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Scenario Development Workshop Synopsis

Integration Group for the Safety Case

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Radioactive Waste Management Committee

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Integration Group for the Safety Case

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Foreword

Scenario development and selection describes the collection and organisation of the scientific and technical information relevant to the potential paths of evolution of a radioactive waste disposal facility (repository) that is necessary to assess its long-term performance and safety. In 1999, the NEA held its first workshop on scenario development in Madrid, Spain, with the objective to review the methods for developing scenarios in safety assessments and their application. Results of the 1999 workshop are documented in a Nuclear Energy Agency report (NEA 2001). Since then, the process of scenario development and analysis for the disposal of radioactive waste has changed and, in 2015, the NEA Integration Group for the Safety Case (IGSC) held a second workshop on this topic at its offices in Paris to further evaluate the experience acquired in developing scenarios since 1999. To prepare for this workshop, the IGSC also launched a survey in 2014 to gather the latest scenario development and uncertainty management strategies used in IGSC member countries.

The purposes of the workshop were to (i) provide a forum to review and discuss methods for scenario development and their contribution to the development of recent safety cases (since the 1999 workshop); (ii) examine the latest methods and compare their scope, consistency and function within the overall safety assessment process, based on practical experience of applications; and (iii) provide a basis for producing the present report summarising the current status of scenario methodologies, identifying where sufficient methods exist and any outstanding problem areas.

This synopsis was drafted by Paul Smith (Safety Assessment Management (Switzerland, GmbH), finalised under the direction of the Workshop Chair (Sylvie Voinis) and Gloria Kwong of the NEA. It was then approved by the Programme Committee and the workshop participants.

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- Ross Kirkes: Sandia National Laboratories, USA
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1. Introduction

This report provides an overview of the state of the art in scenario development related to the long-term safety of geological repositories for radioactive waste. In particular, it discusses how potential scenarios are developed in safety assessments of radioactive waste that contains long-lived radionuclides. Safety assessment is the process of quantitatively and qualitatively evaluating the safety of a repository, often in support of a safety case that also includes a broad range of evidence and arguments that complement and support the reliability of the results of the quantitative analyses (NEA 2013a). Assessments typically describe and evaluate repository evolution and potential radiological and other consequences for a range of scenarios. Some definitions of the term “scenario” are given in Box 1.

Box 1: Definitions of the term “scenario”

IAEA Glossary (IAEA 2007):

Scenario is defined as "a postulated or assumed set of conditions and/or events. Most commonly used in analysis or assessment to represent possible future conditions and/or events to be modelled, such as possible accidents at a nuclear facility, or the possible future evolution of a repository and its surroundings. A scenario may represent the conditions at a single point in time or a single event, or a time history of conditions and/or events (including processes)."

NEA Post Closure Safety Case (NEA 2013a):

A “scenario” is understood as a simplified description of a potential evolution of the repository system from a given initial state. Scenarios are a fundamental basis for the assessment of post closure safety which includes assessing the potential consequences on humans and the environment.

Scenarios arise from uncertainties caused, for example, by the randomness or unpredictability of certain events, the natural variability of geological media and the biosphere, incomplete characterisation of features and processes and the couplings between them and the limited possibility to forecast distant-future biospheres and human habits. Taken together, such uncertainties imply a broad range of possible evolutions of a disposal system, or scenarios, over the very long timescales considered in safety assessments. The development of an adequate set of scenarios for safety assessment is of fundamental importance as it constitutes a key element of the safety case, providing a fundamental basis for the assessment of post-closure safety and for the management of uncertainties in repository programmes.

Identifying the scenarios that should be included in safety assessments is not, however, a trivial matter and the NEA has for many years both facilitated and contributed to discussions on this issue. In 1999, the NEA organised a workshop on scenario development in Madrid, Spain, to review scenario development methodologies and their applications (NEA 2001). Scenario development approaches have, however, evolved considerably since this workshop. In the intervening years, numerous national studies have been carried out, safety cases have been compiled and reviewed, international guidance has been produced and international post-closure safety case projects undertaken.

In view of these developments, the NEA held a second workshop at its offices in Issy-les-Moulineaux, Paris from 1-3 June 2015, the objectives of which were:

- to provide a forum to review and discuss methods for scenario development and their contribution to the development of recent safety cases (since the 1999 workshop);
- to share experiences and examine the latest methods and compare their scope, consistency and function within the overall safety assessment process, based on practical experience of applications; and
- to provide a basis for producing the present report summarising the current status of scenario methodologies, identifying where sufficient methods exist and any outstanding problem areas.

The workshop (see workshop programme as presented in Appendix A) included oral presentations describing the work of national implementing and regulatory bodies and also initiatives by international organisations (Appendices B and C). The workshop also included working group discussions addressing the following topics:

- perspectives on regulatory requirements;
- scenario development (approaches); and
- completeness, comprehensiveness and sufficiency.

In preparation for the workshop, the NEA circulated a questionnaire (Appendix D) to various organisations asking for information on the current state of scenario development within their organisation, as well as changes in associated practices and relevant regulations since 1999. Seventeen organisations representing eleven national programmes responded to the questionnaire, including three joint responses (Table 1). The questionnaire and responses are reproduced in Appendices D and E, respectively. A review of the questionnaire responses is given in Appendix E. The results of working group discussions are given in Appendix F.

The present report is based largely on the presentations and discussions at the workshop, including the working group sessions, and on a review of the questionnaire responses. It is structured as follows:

- Chapter 2 summarises the work of the NEA and other international organisations on scenario development and related topics.

- Chapter 3 discusses regulatory perspectives on scenario development, including general regulatory principles, more specific guidance, the level of detail in regulatory guidance and the importance of dialogue and review.
- Chapter 4 describes the roles of scenario development both in safety assessments and, more generally, in the management of uncertainty in repository programmes. Its role in promoting interdisciplinary communication is also discussed.
- Chapter 5 describes the broad classes into which scenarios are generally divided, including what-if scenarios and the special case of human intrusion.
- Chapter 6 reviews the approaches to scenario development followed by various national programmes, including their evolution, common features and differences between programmes, the main broad steps in scenario development and the tools that have been used to implement these and also the issues of comprehensiveness and sufficiency of the sets of scenarios that are derived.
- Chapter 7 discusses the analysis of scenarios, including the development of models and their application in deterministic and probabilistic calculations.
- Finally, Chapter 8 summarises the main findings of this report and draws some conclusions.

Table 1: Roles and nationalities of responding organisations

Organisation	Country	Role	Notes
Federal Agency for Nuclear Control (FANC)	Belgium	Regulator	
ONDRAF/NIRAS		Implementer	
Nuclear Waste Management Organisation (NWMO)	Canada	Implementer	
Radioactive Waste Repository Authority (RAWRA)	Czech Republic	Implementer	
Posiva Oy	Finland	Implementer	
Agence nationale pour la gestion des déchets radioactifs (Andra)	France	Implementer	
Bundesamt für Strahlenschutz (BfS)	Germany	Implementer	Joint response
Gesellschaft für Anlagen- und Reaktorsicherheit gGmbH (GRS)		Research Organisation	
Japan Atomic Energy Agency (JAEA)	Japan	Research Organisation	Joint response
Nuclear Waste Management Organisation of Japan (NUMO)		Implementer	

Table 1: Roles and nationalities of responding organisations *(cont'd)*

Organisation	Country	Role	Notes
Korea Atomic Energy Research Institute (KAERI)	South Korea	Research Organisation	
Swedish Nuclear Fuel and Waste Management Co. (SKB)	Sweden	Implementer	
Swedish Radiation Safety Authority (SSM)		Regulator	
Environment Agency (EA)	UK	Regulator (for England, Wales, and Northern Ireland)	Response appended to that of RWMD
Radioactive Waste Management Directorate in the Nuclear Decommissioning Authority (RWMD)		Implementer	
US Department of Energy Office of Nuclear Energy (US DOE NE) (for spent nuclear fuel and high level waste)	US	Implementer	Joint response
US Department of Energy Office of Environmental Management Carlsbad Field Office (US DOE EM/CBFO) (for transuranic waste)		Implementer	

2. Work of international organisations

2.1 NEA initiatives

NEA initiatives related to scenario development are documented in various publications (NEA 1992, 2001, 2002, 2003, 2004, 2008a, 2008b, 2010, 2013a, 2013b). The NEA review of safety assessment methods, published in 1991, identified the main tasks in safety assessments as being:

- scenario analysis;
- model representation;
- consequence analysis, including comparison with safety criteria.

In 1993, a second work group commenced work on the NEA database of features, events and processes (FEPs). The database is intended to aid national programmes in identifying, classifying and screening FEPs for scenario development in safety assessments. The NEA produced a publication entitled *Features, Events and Processes (FEPs) for the Geologic Disposal of Radioactive Waste* (NEA 1999) and, in 1998, the Working Group on the Characterisation, the Understanding and the Performance of Argillaceous Rocks as Repository Host Formations (known as “Clay Club”) launched the FEPCAT (Features, Events and Processes CATalogue for argillaceous media) project.

An updated version of the NEA international FEP list and associated database[1] was completed in 2006. More recently, in light of the findings from a 2010 questionnaire on “the use of FEPs in performance assessment studies and the scope for related NEA IGSC activities”, the NEA is supporting the further revision of the FEP list and database to ensure that they remain useful and relevant to the work of member states (NEA 2013b and 2013c).

In 1994, the NEA established an Expert Group on International Performance Assessment (IPAG) to provide a forum for informed discussion on performance assessment, the scope of which was later extended to cover safety assessment and the safety case. In 2000, the Integration Group for the Safety Case (IGSC) was established by the NEA Radioactive Waste Management Committee (RWMC) in recognition of the need to foster full integration of all aspects of the safety case, including scenario development.

1. www.oecd-nea.org/rwm/igsc/assessment-tools.html.

The scenario development workshop in Madrid held in 1999 included 40 representatives of 26 organisations from 12 NEA countries. It reviewed methods in scenario development, such as the use of event trees and directed diagrams, noting differences in both the methods and terminology applied in different organisations. The workshop also discussed the role of FEP databases and the issue of how to provide comprehensive documentation and noted the emergence of new methods for scenario development based around safety functions. Key challenges identified in the Madrid workshop were:

- ensuring full traceability of information and judgements;
- communicating the role and choice of scenarios to wider audiences; and
- the assignment of probabilities to FEPs and scenarios.

The NEA INTESC project (International Experiences in Safety Cases for Geological Repositories), conducted in 2009, analysed a range of safety cases with a view to providing insight into regulatory expectations on the contents and review of safety cases. The main findings of the project are reported in NEA (2009). Regarding scenarios, the project found that regulators generally accept stylised approaches[2] when uncertainties could not be readily quantified or bounded or when the likelihood of some initiating events could be estimated but the timing was unknown. It was also noted that safety functions are increasingly being developed as a methodological element in safety assessment and safety cases, including use in scenario development.

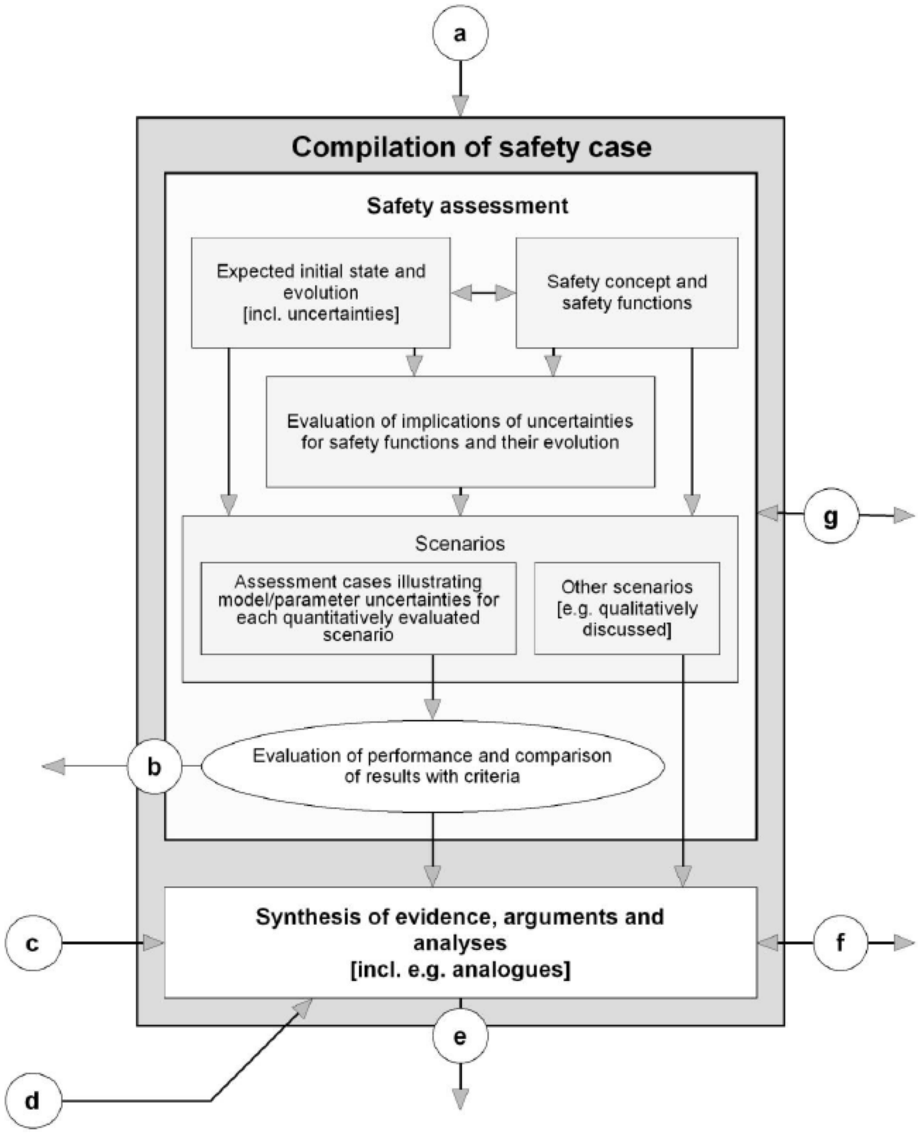
From 2008 to 2010, the NEA also organised a project on Methods for Safety Assessment for Geological Disposal Systems for Radioactive Waste (MeSA) (NEA 2010) with the aim of reviewing and summarising the state-of-the-art at that time. The project involved 18 waste management, research, regulatory and technical support organisations from 11 NEA member countries. One key product of the project was a generic flowchart showing the central role of scenarios in safety assessment and in the wider safety case. The flowchart, which is reproduced in Figure 1, shows how some scenarios will be quantitatively evaluated, whilst others may be more qualitatively discussed. It also shows how the main inputs to scenario development are:

- the expected initial state and evolution of the disposal system, including uncertainties; and
- the safety concept and safety functions[3] of the disposal system.

2. The term “stylised approach” is frequently used in the context of radioactive waste management to refer to approaches that involve imposed rather than scientifically-derived assumptions, although there appears to be no universally accepted definition of the term (see Section 6.2).
3. Safety functions refer to the roles played by individual barriers or barriers in combination with respect to long-term safety. They may be high-level and general in nature, such as isolation by the geological environment from the surface environment and containment by engineered and/or geological system components. They may also be more detailed and concept-specific, such as the function of a clay buffer in filtering colloids generated around the waste.

These inputs are brought together to assess the implications of uncertainties for the safety functions and their evolution. The key role of safety functions in many recent safety assessments and safety cases is discussed further in the present report.

Figure 1. Detailed generic safety assessment flowchart



After Figure 4-2 of NEA (2010). The labelled arrows correspond to the arrows labelled with the same letter in a higher-level, more general flowchart (Figure 4-1 of NEA 2010, also reproduced as Figure 3 in the present report).

The MeSA summary report, as well as the more detailed MeSA Issue Paper No. 3 on system description and scenarios, noted that, in some assessments, scenarios are derived using a bottom-up approach that begins by assessing a range of events or conditions (e.g. climate change, human intrusion, initial container defect) that may trigger changes in the disposal system or affect its performance. Other programmes or organisations structure the scenario definition using a top-down approach, i.e. identifying first the crucial safety functions and then focussing on what combination of processes and conditions could jeopardise one or more safety functions. It was stated that there is no conflict between a bottom-up or a top-down approach and that in fact they are often used in combination, with one applied as a primary method to identify scenarios, and the other serving as a confirmatory tool. As discussed further in the present report, the integration of top-down and bottom-up elements may in reality be a feature of all practical approaches to scenario development.

