, e.g. to gaps of the disposal site investigations, insufficient RW characterization, as well as insufficient data on possible changes of characteristics of barriers and the site in future.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).
As far as possible, there should be used initial data (modelling parameters) specific for the site, which are obtained during study of site characteristics and materials of engineered barriers of the disposal facility; use of different scenarios and different models; use of alternative lines of reasoning. Both deterministic and probabilistic approaches are used.
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
Based on the results of safety assessment, needs for R&D and other activites aimed at reducing, avoiding or mitigating those uncertainties are identified.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
The results of assessment are compared with the disposal objectives and safety criteria, taking into account existing uncertainties. There is performed analysis of sensitivity of the assessment results to the initial data: characteristics of RW, site, engineered barriers. Based on these characteristics, conceptual models of the disposal system, scenarios of its behaviour are developed; potential routes for migration of radionuclides and their impact on humans are determined. The assessment process envisages returning to previous elements of assessment after refining and adjustment of initial data, models and/or scenarios.
4.2f Other information that you would like to add:
N/A
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
Uncertainties related to the schedule of construction and operation are managed implicitly by varying the models related to certain scenario (normal evolution scenarios, alternative evolution scenarios). As an example of socioeconomic uncertainties in Ukraine, duration of existence of Chernobyl exclusion zone and boundaries of this zone can be mentioned. To address this uncertainty, different distances of potential residence are considered.
4.3b How are uncertainties related to waste inventory managed?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
There are performed studies to estimate correctly the total amount of waste in Ukraine and their attributing to different classes as regards their disposal routes. Generic waste acceptance criteria for attributing the waste to certain class has not been established yet, but the guideline on such classification will be prepared in the nearest future. Proper waste characterization at all stages of their management will also help to adress uncertainties related to waste inventory. As regards near-surface disposal facilities, generic waste inventory is used in the safety case to address this type of uncertainties.
4.3c How are disposal concept uncertainties managed?
There was performed the international project (INSC U4.01/09 B) on determination and justification of the optional potential concepts for the disposal of all Ukrainian radioactive waste. In this project, there are considered disposal options for all classes of waste. Generic safety assessment of potential disposal concepts was performed.
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
For near-surface disposal facilities, this type of uncertainties is addressed by development of a set of scenarios (normal evolution, enhance degradation, human intrusion, etc.) and different models describing these scenarios. Probabilistic sensitivity analysis is another way to address such uncertainties. For geological disposal facilities, this issue is not applicable at the moment.
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
Yes
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
Possible ways of addressing such uncertainties could be obtaining additional information and the possibility for retrievability of the waste.
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
Yes, but R&D can help to decrease not all kinds of uncertainties. The R&D to be performed could include researches on ageing properties of engineered barriers, climate changes, etc.
4.3f How are uncertainties in the understanding of key processes managed?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Not applicable at the moment for geological disposal, will be addressed at the later stages of safety case development.
***4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?**.*
Not applicable at the moment for geological disposal, will be addressed at the later stages of safety case development.
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
Not applicable at the moment for geological disposal, will be addressed at the later stages of safety case development. Analysis of FEPs is required by the regulations, but was not performed for geological disposal. At the same time, analysis of FEPs was included to the safety case for near-surface disposal facilities. Selection of FEPs to be included to different scenarios was justified.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
N/A
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
R&D activities, operational feedback, international experience.

Table A-18: VTT (Finland) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 14 September 2019 Part 4 – 26 September 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Suvi Karvonen and Erika Holt	
1.1b From which country and organisation are you?	
Finland, VTT	
1.1c Type of your organisation (WMO, TSO)?	
TSO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Management	
1.2b Please explain briefly your role in your organisation and your background.	
Erika Holt: Customer manager - nuclear and radwaste sector Suvi Karvonen: Research Team Leader of Nuclear Waste Management, Phycisist	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
Permanent disposal of all radioactive waste, both LILW repositories (2 operational since 1990s) and 1 HLW repository in construction. Planning of future VLLW (surface) repository. Operational deep geological repository in 2020's	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
HLW - phase 3 (construction). LILW phase 4 (operational)	
Part 4. Strategies for managing uncertainties	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***
National and international regulations (IAEA, Euratom,...) set the framework for safety requirements.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
No specific requirements.
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
Transparency and traceability, knowledgebase structure has to support uncertainty management.
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
Treatment of uncertainty must run in parallel with safety analysis program. The assessment should aim at demonstrating compliance of the concept with the existing safety criteria. Thorough uncertainty analysis on scenario uncertainty, (conceptual and numerical), model uncertainty, computer code uncertainty, parameter uncertainty and subjective decision making or expert opinion uncertainty; studies of the chemical impact of repository on the environment (heavy metals,…) is planned.
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).
Both deterministic and probabilistic tools can be used. Sensitivity analysis to identify critical parameters.
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
By regulation on safety assessment, safety case shall be the document, where key uncertainties are to be recorded.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
Yes, planned.
4.2f Other information that you would like to add:
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
This is WMO responsibility
4.3b How are uncertainties related to waste inventory managed?
This is described in detail in Posiva's safety case
4.3c How are disposal concept uncertainties managed?
A generic design of a DGR for a hypothetical site has been developed (and has been innovated) to identify bottle necks of the facility construction and operation.
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
N/A
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
No
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
While macroprocesses in a disposal system are relatively easy determined, described and studied, in such long intervals, the influence of microprocesses might be of significant impact. Thus, R&D focusing on the identification and assessment of microprocesses might contribute to decreasing uncertainties in the description of the very long term performance of a disposal system.
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is “yes”, what kind of research would be most appropriate?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3f How are uncertainties in the understanding of key processes managed?
Performing independent parallel assessment (different tools, different approaches)
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
N/A
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***