A further key observation from MeSA was that scenario development involves interactions between safety assessment specialists and specialists in other aspects of the repository development, notably site and waste characterisation and repository design, as well as scientists with specialist knowledge of phenomena influencing disposal system evolution.

Recently, in 2014, the sixteenth meeting of the IGSC included a topical session entitled "Handling extreme geological events in safety cases during the post-closure phase". The session discussed the handling of events such as volcanism, seismic events and extreme climate change by various national programmes, including how the likelihood and consequences of such events are assessed. It was noted that there is a potential benefit to harmonising the treatment of scenarios involving extreme geological events between programmes, including the main assumptions made and the generic data used.

2.2 IAEA safety standards and initiatives

The IAEA safety standards provide a system of safety fundamentals, safety requirements and safety guides for ensuring safety of nuclear facilities. Two specific safety guides address geological disposal facilities for radioactive waste: SSG-14, which addresses all aspects of safety, and SSG-23, which addresses the safety case and safety assessment. A further safety guide, SSG-29, addresses all aspects of the safety of near-surface disposal facilities. Regarding scenario development within the safety case and safety assessment, key statements from these requirements and guides are as follows.

SSG-14, para 5.12:

> *The safety case for the period after closure should address scenarios for the more likely evolutions of the geological disposal facility and its regional setting over very long time periods (e.g. a time period comparable to that over which the waste remains hazardous) and the less likely events that might affect the performance of the facility…*

SSG-14, para 5.15:

… Low probability scenarios that have a potential for major consequences should be explored to understand the robustness of the disposal system. The safety assessment should include some stylized calculations of the consequences of inadvertent human intrusion into the closed disposal facility…

SSG-23, para 6.41:

Robustness of the disposal system is evaluated through comparison of the results of analyses of the base case with a range of scenarios illustrating specific perturbations or uncertainties. Among the different types of perturbation, the most generally considered are those where one component or one of its characteristics is considered to have failed ('what if' scenarios). Scenarios involving such strong perturbations applied to the disposal system are distinguished from scenarios describing degraded behaviour of the disposal system.

SSG-29, para 5.18:

The post-closure safety case should specify a range of credible scenarios for the evolution of the disposal facility and its surroundings over the time period for which the waste represents a potentially significant hazard or as specified in national regulations, some of which prescribe the timescale for the assessment. Consideration should be given to expected scenarios (normal evolution scenarios) and to less likely scenarios.

The IAEA HIDRA project[4] (Human Intrusion in the context of Disposal of Radioactive Waste) aimed to discuss and explore the means of effectively addressing future human actions and human intrusion scenarios in safety cases for radioactive waste disposal facilities. The HIDRA project considered both near-surface and geological radioactive waste disposal facilities, including the commonalities and differences in approaches to human intrusion between these types of facility. The objectives of the HIDRA project were to:

- share experience and practical considerations for development and regulatory oversight of assessments of impacts of future human actions, primarily human intrusion, in the context of the safety case during the lifecycle for a disposal facility;
- provide specific information regarding technical, societal and design considerations to support development of a structured process or methodology for developing scenarios for site-specific application;
- describe the role of assessments of future human actions for siting, design and development of waste acceptance criteria in the context of the safety case;

4. www-ns.iaea.org/projects/hidra/.

- provide suggestions for communication strategies to describe the rationale for assessments of future human actions and for interpretation of the results of those assessments; and
- provide recommendations, as appropriate, for clarification of existing IAEA requirements and guidance relevant to the assessment of future human actions and human intrusion.

The project noted that, while near-surface and geological disposal facilities use fundamentally different approaches to address human intrusion, scenarios selected for each facility type nevertheless have a similar function, which is to provide a basis for human intrusion assessment and potential mitigation measures. The project also recognised the importance of other non-technical factors for reducing the risk of intrusion, such as knowledge / information preservation and communications with other stakeholders. HIDRA continued until March 2015 and a follow-on phase commenced in January 2016.

2.3 WENRA safety reference levels

The Western European Nuclear Regulators Association (WENRA) was established in 1999 to develop a harmonised approach to nuclear safety and to provide an independent capability to examine nuclear safety in member countries, as well as to exchange experience and discuss significant safety issues. Two technical working groups have been established to fulfil these aims:

- the Reactor Harmonisation Working Group (RHWG); and
- the Working Group on Waste and Decommissioning (WGWD).

The approach of these groups may be summarised in terms of four steps:

1. analyse the current situation and the different safety approaches;
2. compare individual national regulatory approaches with selected requirements from the IAEA Safety Standards as defined in WENRA reports on various subjects;
3. identify any differences; and
4. propose a way forward to possibly eliminate the differences.

The resulting proposals are expected to be based on best practices among the most advanced requirements for existing power reactors and nuclear waste facilities.

At the end of 2014, WGWD published a report on safety reference levels (SRLs) for radioactive waste disposal facilities that are intended to provide a basis for future harmonisation on a European level (WENRA 2014). There are 108 SRLs on disposal facilities: DI-01 to DI-108. Scenario development is an important element that is addressed in two of these SRLs:

DI-36:

> *The licensee shall design the disposal facility giving due consideration to both normal evolution of the disposal system after closure and scenarios involving events and processes that might disturb the normal evolution of the disposal system.*

DI-101

> *The licensee shall include in the post-closure safety assessment a scenario analysis that considers the possible features, events and processes that might affect the performance of the disposal system, including events of low probability.*

2.4 The PAMINA project

The PAMINA project (Performance Assessment Methodologies in Application to Guide the Development of the Safety Case) was part of the Sixth Framework Programme of the European Commission. It brought together 27 organisations from ten European countries and one EC Joint Research Centre with the aim of improving and harmonising methodologies and tools for demonstrating the safety of deep geological disposal. The project ran from 1 October 2006 to 30 September 2009, and its main findings are summarised in Galson & Richardson (2011). Scenarios featured in several of the project components. The project observed that scenarios are increasingly being developed by consideration of how particular FEPs could affect the safety functions of a disposal system, as later reiterated by the MeSA project. It also noted the special treatment of inadvertent human intrusion in safety analyses, using one or more stylised scenarios. Furthermore, it addressed the issue of how to assign probabilities to "scenario-forming FEPs". It was concluded that, where statistical evidence is available (e.g. historical drilling frequencies, seismic data), this should be used. Otherwise, probabilities should be assigned on a cautious basis and should be avoided where insufficient information is available, where assessment outcomes do not depend on this probability, or where siting has already explicitly considered the issue and there is nothing that can be done to reduce the probability further. Finally, it was concluded that, if formal expert elicitation is used, it is important to record the experts' thinking, in order to demonstrate transparency in attributing probabilities.

3. Regulatory perspective

3.1 National regulatory context

Many new and updated regulations and guidance documents that are relevant to scenario development have been issued since 1999. Current regulations and guidance on safety assessment in those national programmes participating in the NEA IGSC 2014 questionnaire are summarised in Table 2. For the countries in which a site has been chosen (and is either operating or under regulatory review), comprehensive sets of rules and regulations have been defined that include aspects of scenario development. For other national programmes, a variety of guidelines and/or regulations are in place.

Table 2. Summary of regulations and guidance on safety assessment

Programme	Regulations or guidance
Belgium	Laws and technical guides exist – SAR 2012, RPC-LT 2011 (royal decree given in December 2011).
Canada	Regulatory guide for assessing long-term safety of a deep geological repository and for supporting the safety case for a licence application exists: CNSC G-320.
Czech Republic	No specific legal requirements at present.
Finland	Finnish legal and regulatory requirements relating to the radiological protection and to the analysis of scenarios are found in the Government Decree on the safety of disposal of nuclear waste (GD 736/2008) and in the regulatory Guide YVL D.5.
France	French Act (Dec. 30th 1991 and June 28th 2006 French Acts) and Nuclear Safety Authority Guide (exBasic safety rules BSR- III.2.f of 1991 that was revised in 2008 - NSA-Guide 2008). A national regulatory text is in preparation by the Safety Authority focusing on disposal.
Germany	Safety requirements for heat-generating waste published in 2010; no corresponding requirements for a low or intermediate level waste repository.
Japan	No formal regulatory requirements for the definition and consideration of scenarios for high level waste. In 2004, NSC published a document on the risk-informed approach to safety regulations that discussed a range of important issues in regulating the safety of all kinds of radioactive waste disposal.
Korea	Draft guideline exists for evaluating safety.
Sweden	Regulatory requirements exist: SSMFS 2008:21 and SSMFS 2008:37. One addresses expectations regarding the disposal system, the other addresses implications for long-term radiological protection.
UK	Regulatory guidance exists, GRA, 2009.
US	US regulations exist: 10 CFR 60, 10 CFR 63. Regulations require a comprehensive consideration of FEPs, but give no guidance on the use of safety functions. Regulations include individual protection requirements and consideration of releases from all FEPs and FEP sequences. Regulatory criteria for WIPP (40 CFR 194) and Yucca Mountain (10 CFR 63 and 40 CFR 197) are more specific due to nature of programmes.

Although regulatory requirements and guidance are set out formally in documents such as those listed in Table 2, important guidance can also come from interactions/dialogue and review, as discussed further in Section 3.5. Note also that the international standards set out by the ICRP are recognised by many regulators and many radiation protection regulations are based on these standards. Regarding scenarios, ICRP Publication 122 (ICRP 2013) provides guidance on protection in the event that the disposal facility and its surrounding environment is impacted or altered by natural events (e.g. earthquake) and in the event of inadvertent human intrusion.

3.2 Principles and objectives

Most regulations prescribe general principles and objectives for scenario development. These principle include:

- comprehensiveness;
- the use of a systematic approach;
- traceability and transparency.

In Belgium, for example, the documents Guide technique RPC 2011 and *Projet de guide technique* SAR 2012 require ONDRAF/NIRAS to ensure the comprehensiveness of scenario development as well as to demonstrate the use of a transparent, traceable approach in developing scenarios and managing uncertainties. In Canada, *CNSC G-320* specifies that scenarios must be sufficiently comprehensive to account for all the potential future states of the site and the biosphere, and that scenarios should be developed in a systematic, transparent, and traceable manner through a structured analysis of relevant FEPs.

The term "completeness" is sometimes used as a synonym for "comprehensiveness", although it is recognised that completeness of a set of scenarios can never be proven. As noted in MeSA, completeness in the context of all possible scenarios can easily become an idealistic and impractical goal. Rather than striving for completeness or exhaustiveness, the implementer needs to show that reasonable measures have been taken to minimise the possibility that potentially significant phenomena have been overlooked (see Section 6.5). The aim is to be *sufficiently* complete to give confidence that robustness of the system has been effectively and extensively tested in the safety case. Thus, in practice, only a qualitatively sufficient set of scenarios is deemed necessary in most regulatory environments. It is, however, expected that these scenarios are comprehensive in the sense that they illustrate a wide range of possible evolutions of the disposal system in a credible manner that includes the most important paths of evolution in terms of likelihood and consequences. SSM, for example, requires:

> *"… (a set) that together illustrate the most important courses of development of the repository, its surroundings and the biosphere" (SSMFS 2008:37, general guidance).*

The proponent has to systematically demonstrate, as far as reasonably possible, that all potentially relevant FEPs have been identified, that due consideration has been given to the time periods over which they may be relevant and that their inclusion or omission from the set of scenarios that is finally analysed is well justified.

Especially in programmes that are still in an early stage of development, only rather limited advice is given on how these general principles should be enacted, although it was noted at the workshop that regulatory expectations regarding the application of these principles are likely to increase as a programme progresses.

3.3 Requirements and guidance on scenario development

Current regulations vary significantly in the degree to which they provide requirements and guidance on scenario development over and above the general principles described in the previous section, and in the level of detail of these requirements and guidance. Detailed requirements are also sometimes referred to as "prescriptive". An example of less detailed requirements and guidance is the Canadian case. Although guidance is also provided for defining safety criteria and performing long-term assessments that includes considerations for selection of methodology, assessment timeframes, scenarios, etc., responsibility for selecting each of these rests with the proponent. The regulator (CNSC) judges whether the selections are acceptable, e.g. for a licence application. By contrast, in the US, where there is an operational repository for transuranic (TRU) waste (WIPP), regulatory requirements are far more detailed/prescriptive, in terms, for example, of the FEPs to be analysed and the methods to be used in the analyses.

Many regulations and guidance documents refer to broad types of phenomena that need to be accounted for in scenario development (e.g. geological and climatic events, repository-induced effects, degradation of the barriers over time, future human actions) and some refer specifically to the use of FEPs or safety functions in scenario development. In some cases, a list of internal and external FEPs to be taken into account in the development and categorisation of scenarios may be provided, such as in the French 2008 NSA Guide, though without specifying the method by which this should be done. Specific FEPs may also be identified in regulations that need not be considered in safety assessments. In general, however, the specific scenarios to be analysed and the methods used to develop scenarios are not prescribed in regulations or recommended in guidance. Rather, it is for the proponent to justify which FEPs to include in the scenarios that they analyse and how to represent them in the models.

Some regulations provide a probability cut-off as a basis for disregarding very unlikely FEPs. For example, scenarios with a probability of 10^{-7}/a can be disregarded according to the regulations of the Czech Republic. The corresponding figure in U.S. regulations for spent nuclear fuel and high-level waste disposal[5] is 10^{-8}/a. Most regulations and guidance do not, however, explicitly require or recommend a quantitative evaluation of the likelihood of scenarios and/or their associated FEPs, although likelihood estimates may nevertheless be called for where compliance criteria are expressed in terms of risk, and at least qualitative estimates are needed where scenarios are classified according to likelihood (see below).

One aspect of scenario development covered in several national regulations is scenario classification. As observed in the MeSA project, requirements on scenario classification can be quite limited in countries where potential future repository

5. Criterion applied over the first 10 000 years for the identification of included FEPs. However, the impact of these included FEPs was analysed over a longer, million year time frame.

evolutions are treated within a framework of risk evaluation. In the assessments carried out in such countries, the dose calculated for individual scenarios is weighted as a function of the estimated scenario likelihood. However, where dose criteria or a combination of dose and risk criteria are given, regulations usually also stipulate the classes of scenario to be considered. These classes are generally distinguished on the basis of the FEPs that are covered in the scenarios, their likelihood, and their potential effect on the evolution of the repository. Thus, an assessment of scenario likelihood is still needed, albeit often a qualitative one, in order to assign scenarios to different classes. In Japan, for example, regulations identify a "rigorous discussion on the probability/plausibility of each scenario based on available data/information and/or expert judgement", presented in a structured fashion, as important for all types of disposal system (NSC 2010, Government of Japan 2011).

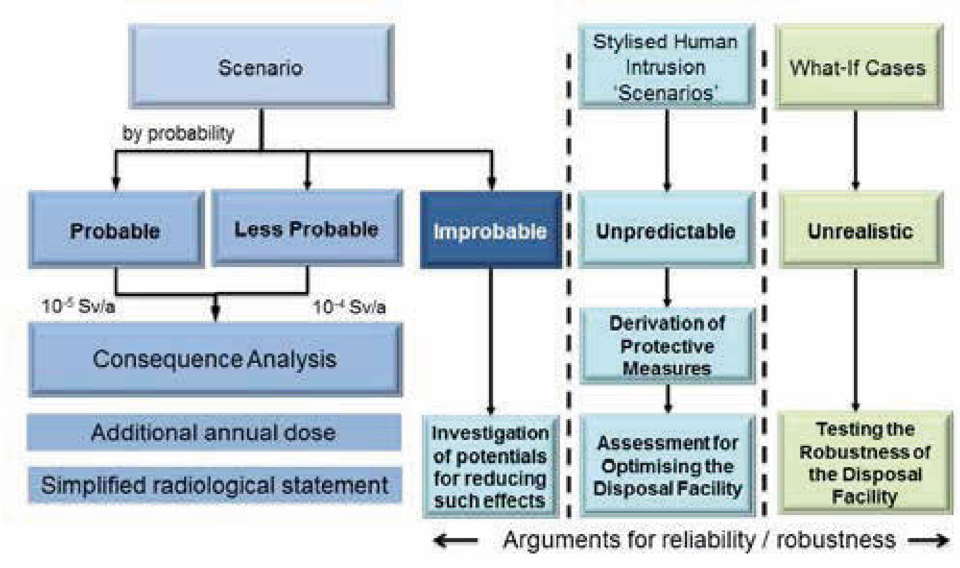
Where a categorisation of scenarios is given in regulations, regulations sometimes set different compliance criteria for each category. Regulatory compliance criteria for human populations in more likely scenarios are most often specified in terms of annual doses[6]. However, compliance criteria for unlikely scenarios may be framed in terms of:

- higher dose or activity release rate limits than for more likely scenarios;
- limits to the expectation value of dose or activity release rates; or
- risk criteria.