Table A-19: Consultant (Czech Republic) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 27 September 2019 Part 4 – 30 September 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Lumir Nachmilner	
1.1b From which country and organisation are you?	
Czech Republic, SURO	
1.1c Type of your organisation (WMO, TSO)?	
TSO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Consultant in RWM	
1.2b Please explain briefly your role in your organisation and your background.	
Advisor on radioactive waste management issues	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
3 near surface facilities in operation, DGR in the siting stage (currently 9 sites evaluated)	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
Phase 1	
Part 4. Strategies for managing uncertainties	
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Our nuclear legislation (based on Atomic Law) requires the assessment of radiological impacts of disposed of waste. Radiohyigenical limits are 250 µSv/yr for individual dose of reference person in the course of the repository lifetime and 20 mSv/yr for workers of the facility. Other criteria are set for outflows and emergency situations, by the regulation on radiation safety. The latest are site dependent and have to be set in the frame of licensing process. However, when waste contains also chemotoxic species, their impact shall also be assessed using adequate tools (based on the Environmental Law); this request is formulated in general terms only, without any further specification. Nuclear regulatory body (SONS) does not follow this issue, the assessment is subject to Ministry of Environment.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
For each regulatory decision a SA shall be performed using adequately available information: conceptual SA - planning, initial SA - site permit, preliminary SA - construction permit, preoperational - operational license, final - repository closure.In addition to these principal steps, SA has to be submitted as a justification document of nuclear facility (repository) conditions changes and/or proposed changes of the system affecting safety. These are usually proposed by repository operator.
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).
Our programme is in the initial stages of site investigation, the issue of uncertainties has not been of high relevance yet
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
Yes, planned.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.2f Other information that you would like to add:
4.3 Managing different types of uncertainty.   ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
Our safety case has not reached the level requiring uncertainty management
4.3b How are uncertainties related to waste inventory managed?
Systematic database of RW/SNF inventory is managed by the national WMO, a study aiming at the assessment of impact of uncertainties in inventories is underway (how precise must be our inventory?). The uncertainty should be assessed by means of sensitivity analyse related to expected dose.
4.3c How are disposal concept uncertainties managed?
Based on different disposal concepts-hard rock, sediments, deep borehole disposal, ...
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
Not yet planned in details.
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
Yes
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
4.3f How are uncertainties in the understanding of key processes managed?
Different conceptual models and system behaviour.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
No list of FEPs developed so far.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
By systematic implementing QMS principles (allocating responsibilities, defining processes, documentation, and control/supervision) the uncertainties could be minimised