For example, in Germany, as illustrated in Figure 2, an effective dose in the range of 0.01 mSv/a for individuals has been used for likely scenarios, and 0.1 mSv/a for those judged less likely. There are typically no quantitative dose or risk limits for scenarios that are judged to be very unlikely, for stylised human intrusion scenarios or for what-if cases. Rather, arguments for system reliability and robustness with respect to such scenarios are developed.

6. Protection of the human and the environment is the most fundamental requirement in all national regulations. Nevertheless, in some countries, such as Finland and Sweden, there is also a regulatory requirement for the protection of non-human biota (flora and fauna).

Figure 2. Example from the German programme of an assessment in which different safety requirements are considered for various categories of scenarios



Where regulations specify risk criteria or limits to the expected value of dose or activity releases, there is an implication that the low likelihood of any potentially high consequence scenarios or initiating FEPs may be taken into account when addressing compliance.

Regulations, in some cases, also specify the time frames to be considered in the development and analysis of scenarios and in the broader safety case, and regulatory expectations may also vary depending on the time frame under consideration. In SSM's regulations (SSM 2008), for example, for assessment timescales up to 1000 years, it is expected that the proponent will provide:

- detailed exploration of conditions and processes, especially transients, relevant to the early evolution of the repository; and
- dose and risk estimates, based on an extrapolation of present-day biosphere conditions.

After 1 000 years, however, and up to around 100 000 years, the requirement is for dose and risk estimates to encompass major external changes, such as glaciation.

While a specific time cut-off for the analysis of scenarios is not always specified in regulations, many require an appropriate assessment timescale. In France, the NSA Guide of 2008 requires the demonstration of geological stability over a period of 10 000 years, during which the dose constraint of 0.25 mSv/a is to be applied. At later times, to account for uncertainties in the evolution of the repository environment, conservative quantitative evaluations are to be carried out, keeping 0.25 mSv/a as a reference value. Some regulations are framed in quantitative terms over a certain time frame, but provide more qualitative safety criteria for still more distant times. In Sweden and Finland, for example, regulations state that safety evaluations in the farthest future (beyond around a million years in the Finnish case) can be mainly based on “complementary considerations”, which can be used for scenarios that cannot reasonably be assessed by quantitative means. Similarly in Switzerland, beyond a million years, it has to be shown that the range of variations of possible radiological impacts are not “higher than natural radiological exposure”. It is thus recognised in at least some regulations that the quantitative evaluation of safety indicators, such as dose, becomes increasingly difficult to justify at very distant times, due to increasing uncertainties, as well as the diminishing hazard associated with the wastes.

For human intrusion scenarios, several national regulations require the radiological impact to the intruder to be considered, as well as the impact to other groups due, e.g. to damage to the repository barrier system or to the improper disposal of excavated material at the surface. There is generally no limit set in regulations to the maximum dose that may be received by the intruder; it is implicitly acknowledged that a person coming into direct contact with high-level waste could receive a high and potentially fatal radiation dose. The absence of regulatory limits for this particular situation is counterbalanced by the necessity to minimise the likelihood of intrusion through measures that make intrusion difficult, including deep disposal itself, appropriate site selection and the design of the closure of the facility, as well as by means of record keeping and consideration of appropriate site markers.

Regarding the analysis of scenarios, regulations may provide some guidance on the use of deterministic and probabilistic methods. Stylisation is generally regarded as appropriate in scenarios considering human intrusion, and in many regulations stylisation is also accepted in the treatment of the future evolution of the biosphere. However, as noted in the INTESC project, the nature and extent of stylisation is still a matter for interpretation on the part of the developer.

3.4 General versus detailed requirements and guidance

Safety requirements often evolve over time, but the level of detail may remain at broadly similar level, at least during the period prior to an initial licence application. The requirements imposed on an operator under licence are, however, likely to be more detailed and prescriptive than those imposed in the pre-licencing phase. Regarding regulatory guidance, it was a finding of the workshop that this should (and does) increase in detail as a programme progresses, although many proponents and regulators see some advantages in limiting, to some extent at least, the level of detail in the formulation of guidance.

Regulatory reviews of safety cases are particularly demanding on the regulator if the requirements to be met and guidance to be followed are rather general. On the other hand, less detailed requirements and guidance have several benefits. In particular, they:

- are more likely to be applicable irrespective of the programme stage reached or the chosen site and design, thus avoiding to some extent the need for frequent updates, and providing stability in the regulatory framework;

- put responsibility for developing the safety case primarily on the proponent, thus maintaining the independence of the regulator in reviewing the safety case; and
- allow the proponent flexibility in selecting the most suitable approach for demonstrating safety, taking into account the programme stage and nature of the site and engineering design.

In spite of the benefit of more stability, even less detailed regulations need periodic updates to take account of lessons learned e.g. from regulatory reviews of safety cases and of advances in international practice/standards[7], although the changes are likely to be less than in the case of more detailed documents.

The workshop found that detailed regulatory guidance can be useful or necessary in certain areas, including some aspects of the formulation and analysis of scenarios, such as the use (individually or in combination) of probabilistic and deterministic analysis methods and the treatment of human intrusion. There was a clear consensus, however, that regulatory requirements and guidance should not define the specific computational tools needed to develop and analyse scenarios. Another observation from the workshop was that there appears to be no pressing demands from any of the proponents represented for more (or less) detailed guidance in their own national regulations, even though the degree of detail found in guidance varies greatly. The fact that proponents appear comfortable with the style of the regulatory requirements/guidance with which they have to deal may imply that regulations properly reflect country-specific aspects such as the stage reached in the repository programmes as well as national and regulatory culture.

Finally, it was noted that the less detailed the regulatory requirements and guidance, the more there is a need for continuous dialogue between the regulator and the proponent to clarify regulatory expectations. The importance of dialogue and review is discussed in the next section.

3.5 Dialogue and review

A key observation made at the workshop was that regulatory guidance is not only provided in formal documents, but also comes from dialogue between the proponent and regulator and from the regulatory review of the proponent’s work, including safety cases, R&D plans and other key documents. In fact, regulatory

7. The questionnaire responses provided examples of changes in laws, regulations and guidance related to scenarios in the context of geological disposal since 1999. In Belgium, for example, guidance by FANC now includes the concept of “penalising scenarios”, which was introduced as a way of assessing the safety of the system beyond the performances assessment period. In Finland, the most salient change to regulations is the mention of safety functions and performance targets/targets properties in the context of scenario definition and classification.

requirements and guidance are sometimes updated specifically to address gaps identified as a result of dialogue and regulatory review. These gaps may be identified by the proponent in the course of their work and communicated to the regulator, or they may be identified by the regulator in the course of their review and during discussions with the proponent (gaps arising due to the evolution of international practice and/or international guidance may also be identified by the proponent or regulator as a result e.g. of participation in international projects).

How dialogue is conducted, i.e. whether it is a more formal or less formal exchange of information and ideas, varies between national programmes and may also vary as a programme progresses from the pre-licencing to the licencing and finally the post-licencing stage. It is, however, always seen as a valuable process for both the proponent and the regulator. An example of a programme that engages in a formal dialogue is that of Switzerland where the exchange of information is documented in meeting minutes prepared by the regulator to ensure transparency of the dialogue process. These meeting minutes are made available to the public upon request after formal completion of any given milestone.

The development of guidance through dialogue tends to be a step-wise process. Thus, for example, SKB presented its safety assessment methodology to the regulator on several occasions before making a licence application, refining it as necessary based both on regulatory feedback and on SKB's own experience in applying the methodology.

In the context of scenarios, dialogue can provide confirmation that the proponent's approach is in line with expectations (or lead to modifications in the approach if it is not), as well as promoting a common understanding on more detailed aspects of scenario formulation and analysis.

4. Roles of scenarios

4.1 Role in safety assessment and the safety case

Scenarios form an integral part of any safety assessment and safety case (see e.g. the generic flowchart in Figure 1), providing the means to examine of the impact of different potential system evolutions on performance and safety. In fact, the further roles of scenarios described in later sections of this chapter may also be seen as roles of safety assessment and the safety case, of which, as noted above, scenarios are an integral part.

The development of scenarios can be considered part of the wider activity of uncertainty analysis. Uncertainties are generally classified as follows in safety assessments (Galson & Richardson 2011):

- Uncertainties associated with significant changes that may occur within the engineered systems and the geological and surface environment over time. These are often referred to as "scenario" or "system" uncertainties.
- Uncertainties arising from an incomplete knowledge or lack of understanding of the behaviour of the system, as well as from the use of simplified models and computer codes to represent this behaviour. This type of uncertainty is often called "model" uncertainty.
- Uncertainties associated with the values of the parameters that are used in the implemented models. These are termed "parameter" or "data" uncertainties.

It is also widely recognised that each uncertainty has a specific nature regardless of its classification. In this respect, irreducible (aleatory) and reducible (epistemic) uncertainties can be distinguished[8].

The range of possible evolutions to which scenario uncertainties give rise is usually condensed into a handful of discrete scenarios that are then analysed, with the principal aim of developing robust arguments for safe repository evolution under all reasonably expected circumstances. Analyses involve the development

8. It was pointed out in the MeSA project (NEA 2010) that, even though the different nature of uncertainties is generally acknowledged in safety assessments, the distinction between epistemic and aleatory uncertainties is usually not made because many uncertainties are best described and understood to be a result of the interaction of both types.

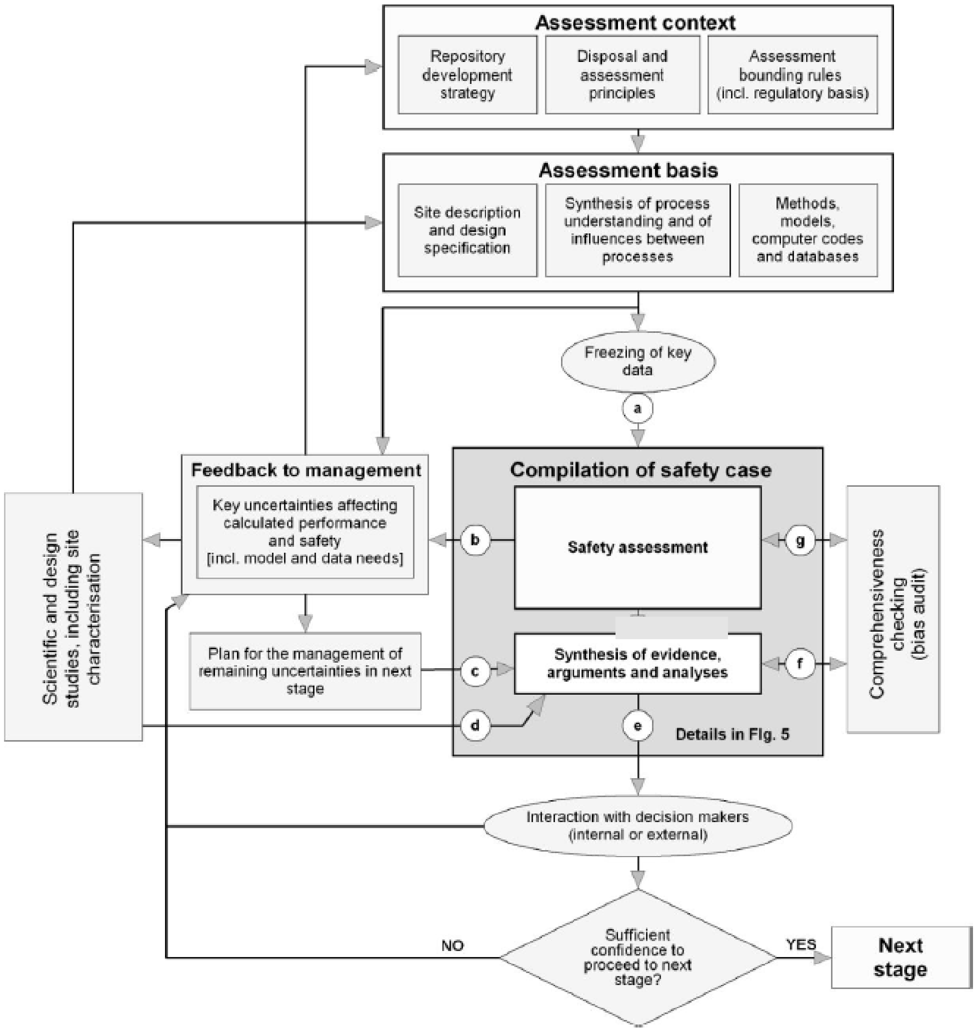
and application of models for each scenario in broad range of calculations that take into account the remaining two classes of uncertainty, as discussed further in Chapter 7, and an evaluation of the results in terms of compliance with safety criteria, i.e. dose and/or risk limits or guidelines. It should be noted that the distinction between scenario, model and parameter uncertainties is not always clear-cut. However, the way in which uncertainties are allocated to each class is far less important than ensuring that all potentially relevant uncertainties are considered.

As well as testing compliance with safety criteria, scenarios can also support the development of general system understanding that is also a key component of any safety case, including, for example, the importance to safety of the various system components and their safety functions, either individually or in combination, and the robustness of the disposal system to phenomena (unknown as well as known) that have the potential to give rise to barrier degradation. This additional role is recognised explicitly in some national regulations. In Sweden, SSM defines a specific class of scenario – residual scenarios – that address conditions and sequences of events without regard to their likelihood. Such scenarios, also termed "what-if" cases, are used in most programmes, and are discussed further in Chapter 5.

4.2 Role in the management of uncertainties and in guiding the repository development process

Uncertainties must be considered not only in the safety case, but in all aspects of repository planning and development. Identifying which uncertainties are most significant to long-term safety, through the development and analysis of scenarios in safety assessments, provides information that can support decisions related to the management of these uncertainties within repository programmes. In particular, Figure 3, from the MeSA project, shows how safety assessment, by identifying key uncertainties affecting calculated performance and safety, can support decisions on which uncertainties should be avoided, reduced or their effects mitigated by further R&D, site characterisation and design development.

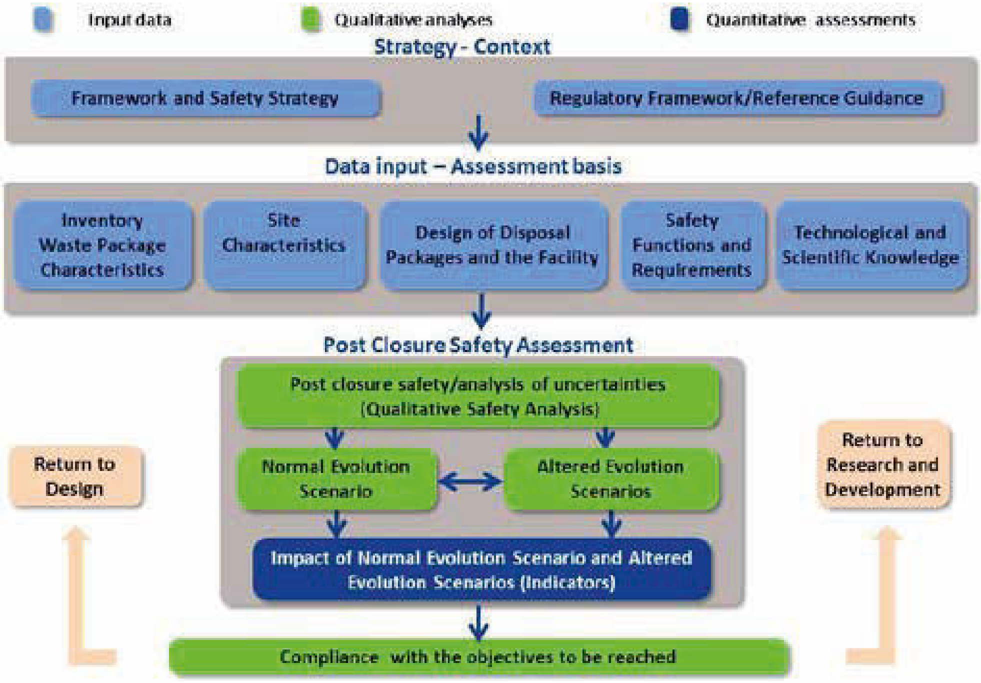
Figure 3. High-level generic safety case flowchart



After Figure 4-1 of NEA (2010). The labelled arrows correspond to the arrows labelled with the same letter in Figure 1.