Table A-20: BGE (Germany) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 28 October 2019 Part 4 – 28 October 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Astrid Göbel	
1.1b From which country and organisation are you?	
Germany, BGE mbH – Federal Company for Radioactive Waste Disposal	
1.1c Type of your organisation (WMO, TSO)?	
WMO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Management	
1.2b Please explain briefly your role in your organisation and your background.	
The Group Communication and Research is responsible for definition and coordination of the RD&D needs of the site selection process for a repository for HLW, communication on issues of the site selection process to different target groups, support of the implementation of a self-questioning and learning procedure and coordination of the committee work of the site selection department. I am head of the team performing the above described tasks. My background is geology and project management of disposal projects and research. Furthermore as LEAR and Project Coordination Contact I foster implementation of EURAD in the BGE. The BGE response is not restricted to a contribution from the department Site Selection Procedure but covers the view of all our disposal projects.	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
The following national radioactive waste disposal programmes are currently ongoing in Germany. - Site selection for a high-level radioactive waste repository in a deep geological formation. - Construction of the Konrad-repository for low and medium-level radioactive waste in a deep geological formation. The repository is expected to be ready for disposal in 2027. - Maintenance of the open ERAM-repository for low and medium-level radioactive waste as well as the planning of the safe and legal closure. The legal closure has already been applied for.	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
- Planning the retrieval of low- and medium-level radioactive waste from the Asse-Mine. Prior to retrieval of the radioactive waste, safety investigations, such as 3D seismic investigations, are applied. - Product control and certification of the casks for the low and medium-level radioactive waste to be disposed in the Konrad repository.
1.4 At what phase is/are the radioactive waste disposal programme(s)?
The site selection process for high-level radioactive waste is ongoing since autumn 2017 (Phase 1). Some ordinances, however, are still under discussion on the political level (Phase 0). The construction of the Konrad-repository for low and medium-level radioactive waste is underway (Phase 3). After disposal was stopped, the maintenance of the open ERAM-repository for low and medium-level radioactive waste and the plan approval procedure for licensing the closure is ongoing (Phase 4). The planning of the retrieval of low- and medium-level radioactive waste from the Asse-Mine includes safety investigations, such as 3D seismic investigations, to ensure a safe closure of the repository. (Phase 4).
Part 4. Strategies for managing uncertainties
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.***
The main requirements with regard to radioactivity are defined in the radiation protection regulations. In addition, federal water law rules toxic waste contents, and workers safety regulations determine the operation of a facility. The international recommendations from IAEA and ICRP as well as from the ESK (Entsorgungskommission) are also taken into account. For the actual step of the procedure of site selection according to the Regulatory Act (Stand AG) an assessment of areas based on available information without further exploration has to be developed. A strategy for this assessment is elaborated at present. The requirements for the preliminary safety analyses including the assessment of uncertainties are in the legislative process at present (EndlSiAnfV and EndlSiUntV). The development of a general strategy for managing uncertainties for the preliminary safety analyses in the site selection procedure will be pursued as soon as the Regulations for Safety Requirements for a repository for a high-level radioactive waste (EndlSiAnfV) and Regulations for the Preliminary Safety Analyses within the site selection procedure for a high-level radioactive waste repository (EndlSiUntV) will pass the Bundestag.
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
Safety assessments are the basis for issuing the licenses or underpinning the decision making process throughout site selection, facility construction, facility operation and closure and preparing the post-closure phase. All of the approaches mentioned above are used. For some uncertainties stylized approaches are applied.
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
For safety assessments several iteration cycles at the following different levels are needed: - generic level - conceptual level (preliminary) - the design level for licensing - revision to adopt the state of science and technology with respect to damage precaution and - finally, the compatibility level to assure that deviations (that will happen) do not affect repository safety
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).
Strategies to deal with uncertainties are: - Demonstration that the uncertainty is not relevant for repository safety - Treating the uncertainty in the safety assessment - Bounding the uncertainty by use of conservative values - Exclusion of uncertainties - Application of accepted stylized approaches
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
If of relevance, the impact of uncertainties on safety is evaluated continuously by safety assessment when new information is available, e.g, from testing of closure measures.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Uncertainties linked to the performance of closure measures will be reduced (or at least bounded) by in situ testing. Uncertainties in the geological barrier performance are narrowed down by (long-lasting) in situ measurements.
4.2f Other information that you would like to add:
4.3 Managing different types of uncertainty.   ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
Different approaches are used for different types of uncertainty. They are related to the site, phase and project organization. Concerning closure measure performance, experiments (esp. in-situ) support uncertainty reduction. Uncertainty about human intrusion is managed by investigating a few hypothetical scenarios. The demonstration of the robustness of the repository to a broad range of credible scenarios is another tool to manage remaining uncertainties.
4.3b How are uncertainties related to waste inventory managed?
4.3c How are disposal concept uncertainties managed?
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
Yes
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
The aspect of the long time frame and related increasing uncertainty is managed by investigating divers scenarios based on a comprehensive and systematical scenario evaluation. For distant future periods bounding simple coping calculations are performed.
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Uncertainties inherent to system are not omitted by additional research often they are transferred to different issues and new uncertainties arise. Uncertainties related to missing knowledge or lack of testing can be reduced in order to solve detailed questions. Furthermore information on geological barrier gained by site characterization due to exploration narrows down the bandwith of potential evolutions.
4.3f How are uncertainties in the understanding of key processes managed?
Uncertainties can be limited based on the results of research and testing on processes underlying barrier system performance and contaminant behaviour. Remaining uncertainties are managed through the implementation of different conceptual models of system behaviour or by addressing bandwidths to parameter values. One way is to take into account different understandings by implementing all of them in a model and use all of them for the calculation of safety functions. If different understandings lead to the same safety level, than the system assessment can be seen as robust. The strategy for the management of uncertainties with regard to the understanding of key processes in the site selection process is yet to be developed.
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
Procedures for recording and managing uncertainties associated with the data acquired and ensuring that they are propagated through to the safety assessment include bounding analyses and methods for representing acquired data in detailed system models and deriving parameter value distributions for safety assessment models based on the outputs of the detailed models.
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
The comprehensiveness of the site specific FEP list is evaluated by comparing the FEP list with FEP lists of other disposal programmes and the FEP data based provided by OECD/NEA. Each FEP of the list is assigned to a class of probability. The information about each FEP is documented in a comprehensive and traceable manner.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.
A way of dealing with evolutions of uncertainties is to establish flexibility measures in the development of safety cases or procedures. This idea is to some extent introduced in the StandAG (self-learning procedure). We are still in a discussion phase. One idea could be to make use of the Bayesian statistics, as a flexible approach which is acknowledging the state of few data, profound expert knowledge exceeding the data quality and prospective of gaining further data/information. This could be emphasized in order to deal with evolutions. The use of this approach should also be communicated to the public. Regarding existing repository facilities the impact of the uncertainties is evaluated by sensitivity analyses and probabilistic calculations, e.g. using probability density functions to describe the uncertainties. From the communication point of view it is important to have a network of citizen experts with whom there is a steady dialogue about all issues concerning the waste disposal programmes.

Table A-21: Andra (France) responses to UMAN Questionnaire Parts 1 and 4, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 13 September 2019 Part 4 –
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
DUMONT Jean-Noël	
1.1b From which country and organisation are you?	
France, Andra	
1.1c Type of your organisation (WMO, TSO)?	
WMO	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Management, Memory preservation	
1.2b Please explain briefly your role in your organisation and your background.	
Coordinator of the Memory programme for future generations and in charge of societal aspects in waste management strategies. Technical background	
1.3 What is the mission of your national radioactive waste disposal programme(s)?	
Manage all the French radioactive wastes, of all kinds: monitor and maintain the near-surface Manche repository (in closure phase), operate near-surface repositories in Aube department, design and study repositories for HLW and LL-IntemediateLevelW, and LL-LowLevelW.	
1.4 At what phase is/are the radioactive waste disposal programme(s)?	
HLW and LL-IW: phase 2; LL-LowLevelW: phases 0 and 1; VeryLowLevelWaste: phases 2 and 4; other waste (near surface repositories Manche and Aube): phase 4	
Part 4. Strategies for managing uncertainties	
4.1 Regulatory basis: What are the principal regulatory compliance requirements for demonstrating the safety of the disposal facility and are requirements or guidance provided with regard to the management of uncertainties? ***4.1a Provide information on the criteria that need to be met in order to demonstrate safety during disposal operations and after disposal facility closure. This may include consideration***	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
of radiological impacts and the impacts of chemotoxic species in the wastes on humans and non-human biota.
Radiological impacts: - as low as possible in operation (ALARA), maximum levels as defined by ICRP. - below 0,25 mSv in long term normal evolution scenario for a DGR. - low as compared to levels of radiation that provide deterministic health effects, in long term degraded scenarios
4.1b Identify any specific requirements or guidance pertaining to how uncertainties should be managed.
Uncertainties on the natural and human post-closure events are managed through the use of scenarios, agreed with the regulator.
4.2 Safety assessment strategy: What is the strategy for managing uncertainties in safety assessments? Provide a high-level summary of the safety assessment strategy, focusing on the approach to managing uncertainties including their reduction and mitigation. This should include information on: ***4.2a When safety assessments are expected to be produced in the disposal facility implementation programme.***
Various levels of safety assessments are produced throughout the programme: - in phase 0, preliminary assessment in order to identify a roadmap; - in phase 1, new version enriched in order to show feasibility; - in phase 2, new version for the license application for construction, - in phase 3, new version for the license application for emplacing the first WP, then revised every 10 years, and before the license application for final closure. - in phase 4, revised versions of the safety case would be made every 10 years, as long as the repository is considered as a basic nuclear facility.
4.2b The different steps of the uncertainty management strategy (e.g. identification, analysis, treatment,…).
Establishing several successive safety assessments, as described above, is a stepwise uncertainty management strategy. Sensitivity studies, in order to explore the robustness of the necessary assumptions. Definition of an operation domain smaller than the authorized domain, so that most of the outings out of the operation domain stay within the authorized domain, while being registered and providing feedback for improvement of the waste management process.
4.2c The high-level approaches for treating uncertainties in the safety assessment (deterministic and/or probabilistic approaches, use of different scenarios, use of alternative lines of reasoning, such as natural or anthropogenic analogue evidence,…).