Figure 4, from the French programme, shows a programme-specific example of how safety assessment, and especially the formulation and analysis of scenarios, provides guidance to both design and R&D. As a further example, Figure 5, from the Finnish programme, shows how the formulation and analysis of scenarios provides input to the “design basis”, which includes design requirements, as well as safety functions and associated parameters and criteria for the engineered barriers and host rock.

Figure 4. Illustration of the process of post-closure safety assessment from the French programme, showing how this process provides guidance to design (including safety requirements) and research and development



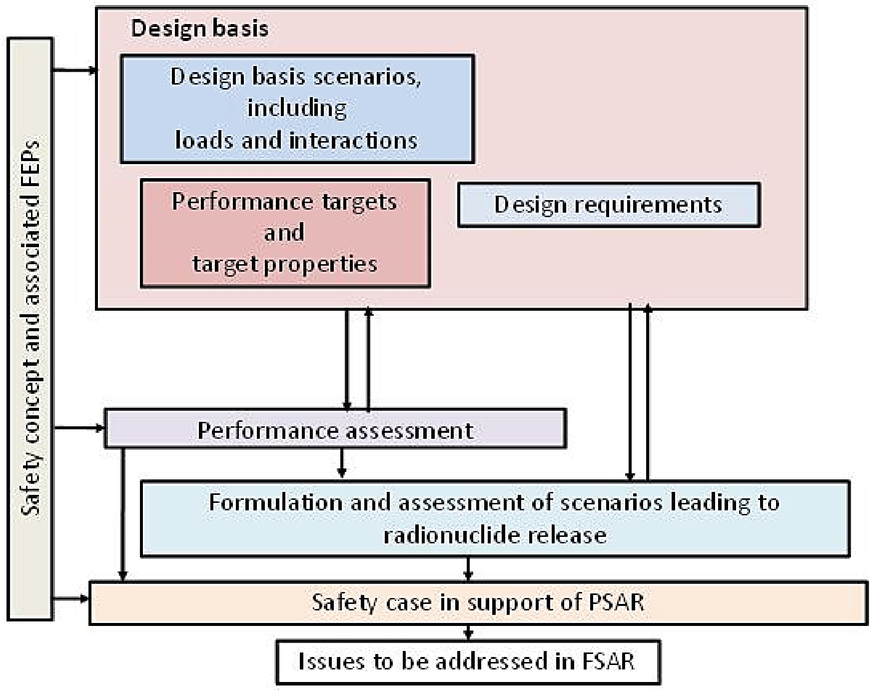
As a programme matures, the focus may shift e.g. from site and concept selection, site characterisation and basic R&D towards design optimisation and ensuring that best available technology (BAT) has been applied. The FEPs included in scenarios to support these activities may also vary as a result, becoming increasingly site-, design- and inventory-specific. If, for example, a programme is at the stage of site selection, and the likelihood and impact of human intrusion is not expected to differ between candidate sites, then human intrusion scenarios may not be analysed (since only *differences* in the likelihood of human intrusion may discriminate between sites). For licensing, on the other hand, an evaluation of such scenarios is generally required.

Although site characterisation and increasing scientific and technical[9] knowledge regarding the initial state and the events and processes affecting evolution aims to reduce uncertainties, they may also lead to the identification of

9. Here, scientific knowledge refers broadly to knowledge of the nature of events, processes and natural features. Technical knowledge refers, for example, to design specifications that define the initial state of the engineered features of a disposal system.

additional FEPs that need to be included in scenario development as a programme progresses. Dialogue with stakeholders may also lead to additional scenarios that need to be addressed to account for stakeholder concerns. Ultimately, the aim is to achieve a comprehensive set of scenarios that is adequate for licencing. Even after initial licensing allowing repository construction to begin, scenario development may continue to some extent, as more detailed knowledge of the underground environment becomes available and in response to changes in boundary conditions, such as evolution of the concept and design and requests to dispose of additional wastes in the facility. Nonetheless, changes to the set of scenarios after licencing are usually limited and have to be justified to the licensing authority.

Figure 5. The development of the repository system as an iteration between requirements, designs and safety assessments, including the formulation and analysis of scenarios



PSAR = Preliminary Safety Analysis Report for construction licence application and FSAR = Final Safety Analysis Report for operating licence application (the main safety documents required by the Finnish authorities). Performance targets for the engineered barriers and target properties for host rock are set such that, if met, the safety functions of these system components will be achieved.

(Source: Figure 1-7 in POSIVA 2012-03).

4.3 Role promoting interdisciplinary communication

A key issue arising from general discussions at the workshop was the role of scenario development in promoting interdisciplinary communication. As illustrated, for example, by Figures 4 and 5, scenario development within safety assessments requires (but can also promote) communication between safety assessors, scientists dealing with phenomenology and engineers dealing with technology. It can thus serve as an integration tool between these three broad disciplines. Here, "phenomenology" refers to the development of scientific understanding of the disposal system and the events and processes that affect its evolution and performance through R&D and site characterisation. "Technology" refers to the development of a repository design and the means for its implementation. The role of scenario development in guiding the work on phenomenology and technology was described in the previous section. For their part, scientists and engineers provide the information, understanding and technical knowledge that are the fundamental basis for scenario development.

Because of this interaction, it is important that new information, understanding and knowledge, as well as key decisions such as design changes, are recorded in a traceable manner and communicated to the safety assessors ultimately responsible for scenario development. The role of interdisciplinary meetings and records of these meetings was emphasised at the workshop, as well as the possible integration of these within management systems.

5. Classes of scenarios

5.1 Main classes of scenarios

All programmes represented at the workshop divide their scenarios into classes, based on the types of FEPs that are covered in the scenarios, their likelihood/probability, and their potential effect on the evolution of the repository. In most cases, this classification is determined by regulations or regulatory guidance. In Finland, for example, STUK’s YVL Guide defines “base” and “variant” scenarios as those that account for uncertainties in the expected evolution of the repository and “disturbance” scenarios as those that account for unlikely events that could impair long-term safety. In France, Safety Rule 2008 requires that “a reference situation” and “altered situations” be addressed and, in Germany, BMU 2010 defines “probable”, “less probable” and “improbable” development situations, while the German Nuclear Waste Management Commission guideline ESK 2012 gives more details of the assignment of safety-relevant scenarios to probability classes. In Sweden, the categories comprise the “main scenario”, “less probable scenarios” and “residual scenarios”.

Terminology used in scenario classification varies between national programmes, although it was noted at the workshop that terminology is less important than ensuring that a sufficiently comprehensive range of scenarios is considered. Irrespective of the differences in terminology, it is possible to distinguish four generic categories of scenario that most programmes consider; see Table 3. This table, which is based on the responses to the NEA scenario development questionnaire, is consistent with the findings of the MeSA project, which identified as common classes of scenario:

1. Scenarios that aim at representing the foreseeable and expected evolution(s) of the disposal system with respect to the most likely effects of certain or very probable events or phenomena.
2. Alternative scenarios that represent less likely but still plausible modes of repository evolution (e.g. barrier degradation more rapidly than expected) as well as scenarios illustrating extreme natural events (e.g. extreme ice-age or a major seismic event), but that are still within the range of realistic possibilities (bounding cases).

Table 3. Generic categories of scenario and national terminology

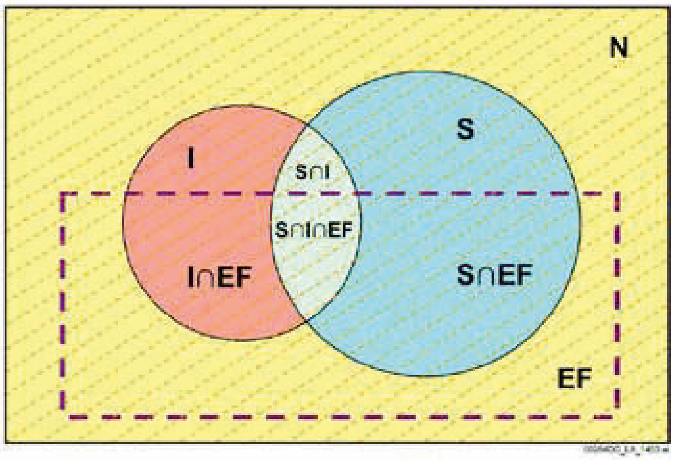
Category	National terminology	
1: representative of the expected evolution of the repository, or a realistic evolution	Belgium, Canada, France, Czech Republic	Normal evolution scenario
	Finland, UK	Base scenario (as well as variant scenarios in Finland)
	Germany	Reference scenario
	Japan	Likely scenarios
	Sweden	Main scenario
	US	Nominal scenario
2: include less probable, but still remain plausible, FEPs	Belgium, France, Czech Republic	Altered evolution scenarios
	Canada	Disruptive scenarios
	Finland	Disturbance scenarios
	Germany	Alternative scenarios
	Japan	Less-likely scenarios
	Sweden	Additional scenarios
	UK	Variant scenarios
	US	Disturbed scenarios
3: scenarios developed regardless of the probability of the event, e.g. to investigate or demonstrate system robustness	France, Germany	What-if scenarios
	Finland	What-if cases
	Japan	Very unlikely scenarios
	Sweden	Residual scenarios
4: scenarios addressing human intrusion and future human actions	Germany	Stylised scenarios
	All programmes (though included in residual scenarios in Sweden)	Human intrusion and future human actions

- What-if scenarios in which implausible or physically impossible assumptions are adopted in order to help bound or conceptually test repository robustness and to assess the relative importance of its various components and safety functions.

- Scenarios addressing human intrusion and future human actions, which are assigned to a separate class since the events or actions in question are poorly predictable or unpredictable (see Section 5.3).

Scenarios in categories 2 to 4 may focus on the impact of a single detrimental FEP, or they may consider combinations of such FEPs occurring simultaneously or at different times in so-called “combined scenarios” or “complex scenarios”. Figure 6, from the US Yucca Mountain, programme shows a Venn diagram illustrating possible individual and combined scenarios that are independent and mutually exclusive. Figure 7, from KAERI, shows how such scenarios can be built up considering the same set of events occurring in various possible temporal sequences.

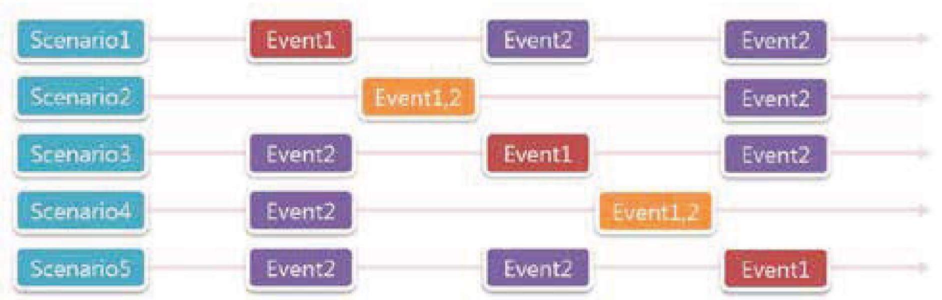
Figure 6: Venn diagram from the US Yucca Mountain programme illustrating potential scenarios arising from perturbing FEPs occurring individually or in combination



N = nominal; I = igneous; S = seismic; EF = early failure; S∩I = seismic/igneous; I∩EF = igneous/early failure; S∩EF = seismic/early failure; S∩I∩EF = seismic/igneous/early failure

A distinction is also sometimes made between assessment scenarios of the types described above and scenarios that guide the development of repository design, termed e.g. “design basis scenarios” in Figure 5 from the Finnish programme. The repository components are designed to fulfil their safety functions and corresponding performance targets if the repository evolves according to any of the design basis scenarios. The assessment scenarios, on the other hand, are used to investigate the performance and safety of the disposal system in a range of situations, including those where one or more performance targets are not fulfilled.

Figure 7. Illustration from the Korean programme of the development of complex scenarios by considering a given set of events occurring in various possible temporal sequences



Defining the expected evolution or a realistic, plausible evolution of the repository (i.e. the first category of assessment scenario) is usually considered one of the starting points in scenario development (after the definition of the safety concept and safety functions). This expected or normal evolution is used to frame and define appropriate additional scenarios, which are normally developed on the basis of perturbations to the normal evolution of the disposal system or the safety functions of particular components of the system. This scenario class is associated with the idea of the system behaving "as intended", but also with the idea of a high likelihood. It is a central task of safety assessment to show that it is indeed likely that the system will evolve as intended.

Approaches to the development of alternative scenarios are discussed in more detail in Chapter 6.

5.2 The role of what-if scenarios

The role of "what-if" scenarios or cases (or residual scenarios in Swedish terminology) in investigating or demonstrating system robustness and in illustrating the functioning of specific barriers is widely recognised. They often include a hypothetical poor performance (or even absence) of one or more barriers to study the role of the remaining barriers and their associated safety functions. An example is the severe shaft failure scenario analysed in the Canadian programme, which is not linked to any specific cause, and is considered in spite of evidence, e.g. from process modelling, for the resilience of the shaft to sources of mechanical loading such as glaciations. Similarly, the definition of what-if scenarios is part of Andra's approach; as an example, a "severely degraded evolution" scenario in which the performance levels of the three main functions all together were radically lowered has been considered. A further example from the Swedish programme is a scenario in which canisters are assumed to fail due to isostatic load, even though current understanding is that the canisters will withstand even the worst-case loading that could occur in the future. The results of these analyses can provide a counter-argument to the possible assertion that there may be events or processes detrimental to the repository barrier system that the programme has failed to identify explicitly in the safety case ("unknown unknowns").

It is, however, also recognised that care is needed in the presentation, communication and interpretation of the analyses of these types of scenarios. Especially when communicating with a non-technical audience, the analyses must be presented in a way that avoids misinterpretation, making sure it is understood that these generally represent extreme, often purely hypothetical situations, rather than expected or possible lines system evolutions. Furthermore, when presenting the analyses to the regulator, it needs to be determined how they can best be used to support wider compliance decisions; due to the arbitrary nature of these assigned or assumed perturbations, no regulatory criteria are associated with this type of scenario. Given that some of these scenarios and cases may give relatively high consequences in terms of dose, it was suggested at the workshop that alternative performance and safety indicators may be more appropriate; e.g. even if safety criteria for dose are exceeded, radionuclide concentrations and fluxes due to the repository may still be low compared with natural concentrations and fluxes.

5.3 The special case of human intrusion

Human intrusion scenarios consider human actions that have the potential to directly jeopardise the isolating capacity of the barriers of the disposal system and, therefore, might have radiological consequences. Human intrusion may be deliberate or inadvertent, and these categories may be further subdivided. In the UK, for example, RWM distinguishes three distinct types of intrusion:

- deliberate intrusion with full knowledge of the repository on the part of the intruder;
- intrusion without knowledge of the repository (inadvertent intrusion), and
- intrusion with knowledge of the repository, but without understanding of what it contains.

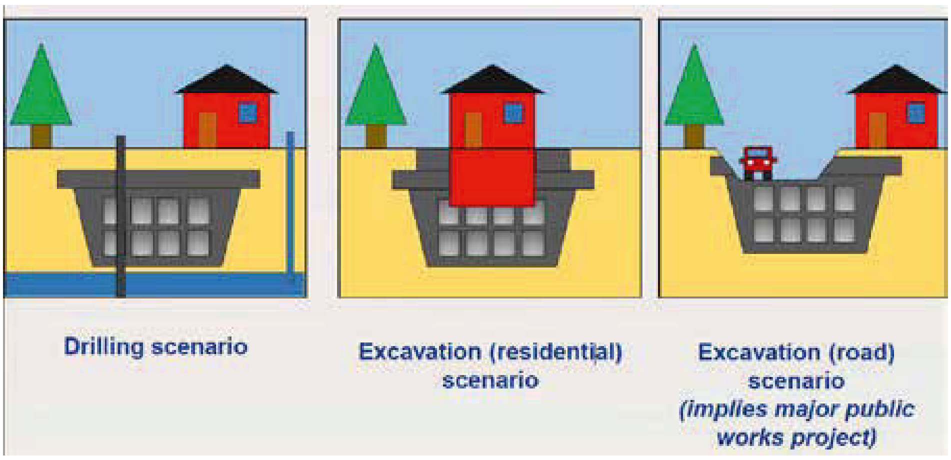
The post-closure safety case for a repository may allude to both deliberate and inadvertent intrusion. For example, it may be argued that one of the prime motivations for disposal over indefinite storage is to reduce the threat (and burden on future generations) associated with any type of intrusion scenario, deliberate or inadvertent. The physical security of the wastes during storage, disposal operations and post-closure is also a relevant consideration.