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Andra's approach is mostly based on deterministic approach, applied to scenarios, models and input data. No probability of scenario or situation is established, and uncertainty and sensitivity analysis is carried out on components (including host rock) on which safety functions are expected and which play a major role in performance and safety case. Deterministic approach is based on several mono or multi-parametric assessments, including reference case (best-estimate). Sources of uncertainties are defined with epistemic and stochastic part. Deterministic approach is completed by probabilistic multi-parametric sensitivity analysis, on input data, in order to fulfil 2 main objectives: (i) uncertainty analysis, with quantification of the domain of PA/SA indicators and which aims to quantify safety margins (ii) sensitivity analysis , which aims to establish a list of relevant input data which drive the results and give a feed-back on R&D in terms of priority to study. Probabilistic multi-parametric sensitivity analysis is carried out by global approach, on whole distribution. When the problem is likely to be complex, the global approach is completed by a local approach, using automatic differentiation (non-intrusive method) or adjoint state (intrusive method). If there is neither linearity nor monotony between results and input data, ANOVA methods have to be used (Variance-based sensitivity analysis referring to Sobol indices). This method requiring a very big number of simulations, it is necessary to set up an accurate surrogate model (such as neural network).
4.2d The procedures for recording key uncertainties identified through safety assessments and initiating research and development, design or other activities (e.g. site characterisation, site selection,…) aimed at reducing, avoiding or mitigating those uncertainties.
The procedure for recording key uncertainties has been presented above. When the list of key data has been established thanks to sensitivity analysis, then feedback to Research and Development is done and some priorities are set up, such as developing new experiments or doing more measurements, with new sensors or new samples.
4.2e The procedures for managing the outcomes of activities aimed at reducing and mitigating uncertainties such that they inform iterative safety assessments through progressive updates to the treatment of uncertainty.
Up-dating safety assessment is performed each 4 or 5 years with new design, up-dated scenarios and new assumptions and data with reduced uncertainties derived from previous analysis. This leads to more and more robust assessment.
4.2f Other information that you would like to add:
4.3 Managing different types of uncertainty. ***4.3a How are uncertainties in the implementation of the disposal facility programme managed?***
The safety case (post closure) is based on a reference waste inventory. If the programme goes normally to its completion, it does not depend, or very weakly, on the uncertainties in the schedule and other socio-economic uncertainties during the construction, operation and closure phases. In order to manage such uncertainties, a work is done at national level in the waste management plan about the needs of storage for waste taken into consideration the schedule delay for example.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3b How are uncertainties related to waste inventory managed?
Provide high level information on how these uncertainties are managed (uncertainties in the volumes, activities, physico-chemical properties,…). This may involve consideration of different inventory scenarios, based on different assumptions about waste (re-)processing (i.e. waste pre-treatment, treatment and conditioning options), disposal routes, future energy policy and reactor operation schedules. Also, provide information on how these uncertainties are recorded and on how they are captured in safety cases. For the Cigeo project (DGR), the design studies of the repository are based on a reference waste inventory, but complementary studies, called adaptability studies, take into account the possibility that other types and quantities of wastes might be sent to the repository. Regarding the evolution of the operation of treatment and conditioning of waste, initially radionuclides and chemical content of the waste are taken into account in the safety case. Then, when the safety case is reviewed, the characteristics of the conditioned waste are used.
4.3c How are disposal concept uncertainties managed?
Uncertainties in the disposal concept to be implemented may be substantial early in the disposal facility implementation programme. Provide information on how such uncertainties are managed. Prior to site selection and characterisation, this may be through generic safety assessments based on consideration of disposal concepts appropriate to different types of near-surface or geological environment. For Cigeo, before the decision was made for the clay rock formation studied at the Bure URL, an alternative option in granite was also considered. Feasibility studies were based on generic properties of granite.
4.3d How are uncertainties in disposal system properties and conditions at the time of facility closure and in the long term after closure managed?
Describe, at a high level, how uncertainties in the properties of the barrier system and in the conditions prevailing in the system (temperature, saturation,…) at the time of facility closure and in the long term after closure are managed (including the types of methods that are used to avoid, mitigate or reduce these uncertainties). For example: (1) uncertainties in parameter values may be captured in parameter value distributions for use in probabilistic assessments (2) uncertainties in barrier performance may be captured by defining different scenarios of disposal system evolution based on different assumptions about how the barriers provide safety functions when subject to the effects of uncertain events or processes (3) analysis of potential material quality control or barrier emplacement errors may be used to define alternative disposal system evolution scenarios based on different assumptions about conditions at the time of facility closure (4) uncertainties in conditions in the very long term (hundreds of thousands of years or more) may be treated by defining different scenarios of disposal system evolution (such as associated with different assumptions about climate change and its impacts or seismic events) and assessing those scenarios deterministically (5) uncertainties in disposal system performance may be managed through decisions about backfilling and closure options and schedules (e.g., backfilling and sealing may be implemented or scheduled in a way that optimises reversibility or waste retrievability) (6) in some cases, research and experiments may support uncertainty reduction, but uncertainty reduction may be challenging when considering very long-term evolution or human intrusion.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Once all kinds of uncertainties are defined in compliance with level of scientific and technical knowledge, they are used, at each step of development of Cigeo project, to set up (i) the relevant deterministic safety choice with a “cautious but reasonable” approach, considering safety margins (ii) the relevant choice to be used in design, considering design margins, (iii) the uncertainty and sensitivity analysis to identify the input data which drive the domain of evolution, which have to be specified (priorities of R&D).
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
Yes, for sub-surface repositories No for deep geological repositories
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
For low level long-lived wastes, the amount of effort to be dedicated to long term protection is a political decision, that should take into account ethical considerations of inter-generational and intra-generational justice. This should be prepared by a large consultation of the civil society.
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is “yes”, what kind of research would be most appropriate?
Yes, research on the effects of low doses on human and non-human biota and research on ethics and governance (how can we resolve ethical dilemmas).
4.3f How are uncertainties in the understanding of key processes managed?
The results of research on processes underlying barrier system performance and contaminant behaviour may be interpreted in different ways such as to lead to different understanding of processes at a conceptual level. Provide information on how such uncertainties are managed, such as through the implementation of different conceptual models of system behaviour. Uncertainties both from models and input data are used in sensitivity analysis to identify key models and input data that explain the range of evolution of THMC indicators.
4.3g How are uncertainties in data managed and abstracted for use in the safety assessment?
Large amounts of data on disposal system performance and contaminant behaviour will be acquired through the research and development activities that support the disposal facility implementation programme, as well as through waste characterisation, site characterisation, site selection and disposal system design, construction and monitoring. Describe procedures for recording and managing uncertainties associated with the data acquired through these activities and ensuring that they are propagated through to the safety assessment (e.g. through abstracted parameter value distributions). This may include bounding analyses or methods for representing acquired data in detailed system models and deriving parameter value distributions for safety assessment models based on the outputs of the detailed models.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Quantification of uncertainties is managed by using a rigorous process of treatment of sound scientific knowledge database, mainly derived from experiments (URL, surface labs) and surveys on clay layer. Treatment of scientific from the “basic” measured data to “integrated” one used for up-scaled numerical simulation. Depending on quality of measurements (example of measurement by pulse-test versus steady state experiment), some data could be affected more “weight”. When the number of data is sufficient, a statistic treatment is done to establish a probabilistic density function. As many data come from URL, uncertainty is thus mainly considered as epistemic. To treat a possible natural variability of some data (stochastic uncertainty), geo-statistical treatment is done, using interpretation of 3D seismic and local boreholes surveys. All the information from data and uncertainties derived from THMC processes from natural and disposal materials are available in specific reports. One is dedicated to summarizing all phenomenological data and their uncertainties, with the degree of confidence in the data. Safety reports contain safety choices, in terms of models and input data.
4.3h How are uncertainties in the completeness of the features, events and processes and scenarios considered in the safety case managed?
Lists of potentially safety-relevant features, events and processes (FEP) are commonly used when designing and assessing the safety of disposal facilities. Describe procedures for managing uncertainties associated with the completeness of such lists as well as of considered scenarios. For example, it may not be possible to determine with certainty whether a FEP should be included in a safety case or how a FEP should be treated in the early phases of the disposal programme. How are uncertainties associated with such decisions recorded and managed? In France, designing disposal facilities and assessing their safety is based on guidance from the regulator, namely: safety guides, stepwise safety assessment files examined by the regulator and its TSO, leading to recommendations and requests.
4.3i If some of the key uncertainties you have identified in question 3.1 (see Part 3 of the questionnaire) are not covered by questions 4.3 a) to h), please explain how these key uncertainties are managed in the safety case.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. “as-built” properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***

A.3 RE Responses to UMAN Questionnaire (Part 1 and Questions 4.3e and 3.2b)

The RE respondents to Part 1, Question 4.3e and Question 3.2b of the UMAN questionnaire are listed in Table A-22. The responses are provided in Table A-23 to Table A-32, as indicated in Table A-22.

Table A-22: RE respondents to UMAN Questionnaire Part 1, Question 4.3e, and Question 3.2b.

Organisation	**Country**	**Table No.**
EnviroCase	Finland	Table A-23
CNRS	France	Table A-24
GRS	Germany	Table A-25
HZDR	Germany	Table A-26
Institute for Nuclear Research (RATEN ICN)	Romania	Table A-27
Institute of Nuclear Chemistry and Technology	Poland	Table A-28
IST-ID	Portugal	Table A-29
LEI	Lithuania	Table A-30
Paul Scherrer Institut	Switzerland	Table A-31
SCK-CEN	Belgium	Table A-32

Table A-23: EnviroCase (Finland) responses to UMAN Questionnaire Part 1, Question 4.3e, and Question 3.2b.

<table>
<tr><td colspan="2">EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)</td></tr>
<tr><td>Date:</td><td>Part 1 – 1 October 2019
Part 4 – 1 October 2019</td></tr>
<tr><td colspan="2">Part 1. Background information</td></tr>
<tr><td colspan="2">1.1 Name, country and organisation
1.1a Name and surname:</td></tr>
<tr><td colspan="2">Ari Ikonen</td></tr>
<tr><td colspan="2">1.1b From which country and organisation are you?</td></tr>
<tr><td colspan="2">Finland, EnviroCase Ltd.</td></tr>
<tr><td colspan="2">1.1c Type of your organisation (WMO, TSO)?</td></tr>
<tr><td colspan="2">Private consultant to industry, mainly (also to regulator in some other countries)</td></tr>
<tr><td colspan="2">1.2 What is your background and role in your organisation?
1.2a Please select your field(s) of work:</td></tr>
<tr><td colspan="2">Safety assessment</td></tr>
<tr><td colspan="2">1.2b Please explain briefly your role in your organisation and your background.</td></tr>
<tr><td colspan="2">Earlier leading the biosphere characterisation and assessment for spent nuclear fuel disposal (crystalline bedrock) and a key contributor to planning and development of the overall safety case. Currently a consultant to the same, with a scope expanding also to other waste and disposal facility types also at other sites and countries (also supporting IAEA Member States in general and in some other countries delivering consultant services to regulators (but not to implementers, then)).</td></tr>
<tr><td colspan="2">Part 4. Strategies for managing uncertainties (Only 3 questions)</td></tr>
<tr><td colspan="2">4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?</td></tr>
<tr><td colspan="2">Yes</td></tr>
<tr><td colspan="2">4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?</td></tr>
</table>

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Bounding analyses, natural analogues, increasing uncertainty with time vs. decrease in radiotoxicity, overall robustness of disposal system, small releases in any plausible conditions and somewhat beyond (thoroughness of scenario analysis), physiological bounds to exposure (both people and biota) preferably connected to the geophysical and hydrological realism of accumulation/dilution vs. exposure, comparisons of orders of magnitude to something understandable to the general public (everyday reference) even if not 100% appropriate in strictly scientific/technical terms, comparison to other risks (NB. difference between involuntary and taken risks), comparison between disposal options ("anyway better than leave it lying around", i.e. what other risks are avoided), retrievability as the last resort, openness regarding the options and their pros/cons and trusting that most people would see the reasonable choice if given sufficient, understandable information
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
Yes, but only to an extent; the foci and resolution should be adjusted with the time frame (ability to constrain plausible alternative futures): the longer the time span, the more quantitative the reasoning can (and must) be since any details would go increasingly wrong out to the future; however, there are some physical bounds to what can happen even in the biological world (fundamentally, thermodynamics...) -- the longer the time span, the more back to the basics (framework) and the lesser with detailed application (numbers); for a much shorter time span, plausible demonstration (monitoring) connected to the option of retrievability can be helpful, but people should not be promised too much; after all, the public acceptance is about being convincing and trustworthy enough, and thus particularly the discussion about the uncertainties and alternatives needs to be systematic, presentable in plain language, transparent, and appreciate diversity in opinion and knowledge basis of stakeholders
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***

Table A-24: CNRS (France) responses to UMAN Questionnaire Part 1, Question 4.3e, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 2 September 2019 Part 4 – 2 September 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Bernd Grambow	
1.1b From which country and organisation are you?	
CNRS, France	
1.1c Type of your organisation (WMO, TSO)?	
RE	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Research on safety-relevant processes or on the performance of individual barriers of a disposal facility	
1.2b Please explain briefly your role in your organisation and your background.	
Scientist in nuclear waste disposal research	
Part 4. Strategies for managing uncertainties (Only 3 questions)	
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?	
Yes	
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?	
additional qualitative information from natural analogues would be useful. Reversibility will not reduce uncertainty for 100000 yr frames, Comparative assessments of alternatives may be useful: disposal against long term interim storage.	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
Yes, for example by research on natural analogues, by clearer distinction between understanding of governing processes from bounding analyses replacing missing or uncertain knowledge by highly certain conservative choices, by foundation of as much as possible hypothesis in process understanding on solid time independent scientific bases like thermodynamics
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***

Table A-25: GRS (Germany) responses to UMAN Questionnaire Part 1, Question 4.3e, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 30 September 2019 Part 4 – 2 October 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Dirk-Alexander Becker	
1.1b From which country and organisation are you?	
GRS, Germany	
1.1c Type of your organisation (WMO, TSO)?	
RE	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Safety assessment	
1.2b Please explain briefly your role in your organisation and your background.	
Senior Scientist, education: physics. Chief expert for statistical methods.	
Part 4. Strategies for managing uncertainties (Only 3 questions)	
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?	
No	
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?	
The reversibility of decision concerning final disposal could be a solution, as well as possible retrievability of the waste. Preservation of knowledge and records is necessary.	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
This is a solution. Research on disposal technologies, predisposal processes, monitoring techniques, as well as development of apropriate apparatus for that and software. R&D on partitioning of actinides and new reactor technologies.
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
Identification of the Overall relevance of increased uncertainties by sensitivity Analysis. If significant Impact on safety, increase of Research.