During operation of the disposal facility and for any a subsequent period of institutional control, a variety of measures will be in place to ensure that human actions do not adversely impact the safety of the disposal system and, in particular, to avoid the possibility of inadvertent intrusion (and reduce the likelihood of deliberate intrusion). Record keeping and markers are additional measures to preserve memory and alert future generation to the hazards associated with the facility. Such measures cannot, however, be assumed to remain effective indefinitely. In the quantitative assessment of radiological consequences, the focus is generally on inadvertent intrusion and exposure, most often associated with a loss of memory of the existence of the repository. The focus on inadvertent intrusion is because it is viewed that the responsibility of any adverse consequences of deliberate intrusion lies with the intruder.

It is recognised that attempts at predicting human actions over long periods of time are inevitably speculative, due, for example, to the unknown nature of future technologies, society and human behaviour in general. Thus, future human actions, and human intrusion in particular, are treated as a separate scenario category requiring somewhat different handling in the safety case compared with other scenarios. A stylised approach is generally considered to be appropriate for the formulation and analysis of intrusion scenarios (see the discussion of stylised approaches in Section 6.2). This means that no attempt is made to cover the full range of possible scenarios, or to assign probabilities to them. Rather, a limited set of illustrative cases is analysed, often defined on the basis of regulations or dialogue between the proponent and regulator. Formal expert elicitation also can be used to help identify, define and parameterise representative human intrusion scenarios.

As noted, e.g. in IAEA SSG-23, there are fundamental differences in the approaches to human intrusion adopted for near-surface facilities and for geological facilities. This is because most human activities (e.g. construction operations, farming, etc.) that could lead to inadvertent human intrusion into a waste disposal facility take place in the near-surface environment, at limited depths of tens rather than hundreds of metres. Thus, following the lapse of active controls and the loss of knowledge about a site, inadvertent human intrusion into a near-surface facility may be quite likely. The principal risk management control that reduces the radiological consequences of inadvertent intrusion into a near-surface facility is the acceptance criteria that limit the radiological toxicity of the wastes. Some illustrative intrusion scenarios for human intrusion into such facilities are illustrated in Figure 8.

Figure 8. Examples of intrusion scenarios for near-surface facilities (illustration from the IAEA HIDRA project)



For more hazardous wastes, deep geological disposal is generally the chosen option, largely because the wastes are thereby isolated from most human activities. Activities that reach depths greater than a few tens of metres are much less likely or frequent than the activities noted above in the context of near-surface disposal. They include drilling (e.g. for water, oil or gas), exploration and mining activities, geothermal heat extraction or the storage of oil, gas or carbon dioxide, the likelihood or frequency of which can often be further reduced by appropriate site selection. In addition, the consequences of future human intrusion can be reduced to some extent by adopting a compartmentalised repository design, whereby, for example, a borehole that intersects and damages one part of the repository has little or no impact on the performance of other parts. Thus, for geological repositories, the relevance of human intrusion is more limited than for near-surface facilities. Future human actions that could lead to intrusion into the repository and its surroundings and significantly impair the performance of any disposal system must still be considered in the safety case, but the safety case will generally emphasise their low likelihood. A set of illustrative intrusion scenarios for geological facilities is shown in Figure 9.

Figure 9. Examples of intrusion scenarios for geological disposal facilities

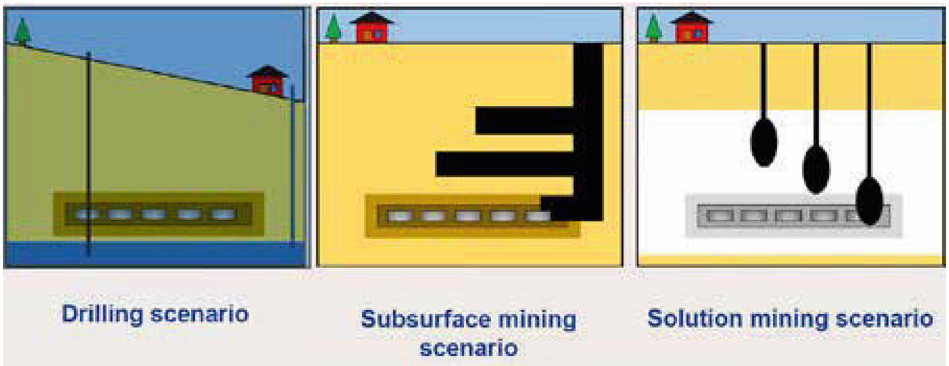


Illustration from the IAEA HIDRA project.

As an example of broad regulatory guidance on (inadvertent) human intrusion/human activity scenarios for geological repositories, SSM's regulations in Sweden require that a safety case includes an analysis of:

- direct intrusion by drilling into the repository; and
- activities that might lead to a deterioration of the protective capability of the repository.

Given the speculative nature of such scenarios, SSM also requires that the results of the human intrusion analysis should be reported separately from the risk analysis for other scenarios.

Regulations in some cases also give more specific guidance as to how human intrusion scenarios should be formulated in the form of stylised assumptions that aim to limit arbitrary speculation on matters that are inherently unpredictable. For example, in several countries, regulations indicate that present-day social structures can be assumed and that the same level of technology is to be considered as is available today. The earliest potential date of occurrence of intrusion is also specified in several regulations (in Finland, for example, regulations specify that loss of memory is to be considered in the context of human intrusion at 200 years following the closure of the disposal facility at the earliest; in France, the corresponding time if 500 years), although maintaining memory of the repository to reduce the likelihood of inadvertent intrusion for as long as possible is viewed as an objective.

6. Approaches to scenario development

6.1 Evolution of approaches

Scenarios are considered to form the fundamental basis for quantitative safety assessments within post-closure safety cases (c.f. Figure 1). Significant evolution in the methods applied in scenario development has taken place in recent years in many countries. An exception is the US, where the scenario development approach that was successfully applied in licencing TRU waste disposal operations at WIPP has continued to be used for recertification of the facility with only minor changes. Furthermore, the development of formal methods for scenario analysis has not been a priority in countries that are still considering generic sites, such as the UK and the Czech Republic.

In all countries, the selection of methods for scenario development is considered to be primarily the responsibility of the proponent. The regulator evaluates the adequacy of the chosen methods in terms of general principles such as comprehensiveness and traceability. As mentioned in the answers to the questionnaire and during the workshop, where scenario development methods have evolved since 1999, this has in part been a result of review by, and dialogue with, regulators as well as other national and international reviews of safety cases. Other factors driving the development of methods have been the evolution of the regulations themselves and also the work of international organisations, as described in Chapter 2.

Many programmes have refined their methodologies with a view to developing scenarios in a systematic, structured and transparent manner. Efforts have also been made to ensure comprehensiveness, traceability of decisions, and the integration and logical structuring of interdisciplinary knowledge, although it is acknowledged that interdisciplinary communication and communication to non-technical audiences could still be improved. Scenarios and scenario development also feature more prominently in the documentation of safety cases than was the case in the past, with an emphasis on transparency, traceability of decisions and comprehensiveness, due to their central position in safety cases.

As well as the methods for scenario development, the knowledge base on which scenarios are built has increased considerably in many national programmes, including, for example, new field investigation data, research results from URLs and above-ground laboratories and new knowledge of engineering materials.

6.2 Common features and differences in current approaches

Methods for scenario development are often described as primarily either top-down or bottom-up. Top-down approaches take the safety concept and the safety functions of the disposal system as their starting point, whereas bottom-up approaches start with a phenomenological system description based on the available scientific and technical knowledge concerning FEPs and their interaction. However, it has been questioned, e.g. in the MeSA project, whether an exclusively bottom-up approach, i.e. an approach that consists of piecing together individual FEPs, has ever been successfully implemented without having also developed an integrated safety concept or at least a preliminary understanding of the system evolution. One major outcome of the 2015 workshop is that most, or perhaps all, practical scenario development methods involve certain common steps (see Section 6.3), even though there remain many programme-specific details and differences in terminology. Furthermore, these methods, which are all broadly consistent with Figure 1, are not properly described as being either top-down or bottom up, but rather embody aspects of both.

Most methods for scenario development start presented at the workshop with an integrated description of the initial state of the disposal system and its subsequent evolution, including the main uncertainties in these. In line with Figure 1, there are two distinct aspects to this description:

- the safety concept and the safety functions of the disposal system;
- a phenomenological description based on the available scientific and technical knowledge concerning FEPs and their interactions.

The first of these is often considered primarily the responsibility of safety assessors (although technical experts provide important input), whereas the second is developed primarily by scientific and technical experts. Bringing these two distinct elements together requires, but can also promote, communication between safety assessors, scientists and engineers (see Figures 4 and 5).

The widespread use of the safety functions of the disposal system in the formulation of scenarios is a key development of recent years. This development sometimes features in regulations and guidelines. Finnish regulations, for example, mention safety functions, as well as performance targets and target properties for the repository barrier system (see the definition in the caption to Figure 5). In Belgium, the greater visibility of safety functions in current scenario development is in part a result of recommendations from the regulatory review of the SAFIR-2 safety assessment. In France, the NSA Guide of 2008 introduced the notion of safety functions supporting the main function of the disposal system to protect humans and the environment.

Since 1999, several methods have been developed to identify uncertainties that could challenge the safety functions and hence give rise to alternative scenarios representative of degradation or loss of performance of component or components that fulfil a safety function (e.g. early canister failure, seal defects). Some of these methods are outlined in Section 6.3.

All methods for scenario development also involve the use of FEP lists and/or FEP databases, which have become more comprehensive over time. These FEPs are screened to exclude those that are inapplicable to the disposal system at hand or are ruled out by regulations, as well as those that can be argued to have negligible impact and/or a very low likelihood of occurrence. The use of expert judgement, e.g. to assess the likelihood of occurrence of FEPs, is another feature of all scenario development methods, as well of other aspects of the safety case such as model development and data selection. Expert judgement can take a number of forms, including specialists working together on specific topics, panel discussions, and external peer review. In all cases, expert judgement implies that there is a degree of subjectivity in the decisions that are made. Thus, transparency and traceability of decisions made by expert judgement is of paramount importance. Formal, systematic methods are available that can be used to provide transparency and traceability in how the experts arrive at their judgements.

Any repository evolution scenario will include a range of assumptions regarding the initial state of the disposal system and the FEPs affecting the evolution of the engineered barrier system, its geological environment, the surface environment and exposure pathways. As noted in Chapter 2, the term “stylised approach” is frequently used in the context of radioactive waste management to refer to approaches that involve imposed rather than scientifically-derived assumptions. A stylised approach to defining aspects of biosphere evolution, future human actions and lifestyles and (as discussed above) to developing human intrusion scenarios, based on regulations or on dialogue between the proponent and regulator, may often be sufficient to meet the purposes of an assessment. According to the MeSA project, stylised approaches or scenarios are also used where site-specific information is lacking, or where the purpose of the assessment does not require site-specific information. On the other hand, according to the INTESC project, the term “stylised” should not be misunderstood as “generic”; although stylised assumptions are imposed rather than derived, there is nevertheless some potential for site- or even concept-specific information to influence or bound the formulation of stylised assumptions regarding, for example, landscape evolution, biosphere characteristics, exposure pathways and future human actions. This highlights the fact that there appears to be no universal acceptance of what precisely constitutes a stylised approach, although it is clear that all safety assessments make some use of imposed assumptions for handling poorly quantifiable or unquantifiable uncertainties in scenario development.

What-if scenarios (i.e. Category 3 in Table 3) are one type of scenario that can reasonably be described as being developed using a purely top-down, safety-function-based approach. In these scenarios, barriers or safety functions are often hypothetically removed, or assumed to fail, either one-by-one or in combination. These scenarios are not the result of any specific failure mechanism or uncertainty; they are developed purely to help bound or conceptually test repository robustness and to assess the relative importance of various repository components and safety functions (see Section 5.2).

6.3 Broad steps in scenario development

As noted above, there are certain broad steps that are common to many current scenario development methodologies.

i. Development of an integrated understanding and description of the disposal system and its evolution (including safety functions)

The development of an integrated description of the system and its evolution involves the synthesis of wide ranging information, e.g. from site characterisation, URL and surface laboratory studies, natural analogues and detailed thermal, hydrogeological, mechanical, chemical and gas (THMCG) process modelling. The character of the description of the disposal system and its evolution can depend on the programme stage, and the description evolves iteratively from one stage to the next as more information is acquired. Early on, at the site selection stage, it is reasonable to make assumptions about general site characteristics of the geosphere and biosphere, to use data from roughly analogous locations and to consider generic design choices (although, if site selection is considering different sites with different geologic environments and/or climates, these differences must be part of the site selection and design decisions). However, at later stages of the programme, and particularly during the licencing process, the system description has to be based on traceable site-specific data with appropriate quality assurance and has to include a clear identification and description of system components important to safety. Ideally, for the period during which a safety assessment is being carried out, the data to be used are "frozen" to ensure their consistent use in the various modelling activities undertaken within the assessment.

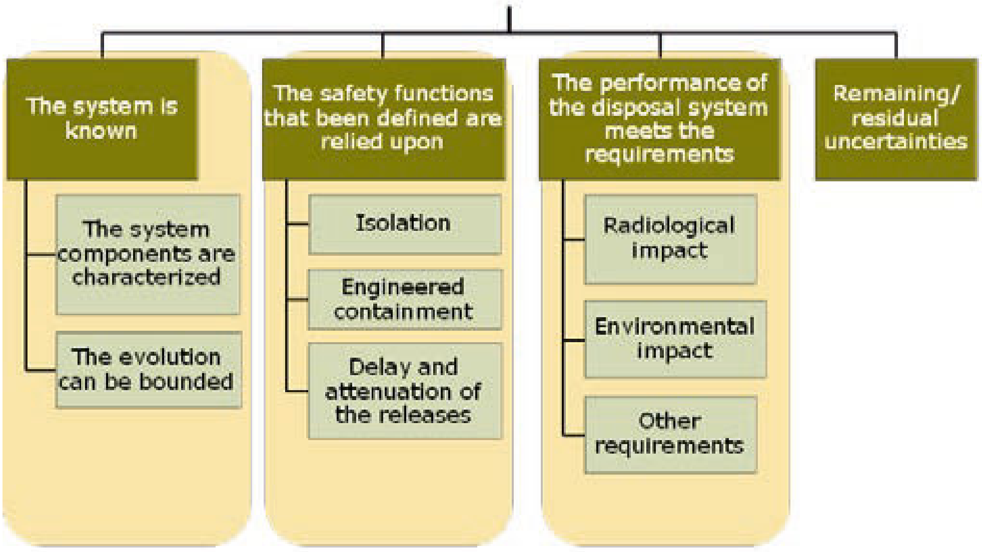
As part of the system description, safety functions are normally assigned to the engineered components of the repository and to the geosphere. Safety functions can range from those that are rather general, such as physical containment of radionuclides within waste packages or containers, to those that are more detailed and specific, such as limitation of microbial activity in clay-based buffer materials.

In some cases, the description of the evolution of the repository system (near field and geosphere) and that of the biosphere (that part of the environment normally inhabited by or accessible to humans, or used by humans, including groundwater, surface water, the atmosphere, and marine resources) are largely decoupled, e.g. because events and processes occurring in the biosphere generally have only a limited effect on the geosphere. Climate evolution, however, is an overarching FEP affecting the evolution of the entire disposal system. The biosphere is not generally assigned safety functions other than, in some cases, dilution. However, the properties of the biosphere influence how radionuclides are distributed in the human environment and so these properties and their attendant uncertainties are also taken into account when formulating scenarios, albeit often using a stylised approach (see above).