Table A-26: HZDR (Germany) responses to UMAN Questionnaire Part 1, Question 4.3e, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 30 September 2019 Part 4 – 30 September 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Brendler, Vinzenz	
1.1b From which country and organisation are you?	
Germany, HZDR	
1.1c Type of your organisation (WMO, TSO)?	
RE	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, (Radio/Geo)chemistry, databases, modelling, numerics	
1.2b Please explain briefly your role in your organisation and your background.	
Head of Department "Surface processes", partly administrative, partly researching	
Part 4. Strategies for managing uncertainties (Only 3 questions)	
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?	
Yes	
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?	
The long time scales make any prognostics about developments in climate very difficult. It is even worse with respect to societal developments - will mankind survive the next few hundred years at all ?? It would be more honest to just reduce the time frame to a useful span. If climate kills us in the next few hundred years why bother about nuclear waste disposal after hundred thousand years?	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
more R&D will not solve that rather political/societal dilemma
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties.   ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
Strategies to overcome such problems are very diverse. They stretch from a "Do nothing" option (ignore the respective process as it may hopefully not be essential and the harm of ignoring may be smaller than using some estimates not really defensible) over the famous "Expert guess" which can be anything between pure assumptions and the application of well established informal rules, further on to "Estimates" stemming from pure correlations in the sense of empirical fits, over chemical analogues, the usage of structure-based incremental systems, linear free energy relationships, or quantum chemical approximations (to name just the most prominent examples), to the "Re-computation" of parameters from other (hopefully similar) models (e.g. going from the Pitzer-approach to SIT parameters and vice versa – this direction being the more challenging one), the "Re-fitting" of a pool of already existing raw data and – finally – the hard way of setting up an experimental program to derive the parameters in the lab.

Table A-27: Institute for Nuclear Research (RATEN ICN) (Rumania) responses to UMAN Questionnaire Part 1, Question 4.3e, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 1 October 2019 Part 4 – 2 October 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Crina Bucur and Daniela Diaconu	
1.1b From which country and organisation are you?	
Romania, Institute for Nuclear Research Pitesti	
1.1c Type of your organisation (WMO, TSO)?	
RE, waste generator	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Crina Bucur: Research on safety-relevant processes or on the performance of individual barriers of a disposal facility Daniela Diaconu: Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Management	
1.2b Please explain briefly your role in your organisation and your background.	
Crina Bucur: Responsible on RATEN R&D programme on Radioactive Waste and Spent Fuel management. Experience on experimental measurements of radionuclide transport parameters in different materials component of natural and engineered barriers of a disposal facility, as well as in performance assessment for LIL waste disposal. I was involved and coordinated the experimental work performed by RATEN ICN under EU-funded research projects CARBOWASTE, FORGE, CAST, and CEBAMA. I'm currently coordinating for RATEN the CHANCE (acting as Task leader for Task 2.1) and EURAD projects and is one of EURAD Bureau member as representative of RE. Daniela Diaconu: Role in RATEN: senior researcher; Responsible for Saligny site characterisation (until 2008); International Cooperation Program Manager; Background: Physicist; PhD in Condensed Matter Physics; currently: activities in the radioactive waste field: site charactierisation, performance and safety assessment for LIL - SL waste disposal; performance assessment for conceptual geological disposal of spent fuel and ILW - LL in granite and clay.	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Part 4. Strategies for managing uncertainties (Only 3 questions)
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
Daniela Diaconu: Yes
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
Daniela Diaconu: For the general public, leaving a "door open" (reversibility or retrievability) could help in gaining a more favorable attitude, but not necessary certainty in the statements on long term. Continuous improvement of the models used in safety analysis and use of different natural analogues for codes validation could in my view to increase the confidence in these statements. increase the confidence in the results/predictions of the models improving them continuously; use different natural analogues for codes validation;
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
Daniela Diaconu: Yes. time evolution of the disposal system components; numerical modeling of coupled processes
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
Daniela Diaconu: assessment at each stage the uncertainty and adequately address them in the safety case

Table A-28: Institute of Nuclear Chemistry and Technology (Poland) responses to UMAN Questionnaire Part 1, Question 4.3e, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 1 October 2019 Part 4 – 3 October 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Katarzyna Kiegiel and Grazyna Zakrzewska-Kołtuniewicz	
1.1b From which country and organisation are you?	
Poland, Institute of Nuclear Chemistry and Technology	
1.1c Type of your organisation (WMO, TSO)?	
Katarzyna Kiegiel: Scientific Institute Grazyna Zakrzewska-Kołtuniewicz: RE	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Katarzyna Kiegiel: Research on safety-relevant processes or on the performance of individual barriers of a disposal facility Grazyna Zakrzewska-Kołtuniewicz: Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Management	
1.2b Please explain briefly your role in your organisation and your background.	
Katarzyna Kiegiel: The senior scientist that is participated in the implementation of the Polish Nuclear Power Program in Poland. The Program outlines the scope and structure of activities which must be taken in order to implement nuclear power, decommissioning of nuclear facilities after the end of operation and develop safe procedures of management of spent nuclear fuel and radioactive waste. In the INCT (Institute of Nuclear Chemistry and Technology) are carried out works on waste disposal, particularly those involving highly radioactive wastes. Grazyna Zakrzewska-Kołtuniewicz: Head of Department, Chemical engineering, Professor in Chemistry	
Part 4. Strategies for managing uncertainties (Only 3 questions)	
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?	
Grazyna Zakrzewska-Kołtuniewicz: Yes	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
Grazyna Zakrzewska-Kołtuniewicz: qualified staff tracking all news and available literature on the subject, industry and science cooperation, international cooperation; adequate financing enabling rapid implementation of new control and measurement systems, new characterization techniques.

Table A-29: IST-ID (Portugal) responses to UMAN Questionnaire Part 1, Question 4.3e, and Question 3.2b.

<table>
<tr><td colspan="2">EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)</td></tr>
<tr><td>Date:</td><td>Part 1 – 30 September 2019
Part 4 – 1 October 2019</td></tr>
<tr><td colspan="2">Part 1. Background information</td></tr>
<tr><td colspan="2">1.1 Name, country and organisation
1.1a Name and surname:</td></tr>
<tr><td colspan="2">PAIVA</td></tr>
<tr><td colspan="2">1.1b From which country and organisation are you?</td></tr>
<tr><td colspan="2">IST-ID, Portugal</td></tr>
<tr><td colspan="2">1.1c Type of your organisation (WMO, TSO)?</td></tr>
<tr><td colspan="2">RE</td></tr>
<tr><td colspan="2">1.2 What is your background and role in your organisation?
1.2a Please select your field(s) of work:</td></tr>
<tr><td colspan="2">Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Safety assessment, Management, Public acceptance and social implications of radwaste decisions</td></tr>
<tr><td colspan="2">1.2b Please explain briefly your role in your organisation and your background.</td></tr>
<tr><td colspan="2">More than 25 years expertise in radwaste management, technologies and policies as a WMO, TSO and Researcher; Co-responsible for waste management group until 2012, Expertise in different radwaste treatment technologies; national representation in WG's (AQG, WASSC, Joint Convention, ART. 37º/EURATOM, OSPAR), Responsible and member for R&D projects on radwaste strategies in Portugal (KADRWaste) E&T (ENEN/PETRUS), emergencies and social acceptance (PREPARE/CONFIDENCE). Participation in IAEA projects (RER9143). Full researcher at the Centre for Nuclear Sciences and Technologies (C2TN) of the IST-ID (technical university).</td></tr>
<tr><td colspan="2">Part 4. Strategies for managing uncertainties (Only 3 questions)</td></tr>
<tr><td colspan="2">4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?</td></tr>
<tr><td colspan="2">Yes</td></tr>
<tr><td colspan="2">4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?</td></tr>
</table>

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Retrievability of waste
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
Fundamental and applied studies in radionuclide migration in new materials and more robust safety assessment for a wider ensemble of different conditions
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***

Table A-30: LEI (Lithuania) responses to UMAN Questionnaire Part 1, Question 4.3e, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 3 October 2019 Part 4 – 3 October 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Gintautas Poškas	
1.1b From which country and organisation are you?	
Lithuania LEI	
1.1c Type of your organisation (WMO, TSO)?	
RE	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Safety assessment	
1.2b Please explain briefly your role in your organisation and your background.	
Senior researcher. Radwaste management safety.	
Part 4. Strategies for managing uncertainties (Only 3 questions)	
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?	
No	
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?	
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***

Table A-31: Paul Scherrer Institute (Switzerland) responses to UMAN Questionnaire Part 1, Question 4.3e, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 24 September 2019 Part 4 – 29 September 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Wilfried Pfingsten	
1.1b From which country and organisation are you?	
Paul Scherrer Institut	
1.1c Type of your organisation (WMO, TSO)?	
RE and research waste generator	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Safety assessment, Management	
1.2b Please explain briefly your role in your organisation and your background.	
Senior Scientist	
Part 4. Strategies for managing uncertainties (Only 3 questions)	
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?	
No	
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?	
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
Retrievability is included in the concept...

Table A-32: SCK-CEN (Belgium) responses to UMAN Questionnaire Part 1, Question 4.3e, and Question 3.2b.

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)	
Date:	Part 1 – 13, 26 and 27 September 2019 Part 4 – 26, 27 and 28 September 2019
Part 1. Background information	
1.1 Name, country and organisation ***1.1a Name and surname:***	
Sven Boden, Weetjens Eef and An Bielen	
1.1b From which country and organisation are you?	
Belgium, SCK-CEN	
1.1c Type of your organisation (WMO, TSO)?	
RE	
1.2 What is your background and role in your organisation? ***1.2a Please select your field(s) of work:***	
Sven Boden: Decommissioning Weetjens Eef: Research on safety-relevant processes or on the performance of individual barriers of a disposal facility, Safety assessment An Bielen: I'm involved in the management of radioactive waste and liabilities	
1.2b Please explain briefly your role in your organisation and your background.	
Sven Boden: Responsible for all radiological characterization aspects for decommissioning activities Weetjens Eef: Scientific collaborator An Bielen: I obtained a PhD in Biological Science, after which I joined the SCK•CEN in 2015 as a scientific collaborator in the department Management of Waste and Liabilities. We are working on a method to determine uncertainties which are related to radiological characterization of the nuclear waste of SCK•CEN. Uncertainties of the measurements itself need to be taken into account, as well as the correlation factors included in the isotopic vector need to be evaluated. The uncertainties (measurement, isotopic vector,..) might have an important effect in determining the level of activity in waste packages, and in the acceptance of waste for disposal. Furthermore, I'm involved in the management and follow-up of nuclear liquid waste streams. I also study and digitize all available data concerning characterisation which can lead to new characterisation methodologies.	

EURAD - UMAN Questionnaire: Part 1 (background information) and Part 4 (generic strategies for managing uncertainties)
Part 4. Strategies for managing uncertainties (Only 3 questions)
4.3e Do you think that the timeframes of hundreds of thousands of years involved in geological disposal could make any statement on the long term highly uncertain?
Sven Boden: Yes Weetjens Eef: No An Bielen: No
4.3e-1 If you answered yes to question e): how do you think this problem should be addressed? Would it be possible to gain certainty with additional information or by implementing another approach? In this latter case, which one (reversibility of decision process, retrievability of the waste, etc.)?
Sven Boden: A certain level of retrievability might always be considered.
4.3e-2 If you answered yes to question e): do you think that by increasing R&D one can decrease the encountered uncertainties? If your answer is "yes", what kind of research would be most appropriate?
Sven Boden: No
Part 3. Views on the types of uncertainties that need to be addressed in safety cases and their possible evolution throughout the programme phases
3.2: Some uncertainties will decrease as new information becomes available (e.g. "as-built" properties, monitoring data, RD&D results,…) whereas activities associated with the programme (process modelling, safety assessment,…) can also lead to new viewpoints and sometimes new uncertainties. ***3.2b Do you identify measures that can be taken to deal with these possible evolutions? If yes, please explain briefly what these measures are.***
Weetjens Eef: secured long term funding, long term political consensus, knowledge management An Bielen: Funding, knowledge management