Because of the multiple disciplines involved and the rather long time needed to obtain a system description encompassing the full range of relevant space and time scales, a structured synthesis of information that gives an integrated and systematic view of the disposal system is clearly beneficial. For example, in the approach developed by ANDRA, termed Phenomenological Assessment of

Repository Situations (PARS), a series of time frames and repository situations is identified, dividing repository evolution into intervals in space and time on the basis of the phenomena that may occur and the associated uncertainties in each time frame and situation. The discretisation scheme is based on expert judgement as informed by evidence from laboratory and underground rock laboratory (URL) experiments, natural analogues, scoping calculations, modelling studies and performance assessments. In the Belgian programme, ONDRAF has developed a hierarchy of safety statements that allow scientific and technical information to be structured in a manner that supports the development of the safety case and, as explained under point iii below, of scenarios. General statements concerning the safety concept and safety functions, at the highest levels, are underpinned with more detailed and specific lower-level statements. Lowest level statements include statements of phenomenological understanding derived directly from the assessment basis. The highest-level statements in the hierarchy are shown in Figure 10.

Figure 10. Highest level safety statements in the ONDRAF/NIRAS statement hierarchy



ii. Definition of the main/reference/normal evolution scenario

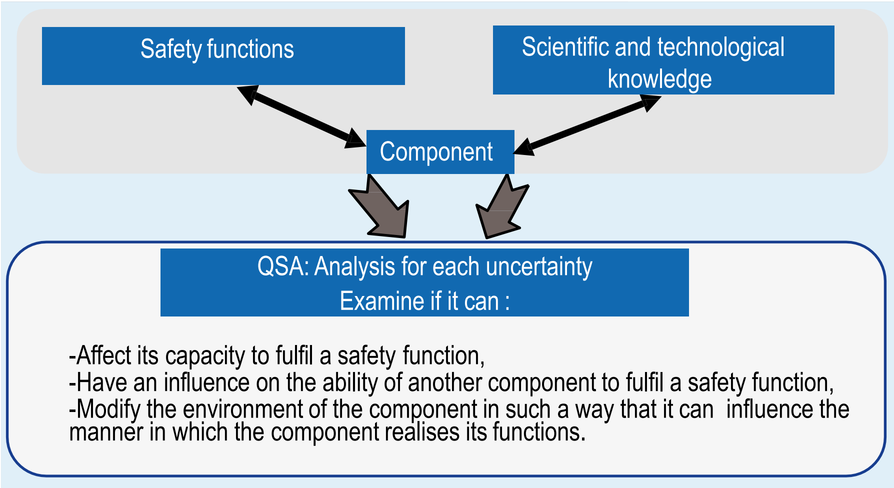
Based on the system description, the main/reference/normal evolution scenario is generally defined before other, alternative scenarios. This main/reference/normal evolution main scenario usually includes FEPs the occurrence/presence of which is judged to be probable. An apparent difference in approach was identified at the workshop between, for example, ONDRAF/NIRAS, which takes its reference scenario to be, by definition, a scenario in which all safety functions operate as intended in the presence of such FEPs, and some other programmes, such as SKB, that defines its main scenario as an expected, realistic or at least plausible evolution of the repository, and then performs analyses to determine if the safety functions are provided in this scenario and to identify situations when they are not. This difference may, however, be less significant than it appears. This is firstly because ONDRAF/NIRAS's safety functions are very broad, and include, for example, isolation of the waste and a period of complete containment of radionuclides within the overpacks. SKB's can be much more specific, such as, for example, the safety function of the buffer to limit microbial activity. ONDRAF/NIRAS's safety functions, operating as intended, are seen as essential to the implementation of the safety concept. This is not necessarily the case with SKB's safety functions, since it is asserted that the repository can provide an adequate level of protection even with a degraded performance of one or more safety functions. Secondly, as part of the overall safety case methodology, ONDRAF/NIRAS also performs analyses to test whether the safety functions will indeed operate as intended, as assumed in the reference scenario. If this is found not to be the most likely case, ONDRAF/NIRAS would consider either developing better system understanding to allow for less conservative analyses, or potentially even change the repository design.

iii. Definition of alternative scenarios

Having defined the main/reference/normal evolution scenario, the next step is to define alternative scenarios that include less probable FEPs and/or probable FEPs with less probable characteristics or outcomes (e.g. earlier than expected occurrence of canister failure, faster than expected rates of waste degradation). The derivation of these other scenarios generally involves identifying FEPs and uncertainties in the system description not encompassed by the main/reference/normal evolution scenario, in particular those that could cause a loss (or significantly degraded performance) of one or more of the safety functions, and thus perturb the normal or expected evolution of the disposal system. As noted earlier, several methods have been developed to accomplish this step.

In France, for example, ANDRA has developed an approach termed Qualitative Safety Assessment (QSA) to explore possible malfunctions of the repository components and examine if these can affect the capacity of a component to fulfil its safety functions, or have an influence on the capacity of other components to fulfil their safety functions. The role of QSA is illustrated in Figure 11.

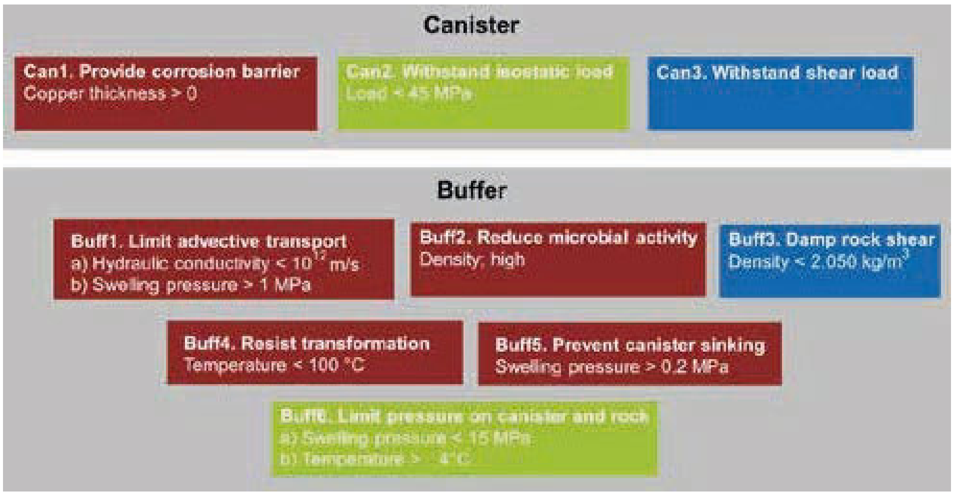
Figure 11. QSA as a tool use by ANDRA to assess the effects of detrimental FEPs and uncertainties on safety functions



In the Swedish programme, SKB has developed and applied the concept of safety function indicators, which are measurable or calculable properties that indicate the extent to which the system components achieve their safety functions. Safety function indicators are usually compared with indicator criteria that define, where possible, quantitative limits (maximum or minimum conditions) that bound the conditions under which the corresponding safety function may be maintained. Figure 12 illustrates safety functions, indicators and criteria for the canister and buffer used in SKB's SR-Site project. For example, there is a safety function that a canister containing spent nuclear fuel should withstand isostatic loads. The safety function indictor is the isostatic load on the canister. The corresponding criterion used in SR-Site was that this should be less than 45 MPa, which was the "design load" on the canister. FEP and uncertainties, such as the occurrence of an unexpectedly thick ice sheet, that could lead to such criteria not being met potentially give rise to scenarios. In Finland, performance targets (for the engineered barriers) and target properties (for the rock) have a similar role to the safety function indictor criteria used in Sweden.

In Belgium, the ONDRAF/NIRAS hierarchy of safety and feasibility statements also provides a means to assess the effects of detrimental FEPs and uncertainties on safety functions. An argumentation approach is adopted, whereby the potential impact of perturbing FEPs and associated uncertainties on low-level statements is considered first. Any uncertainty that calls into question the validity of low-level statements may also call into question the higher-level statements that the low-level statements underpin. In this way, uncertainties may propagate through the hierarchy of statements, from the bottom-up. Any uncertainty propagating as far as high-level statements representative of the safety functions of the disposal system gives rise, potentially, to altered evolution scenarios.

Figure 12. SKB's safety functions, indicators and criteria for the canister and buffer



Source: Figure 8-2 of SKB 2011.

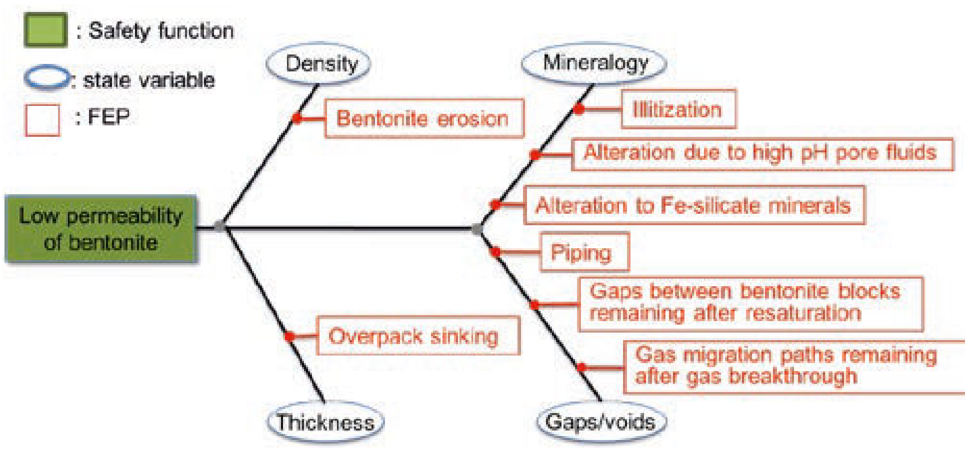
In Canada, NWMO's "high-level safety features", which have been specified for the geology, for the waste characteristics, for design and for institutional control, play a similar role in scenario development to the ONDRAF/NIRAS high-level safety statements. Table 4 illustrates the approach, whereby any FEP that could compromise the safety feature is considered to be potentially scenario generating. Those potential scenario-generating FEPs that are not ruled out (e.g. on the grounds of their very low probability) are grouped to define a set of "disruptive event scenarios".

Table 4. Use of high-level "safety features" in disruptive scenario identification by NWMO

Safety Feature	Potentially Compromised by	Consider as Failure Mechanism
The depth of the host rock formation should be sufficient for isolating the repository from surface disturbances and changes caused by human activities and natural events.	Near-surface design adopted (FEP 1.1.02).	**No,** only a deep design is being considered for the repository.
	Meteorite impact (FEP 1.5.01).	**No,** due to low probability of meteor impact capable of compromising safety due to the relatively small repository footprint (~6 km^2) and depth of repository (~500 m). See Garisto (2013) for further discussion of probabilities.
	Exploration borehole penetrates into repository providing enhanced permeability pathway to surface environment and potential for direct exposure to waste (FEP 1.4.04).	**Yes,** although the absence of economically exploitable resources, and the depth (~500 m) and relatively small repository footprint (~6 km^2) mean that the probability of such a borehole intruding into the repository would be very low during the period of greatest potential hazard.
	Mining and other underground activities resulting in excavation in the vicinity of the repository (FEP 1.4.05).	**No,** due to assumption of the absence of commercially viable mineral resources near or below repository level. Shallow quarrying or tunnelling activities are unlikely to affect the repository because of repository depth (~500 m). Also, most underground activities would likely be preceded by exploration boreholes, as addressed above.

Similarly in Japan, an argumentation model approach is adopted, whereby evidence and arguments supporting detailed statements regarding the safety functions are compiled, and then critical questions are examined that challenge the evidence and arguments. An example from the Japanese programme of the range of FEPs that could detrimentally affect the safety function of the low permeability of a bentonite buffer is shown in Figure 13.

Figure 13. Example from the Japanese programme of FEPs potentially affecting the safety function of the low permeability of a bentonite buffer and its associated state variables



In all these approaches, the impact of the perturbing FEPs, either individually or in combination, is considered when defining scenarios for the evolution of the repository, which are assigned to various categories as discussed in the previous chapter. Some scenarios may be fairly trivially combined if their consequences are qualitatively similar and can be analysed with the same model. Other combinations involving multiple, unlikely FEPs can often be excluded from detailed analysis on the grounds of their low probability. However, there are sometimes combinations that are less readily analysed or excluded. In Korea, for example, KAERI has developed a detailed method for developing and analysing complex scenarios featuring various temporal combinations of events (see Figure 7).

iv. Comprehensiveness checking

Finally, FEP lists and other tools may be used to confirm that key FEPs and uncertainties are covered adequately in one or more of the identified scenarios and associated calculation cases. This procedure is sometimes described as completeness or comprehensiveness checking. If coverage is deemed to be inadequate, then additional scenarios and/or calculation cases are developed. There are, however, other aspects to completeness or comprehensiveness checking, as described in Section 6.5.

6.4 Tools for implementing the broad steps

Tools for implementing the broad steps in scenario development described above take a variety of forms, ranging from advanced software, including knowledge management tools, which can be applied to scenario development as a whole, to more specific procedures, charts, diagrams and computational tools that are more limited in scope. A few of these tools that were mentioned in questionnaire responses or at the workshop are described briefly, below.

1. Interaction meetings

"Interaction meetings" provide a platform for interdisciplinary communication and can also be a means of formalising the process of expert elicitation. Such meetings are used, for example, to agree on the selection of scenarios and to determine modelling approaches and parameter values or ranges for their analysis through discussions between safety assessors and specialists in relevant disciples. The formalised procedures adopted for these meetings are considered to be helpful in increasing transparency and allowing for clear communication with a variety of stakeholders.

2. FEP lists, catalogues and databases

Project-specific or national FEP lists, catalogues and databases have been developed by most programmes as a tool in scenario development. The NEA International FEP list and associated database is also widely used, mainly as a basis or checklist for project-specific or national lists. To facilitate the compilation and development of scenarios, the NEA is developing a web-based database which includes an international FEP (IFEP) list that includes all relevant factors to all stages of a repository development programme from inception to repository closure. The IFEP list will also have the ability to cross-link to project-specific FEP lists which will allow users to screen FEPs and, if required, give the likelihood of occurrence of that particular FEP based upon the project-specific considerations. In 2015, the IGSC FEP Task Group issued a revised IFEP list (in press) following a thorough review of ten (10) recent national project specific FEP lists. The electronic web-based NEA database, anticipated to be released in late 2015 or early 2016, will be equipped with this 2015 version.

As well as their use in completeness checking, FEP databases can also provide a means to analyse or assess the effects of detrimental FEPs and uncertainties on the barriers and safety functions. In the German programme, for example, a FEP database has been developed that justifies important decisions and categorisations required for the development of scenarios. To this end, in addition to the standard FEP description information, the database also contains the following information:

- statements on probability for each FEP,
- the influence of each FEPs on specific barriers in the repository system, e.g. shaft or drift seals, and
- the dependencies among the relevant FEPs.

FEP lists, catalogues and databases tend to become more developed as national programmes progress through successive stages.

3. Storyboards

Storyboards, which are diagrammatic illustrations of the FEPs and their interactions in a given scenario and/or time frame, are a useful means to promote discussions between experts in the course of interaction meetings and other exchanges, and can help, for example, in the identification of uncertainties. An example of a storyboard from the Belgian programme is shown in Figure 14.

FEP charts or diagrams can be also used as a basis for discussing how FEPs are related to system evolution and their influence upon each other. Figure 15 shows an example of a FEP chart from the Japanese programme and Figure 16 and example from the Swedish programme used in SR-Site to cover factors important for radionuclide containment.

These charts give an overview of all initial-state properties, important processes and external influences that can affect the system evolution including, in the Swedish case, safety function indicators. Note that, even if FEPs and uncertainties are identified that could lead to safety function indicator criteria not being upheld, this does not necessarily mean that the repository is unsafe, but rather that more elaborate analyses and/or other additional information are needed to evaluate safety.

Figure 14. ONDRAF/NIRAS storyboard for the high-level waste HLW and the surrounding near field

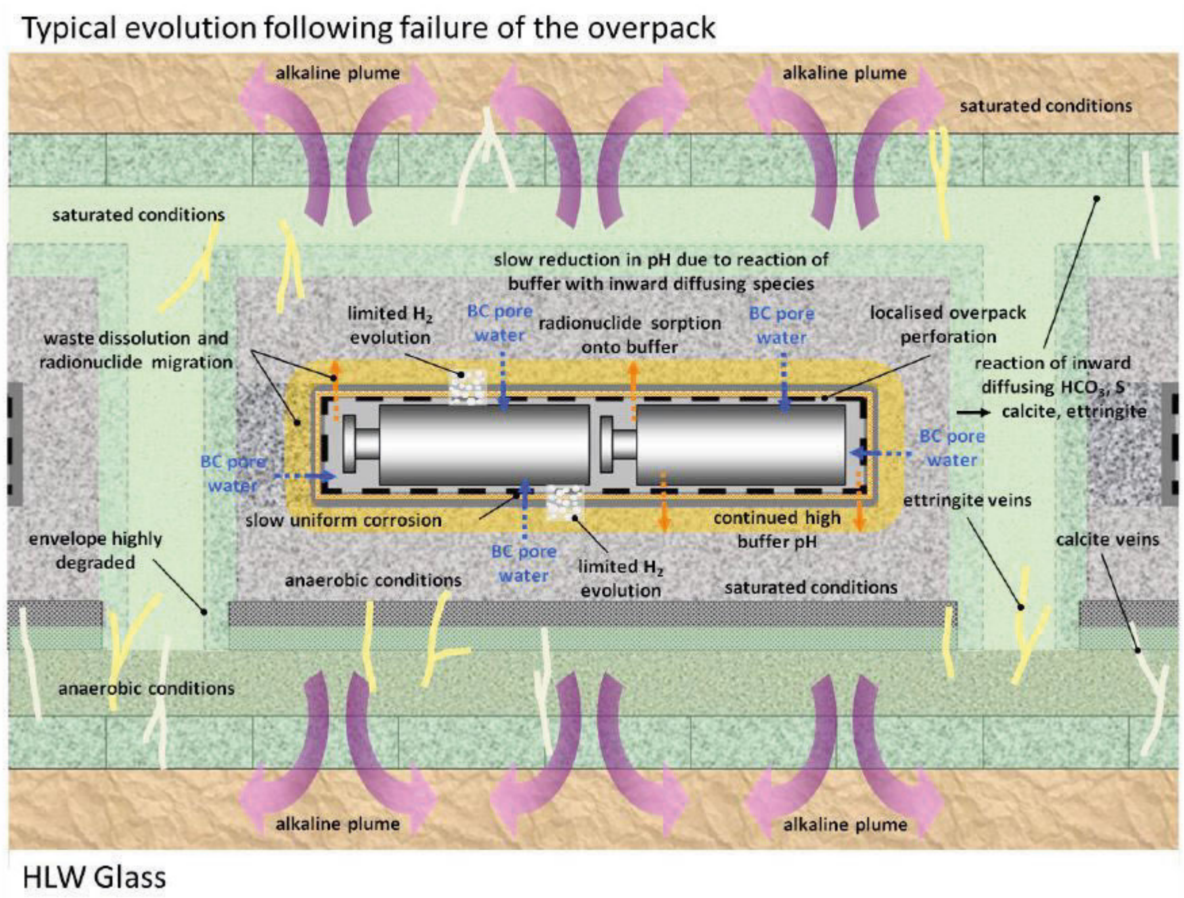


Figure 15. Example of a FEP chart from the Japanese programme

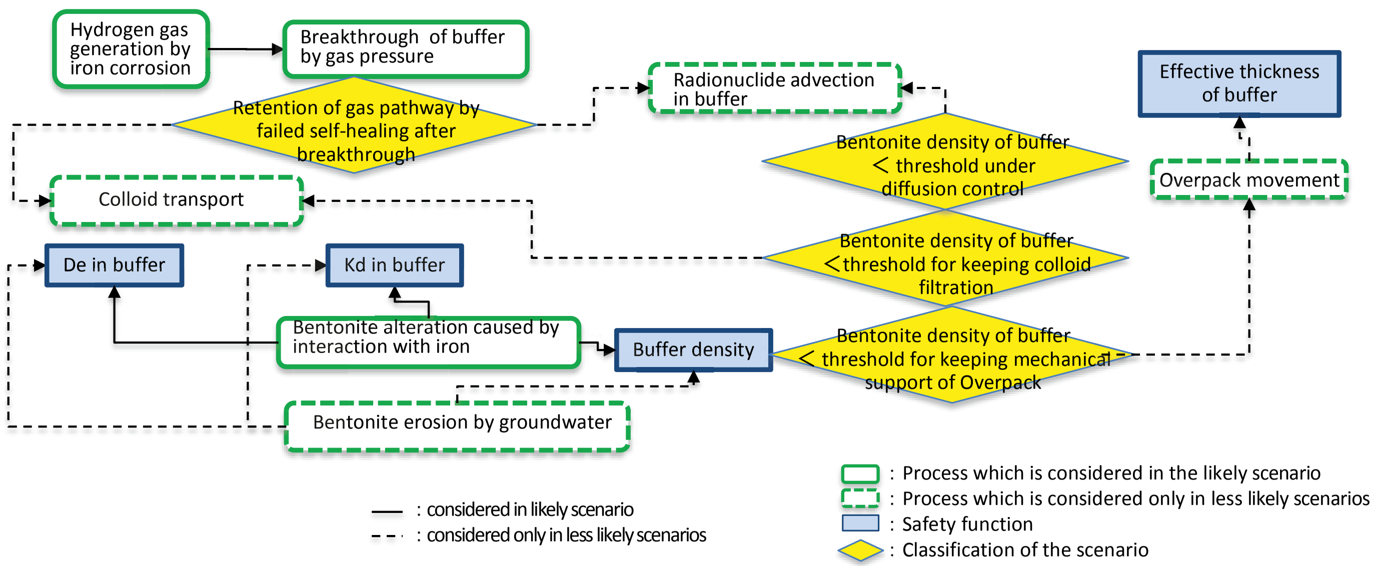
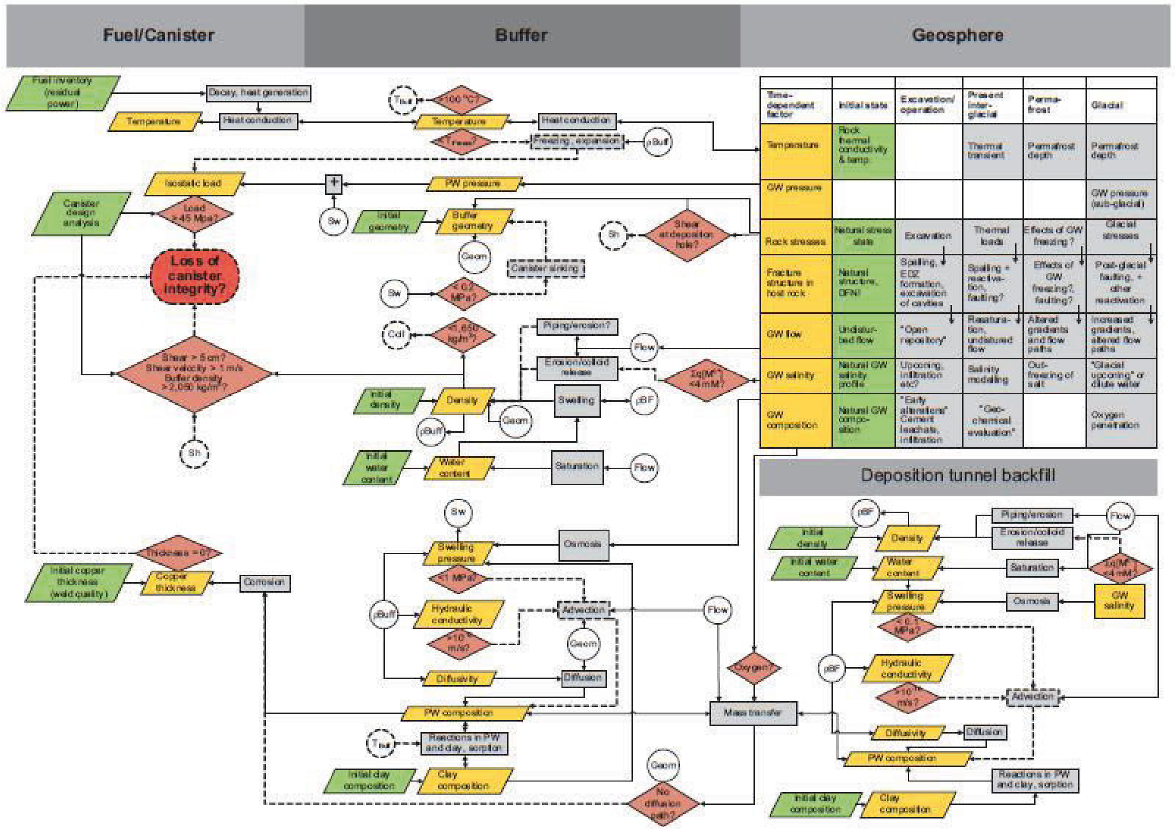


Figure 16. The SR-Site FEP chart, covering factors of relevance for containment



Colour coding: green – initial state factors; yellow – variables; grey – processes; red – safety function indicators. Solid lines: influences that always occur. Dashed lines: influences if there is safety function indicator violation. Circles: interrupted influence lines (to increase readability) (from Figure 8-4 of SKB 2011).

4. Sensitivity analyses

Model sensitivity analyses are used in many programmes to develop an understanding of how a repository system functions in providing safety, helping to identify, for example, what is important with respect to the rates of processes, timing of events, spatial extent of features, etc. This is also a regulatory requirement in the Belgian programme.

6.5 Addressing the issues of comprehensiveness and sufficiency

Comprehensiveness in scenario development, i.e. ensuring that the set of scenarios is sufficient for the application at hand and that no important phenomena or uncertainties have been overlooked, is a general principle of scenario development enshrined in some way in most regulations, as discussed in Section 3.2.

A number of approaches are used together to ensure conformity with this principle, several of which have been mentioned earlier in this document. FEP lists are used in most programmes either directly in scenario development or (less directly) in comprehensiveness checking to confirm that key FEPs and uncertainties are covered adequately in one or more of the identified scenarios. Procedures to promote the comprehensiveness of both scenarios and FEP lists include:

- Interaction meetings, internal workshops and internal or external peer review. External reviews in particular are valuable, since they can avoid the biases or habitual oversights that may inadvertently develop within any given programme. In addition, publishing in peer-reviewed journals, presenting at conferences, and pursuing collaborative research promote comprehensiveness.
- Application of multiple FEP classification/organisation schemes, which is an approach that has been adopted in the US.
- Use of FEP matrices. These are two-dimensional structures used to show the interaction between FEPs that can aid in FEP organisation and checking and promote comprehensiveness. They can also support the development of an integrated understanding and description of the disposal system.
- Comparisons/audits with scenarios and FEP lists developed by other comparable national programmes, as well as generic FEP lists such as that developed by the NEA.

More generally, the use of methods based around both FEPS and safety functions can be seen as favouring comprehensiveness. In particular:

- the development of a detailed, FEP-based description of the disposal system should reduce the likelihood that any important detrimental FEPs and uncertainties have been overlooked; and

- the identification and analysis of safety functions should reduce the likelihood that potentially safety-relevant impacts of these detrimental FEPs and uncertainties have been overlooked.

Although it is impossible to demonstrate that all possible FEPs within a complex and evolving system have been identified, the what-if scenarios, developed by many programmes can be seen as a means to examine the robustness of the barrier system to any reasonably conceivable detrimental phenomenon, even those that may have been overlooked e.g. in the development of FEP lists.

It was, however, noted in the workshop that “the devil is (often) in the detail”. A key challenge for the implementer in applying their methodology, as well as for the regulator in assessing implementation, is to identify the key judgments that have been made, either in discounting the potential importance of a FEP (bottom-up) or the in identification of different categories/causes of safety function failure (top-down). There are, in particular, judgments that are made regarding “plausibility”, where a phenomenon is known to exist (i.e. the FEP is in the database), but the underlying knowledge-base is sparse, or at least debatable. This is particularly relevant if a case can be made for uncertainty associated with that FEP giving rise, under certain circumstances, to loss of significant degradation of one or more safety functions, or even to multiple common cause failures to barriers and safety functions. Sensitivity analyses in which specific FEPs are included in the analysis, but do not operate as expected, could be a useful way to explore the potential importance of the issue and its implications, focusing attention on whether a potential scenario-initiating FEP requires further attention.

A comprehensiveness/sufficiency issue of increasing interest concerns scenarios arising from deviations from the planned initial state of the disposal systems that are undetected, such that no corrective measures are applied. These could arise, e.g. from manufacturing defects and/or failure of quality control, or from mishaps during repository construction, operation and closure. These are increasingly of concern for programmes approaching licencing; an examination of such scenarios is a requirement in some regulations, such as those in France, Sweden and Finland. The issue is addressed in the ongoing IAEA GEOSAF-II project[10], which is considering the interface between the operational/closure phases and the post-closure phase of repository evolution.

10. www-ns.iaea.org/projects/geosaf/.

7. Analysis of scenarios

The following paragraphs provide an overview of the main concepts and methods used in the quantitative evaluation of the radiological and other consequences of scenarios, termed the analysis of scenarios in the present report. The overview is brief, since this topic was not one of the main areas addressed by the questionnaire or workshop. Detailed reviews of the state-of-the-art in issues associated with the analysis of scenarios, including the development of conceptual and mathematical models, the treatment of uncertainty and the use of sensitivity analysis were carried out in the MeSA and PAMINA projects, and the interested reader is referred to the reports of these projects, NEA (2010) and Galson & Richardson (2011), for further information.

7.1 Development of models of scenarios

Scenarios are analysed by means of conceptual models, mathematical models, their abstraction into assessment models (and corresponding computer codes) and input data. Sometimes a single assessment model can be used to handle more than one scenario (though with different input parameter sets). For other scenarios, however, models must be tailored to the specific FEPs and interactions included in the scenario.

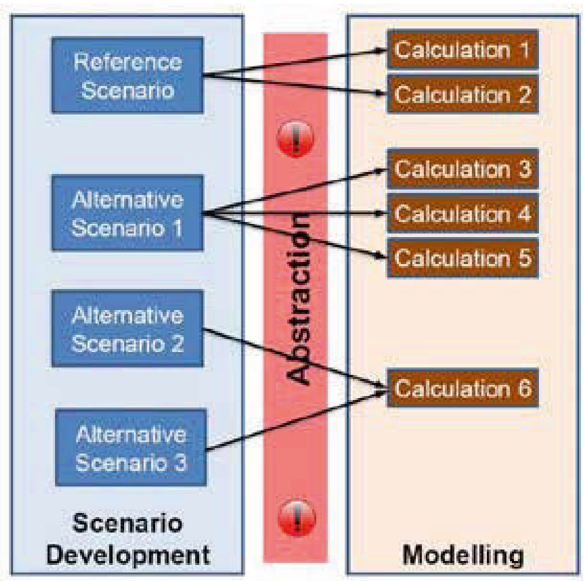
Abstraction can be considered to be the process of incorporating scientific knowledge relevant to a scenario into a model, taking into account the limits of, and uncertainties in, this knowledge, as well as requirements related to the intended purpose of the model. These requirements may include, for example, the types of safety indictors and performance indicators to be calculated, the robustness or conservatism of the calculation results with respect to model and data uncertainties and ease of verification of the computer code used to implement the model.

Abstraction implies 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, nevertheless, confidently expected to lead to lower consequences than those calculated using the model. The abstraction process generally involves a high degree of expert judgement.

7.2 Deterministic and probabilistic analysis techniques

The significance of model and data uncertainties relevant to each scenario are generally explored in sensitivity analyses. These can be limited to subsystems (e.g. analyses of the performance of the canister or buffer), or can cover total system performance. Sensitivity analyses involve multiple calculations, each with its own specific model assumptions and/or parameter values, which span the ranges of uncertainty (Figure 17). Specific approaches include probabilistic techniques, where calculation cases (or "realisations") are generated by sampling parameter values at random from probability density functions (PDFs), a set of individually performed deterministic calculations, or, as in many recent safety assessments, a combination of both approaches.

Figure 17. Schematic illustration of the use of multiple calculation cases in the analysis of scenarios



Scenario uncertainties may also be handled using either deterministic or probabilistic analysis techniques. It was pointed out in the PAMINA project and during the workshop that it is rarely the case that "all" uncertainties are addressed probabilistically ("all" meaning not all uncertainties that exist, but all uncertainties accounted for in the assessment). In fact, the majority of programmes appear now to use a combination of deterministic and probabilistic calculations, often with parameter uncertainty treated probabilistically and alternative scenarios and/or model assumptions assessed individually, with or without assigning probabilities to them. In some cases, a deterministic approach is used in the initial evaluation of a scenario, and then a probabilistic approach is used to cover a wide range of uncertainties systematically.

8. Summary and conclusions

This report provides an overview of the state of the art in scenario development related to the long-term safety of geological repositories for radioactive waste, based largely on the presentations and discussions at a recent NEA workshop together with a review of responses to a questionnaire.

Since the previous NEA workshop in 1999, work by international organisations, including the NEA MeSA and INTESC projects, IAEA safety standards and the HIDRA project on human intrusion, WENRA safety reference levels and the EC PAMINA project, has provided new insights on scenario development, as has the 2015 NEA workshop that is the basis for the present document. These insights have been taken up by national programmes in developing and applying scenario development methodologies and in formulating regulations and regulatory guidance. Efforts have been made to ensure comprehensiveness, traceability of decisions, and the integration and logical structuring of interdisciplinary knowledge in the development of scenarios. Scenarios and scenario development also feature more prominently in the documentation of safety cases than was the case in the past, with an emphasis on transparency and traceability of decisions.

Regulatory guidance is not only provided in formal documents, but also comes from dialogue between the proponent and regulator and from the regulatory review of the proponents work. Dialogue can provide confirmation that the proponent's approach to scenario development is in line with regulatory expectations (or lead to modifications in the approach if it is not), as well as promoting a common understanding on more detailed aspects of scenario formulation and analysis. Most regulatory documents identify general principles and objectives for scenario development. In general, however, the specific scenarios to be analysed and the methods used to develop scenarios are not prescribed in regulations. Rather, it is for the proponent to justify which FEPs to include in the scenarios that they analyse and how to represent them in the models. Although the level of detail in regulatory guidance should (and does) increase as a programme progresses through the licencing process, many proponents and regulators see some advantages in limiting, to some extent at least, the degree of detail in the formulation of such guidance. In any case, the workshop noted no pressing demands from any of the proponents represented for more (or less) detailed requirements/guidance in their own national regulations.

Scenario development is an integral part of any safety case. It is used to develop and demonstrate understanding of the system and to show (or to test whether) safety criteria, normally formulated in terms of dose and/or risk, are met for a range of potential evolutions of the disposal system. Scenario development supports the management of uncertainties within and between programme stages (safety strategy), in integrating scientific and technical knowledge with a focus on its relevance to the repository safety functions and in promoting interdisciplinary communication.

All programmes represented at the workshop divide their scenarios into classes or categories, based on the types of FEPs that are covered in the scenarios, their likelihood/probability, and their potential effect on the safety functions. In most cases, this classification is determined by regulations or regulatory guidance. In addition to the main (more plausible) scenarios, the value of "what-if" scenarios or cases in investigating or demonstrating system robustness and in illustrating the functioning of specific barriers is widely recognised. Future human actions, and human intrusion in particular, are treated as a separate scenario category requiring somewhat different handling in the safety case compared with other scenarios, using stylised approaches.

The integration of top-down and bottom-up elements appears to be a feature of all practical approaches to scenario development. The widespread use of the safety functions of disposal systems in the formulation of scenarios is a key development of recent years and a set of methods to analyse or assess the effects of detrimental FEPs and uncertainties on safety functions has been developed.

The workshop identified that there is a clear trend towards using approaches based on identifying FEPs and their attendant uncertainties that could challenge the safety functions for the derivation of alternative scenarios. The impact of the perturbing FEPs, either individually or in combination, is then considered when defining scenarios for the evolution of the repository, which are assigned to various categories. FEP lists and other tools are used to confirm that key FEPs and uncertainties are covered adequately in one or more of the identified scenarios and associated calculation cases.

Scenarios are analysed by means of conceptual models, mathematical models, their abstraction into assessment models (and corresponding computer codes) and input data. The significance of model and data uncertainties can by explored in sensitivity analyses that can be limited to subsystems or can cover total system performance. Specific approaches include probabilistic techniques, where parameter values are sampled at random from probability density functions (PDFs), a set of individually performed deterministic calculations, or a combination of both approaches.

It can be concluded from the overview given in this report that clear advances have taken place in recent years addressing key challenges identified in the 1999 workshop. Whilst there has been a substantial degree of international harmonisation in approaches to scenario development, experience in applying such approaches has nevertheless shown that "the devil (often) is in the detail". Further development may be helpful in areas including:

- communicating the role and choice of scenarios between experts within a waste-management programme and also to wider audiences;
- assigning likelihoods to FEPs and scenarios;

- the use of quantitative outcomes from what-if (barrier neutralisation) scenarios in evaluations of system “robustness”;
- the use of methods such as sensitivity analyses to guide possible future R&D, e.g. in cases where a FEP is known to exist, but the existing knowledge-base is too sparse to make a definitive judgement on whether or not the FEP is likely to be scenario generating; and
- further development and integration of broad regulatory guidance relating to the use of imposed or stylised assumptions in areas of scenario analysis where these are appropriate, e.g. in relation to future human actions and biosphere assessment.

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Appendix A. NEA scenario development workshop programme

		DAY 1 – Monday 1 June 2015
13:00	**1.0**	**Opening Remarks –** *(15 min)*
13:00		**Welcome Notes**

- Welcome remarks
- NEA work on scenario development since the 90's
  - 1992 NEA PAAG report,
  - 1993 PAAG working group results documented in NEA FEP report,
  - 1996 IPAG study
  - 1999 Madrid Workshop
  - 2014 IGSC Topical Session on "Extreme Geological Events"
- Introduce workshop chair

Gloria KWONG, NEA

NEA 2015 SCENARIO DEVELOPMENT WORKSHOP

Chair: Sylvie VOINS, Andra ***Rapporteur: Paul SMITH***

13:15	**2.0**	**Introduction** – *[40 min]*

- Key aspects of scenario development, its roles in safety assessment, development approaches, definitions and expectations
- Recap key conclusions of the 1999 workshop
- Key findings of the MeSA, PAMINA Projects
- Summary of the 2014 questionnaire responses – 4 parts, each to be discussed in more details in following sessions
- Summary of progress in scenario development since 1999 – evolution of safety cases, use of safety functions, etc.
- Workshop purpose, structure and sessions

Sylvie VOINIS, Andra, France

13:55	**3.0**	**Special presentation on IAEA Human Intrusion HIDRA Project** *[20 min + 5 min questions]*
13:55		▪ Decision making for human intrusion, timeline and integration into the safety case ▪ Protective measures ▪ Human intrusion scenarios ▪ Societal factors *Lucy BAILEY, HIDRA Chair / Yumiko KUMANO, IAEA*
14:20	**4.0**	**Regulatory Perspectives on Scenario Development – Presentation**
14:20	4.1	**International standard** *[20 min + 5 min questions]* *Bengt HEDBERG, WENRA*
14:45	4.2	**National presentation** *[20 min + 5 min questions]* *Michael EGAN, SSM, Sweden*
15:10		*Break – [30 min]*
15:40	4.3	**Perspectives on regulatory requirements - 3 working group discussions** *[1hr 30 min]* Questions: ▪ To what extent is prescriptive guidance necessary? (e.g. to limit arbitrary speculation ?) ▪ To what extent is the regulatory guidance adequate for scenario development? (what should a regulator expect to see in terms of treatment, levels of details and documentation?) ▪ To what extent is the regulatory guidance adequate for the step by step development of the disposal programme (e.g. to limit excessive demands at a preliminary stage)?
17:10	**4.4**	**Summary of working group discussions**
17:10	4.4a	**Group 1 summary** *[15 min]* *Group 1 rapporteur*
17:25	4.4b	**Group 2 summary** *[15 min]* *Group 2 rapporteur*

17:40	4.4c	**Group 3 summary** *[15 min]* *Group 3 rapporteur*
17:55	4.4d	**Discussion** *[20 min]* *All*
18:15		**End of Day 1 / Cocktail reception**

DAY 2 – Tuesday 2 June 2015

09:00	**5.0**	**Scenario Development – National presentations**

Scenario Development National presentations – *[20 min + 5 min clarification question each]*

- Objectives in PA/SA (in line with stage of the program)
- Terminology/classification/definitions
- Approach/methodology (in particular use of safety functions/use of FEPs, place of technology knowledge and scientific knowledge)
- Temporal sequences, handling of issues related to timescales
- From scenarios to safety models
- Evolution of scenario methods as safety cases are refined
- Indicators
- If experience used in other field/industry was applied in your scenario development, please describe in your ppt.

09:00	5.1	**Methodological developments pertaining to scenario since SAFIR 2** *Manuel CAPOUET, ONDRAF/NIRAS, Belgium*
09:25	5.2	**Scenario development at the NWMO** *Neale HUNT, NWMO, Canada*
09 :50	5.3	**Scenarios for the safety assessment of underground repositories, Czech Republic Case** *Soňa KONOPASKOVA, RAWRA, Czech Republic*
10 :15	5.4	**POSIVA's scenario development methodolog**y *Nuria MARCOS / Paul SMITH, POSIVA Oy, Finland*

10 :40	5.5	**Andra's scenarios development methodology and application for Cigéo post-closure safety assessment** *Lise GRIFFAULT, Andra, France*
10:40		**Break – [30 min]**
11:10	5.6	**Scenario development: The German strategy** *Jens WOLF, GRS, Germany*
11:35	5.7	**Scenario development for risk-informed safety assessment of geological disposal** *Akie Makiuchi, NUMO, Japan*
12:00	5.8	**Development of complex scenarios for the risk-based safety assessment of geological repository** *Jongtae JEONG, KAERI, Korea*
12:25		**Lunch** – *[1hr 35 min]*
14:00	5.9	**Scenarios in the safety assessment SR-Site; Methodology and application** - *[25 min]* *Allan HEDIN, SKB, Sweden*
14:25	5.10	**Scenario development in the US** - *[35 min]* *Geoff FREEZE / Ross KIRKES / Christi LEIGH*
15:00	5.11	**Scenario Development – Working group discussion** – *[1hr 30 min]* Questions to discuss: ▪ What are the classes of scenarios and their roles in your approach? Please indicate their objectives with respect to the stage of the programme's development and also your opinion on how to use stylized scenarios (e.g. narrative *vs.* non sequential, representative vs. conservative)? ▪ How do you proceed in scenario development? Use of safety functions, use of FEPs? Top-down/bottom-up approach/mixed approach? What is the role of expert judgment? ▪ How do you proceed from scenario to safety models and/or calculation cases? Place of sensitivity case?
16:30		**Break** – *[30 min]*

17:00	**5.12**	**Summary of working group discussions**
17:00	5.12a	**Group 1 summary** - *[15 min]* *Group 1 rapporteur*
17:15	5.12b	**Group 2 summary** - *[15 min]* *Group 2 rapporteur*
17:30	5.12c	**Group 3 summary** - *[15 min]* *Group 3 rapporteur*
17:45	5.12d	**Discussion** - *[30 min]* *All*
18:15		**End of Day 2**
		DAY 3 – Wednesday 3 June 2015
	6.0	**Scenario completeness, comprehensiveness and sufficiency**
9:00	6.1	**Scenario completeness in the US** - *[15 min]* *Geoff FREEZE / Ross KIRKES / Christi LEIGH*
09:15	6.2	**Working group discussion on completeness, comprehensiveness and sufficiency** - *[1 hr]* Questions to discuss: ▪ How do you determine whether the set of scenarios considered in the safety analysis is sufficiently complete? ▪ How do scenarios evolve at different developmental stages (e.g. site generic vs. site specific?) ▪ What is the role of internal and external peer review?
10:15	**6.3**	**Summary of working group discussions**
10:15	6.3a	**Group 1 summary** - *[15 min]* *Group 1 rapporteur*
10:30	6.3b	**Group 2 summary** - *[15 min]* *Group 2 rapporteur*
10:45	6.3c	**Group 3 summary** - *[15 min]*

		Group 3 rapporteur
11:00	6.3d	**Discussion** - *[25 min]*
		All
11:25	**7.0**	**Workshop summary / key conclusions**
11:25		**Chair's summary** - *[20 min]*
		Sylvie VOINIS
11:45		**Workshop Adjourn**

Appendix B. Compilation of workshop abstracts

HIDRA: IAEA project on Human Intrusion in the context of Disposal of Radioactive Waste

Lucy Bailey (RWM, UK) and Yumiko Kumano (IAEA)

The HIDRA project (Human Intrusion in the context of Disposal of Radioactive Waste) was launched following a Technical Meeting at the IAEA headquarters to discuss and explore the means of effectively addressing future human actions and human intrusion in safety cases for radioactive waste disposal facilities.

The HIDRA project addresses both near-surface and geological radioactive waste disposal facilities, including the commonalities and differences in approach between these types of facility. The objectives of the HIDRA project are to:

- Share experience and practical considerations for development and regulatory oversight of assessments of impacts of future human actions, primarily human intrusion, in the context of the safety case during the lifecycle for a disposal facility;
- Provide specific information regarding technical, societal and design considerations to support development of a structured process or methodology for developing scenarios for site-specific application;
- Describe the role of assessments of future human actions for siting, design and development of waste acceptance criteria in the context of the safety case;
- Provide suggestions for communication strategies to describe the rationale for assessments of future human actions and for interpretation of the results of those assessments; and
- Provide recommendations, as appropriate, for clarification of existing IAEA requirements and guidance relevant to the assessment of future human actions and human intrusion.

The project continued until 2014 and a follow-on phase is currently being considered. Three working groups were created focusing on human intrusion scenarios, societal factors, and protective measures, respectively.

It is planned that the outcome of the project will be published as a technical document to provide guidance on how to address human actions in the safety case and safety assessment of radioactive waste disposal in the future, and how those assessments may be used to optimise siting, design and waste acceptance criteria within the context of a safety case. The report also describes a catalogue of “measures” that may be considered to reduce the likelihood and/or consequences associated with human intrusion.

SSM’s regulatory expectations regarding selection and definition of scenarios for post-closure safety analysis

Michael Egan; Swedish Radiation Safety Authority

The Swedish Radiation Safety Authority (SSM) has published regulations (and related general guidance) relating the long-term safety of facilities for the disposal of spent fuel and radioactive waste. SSM’s regulations are currently presented in two separate documents. These reflect arrangements prior to 2008, when responsibilities for radiation protection and the safety of nuclear installations were divided between two separate regulatory authorities. These two sets of regulatory requirements are currently being applied in SSM’s regulatory review of the licence application from the Swedish Nuclear Fuel and Waste Management Company (SKB) to construct and operate a disposal system for spent nuclear fuel.

Both sets of regulatory requirements, and in particular the associated general guidance on their application, cover the use of scenario analysis as part of the examination of the evolution of a disposal facility and estimation of potential radiological impact over a range of timescales. Requirements for quantitative safety assessment of the repository system are presented in terms of overall expectations regarding scope and purpose, including: providing fundamental understanding of safety functions and performance over different time periods, the significance of uncertainty in relation to demonstrating compliance with criteria for radiological protection and use of the results to provide feedback to design considerations. In relation to scenario analysis, the primary focus is therefore on the role of scenarios in contributing to such outcomes, rather than seeking to prescribe how scenarios should be developed.

In our workshop presentation, we describe how considerations of, for example, scenario categorisation, scenario likelihood and timeframes for analysis are addressed in SSM’s regulations. In addition, as an input to workshop discussions, we offer some more general reflections on the role of regulatory guidance in the selection and definition of scenarios for post-closure safety analysis. Such observations are in part based on considerations that have arisen during the course of the ongoing assessment of SKB's licence application. Potentially relevant considerations include: the relationship between expectations for scenario analysis and the fundamental safety concept for the repository system, the potential role of a scenario-type approach to investigate robustness to deviations from the assumed initial system state, expectations at different stages in a step-wise permitting process.

Methodological developments pertaining to scenario since SAFIR 2

Capouet M.1, Depaus C.1 and Weetjens E.2
ONDRAF/NIRAS, Avenue des Arts 14, 1210 Brussels, Belgium
Belgian Nuclear Research Centre, Boeretang 200, 2400 Mol, Belgium

The last formal safety assessment exercise dates back to 2001 (SAFIR 2). The assessment was based on Boom Clay as reference host rock. The scenario derivation methodology relied mainly on developments made in the nineties at the international level in the framework of the EC EVEREST project and of the NEA discussions. The SAFIR 2 scenario development methodology was mainly based on compilation and screening of FEPs. International FEP catalogues and expert judgments fed these processes. This bottom-up approach was complemented with a top-down analysis (PROSA methodology) consisting of analysing all possible states of the barriers of the disposal system. Impact analysis was then investigated by assuming that each of these barriers is either present (active) or absent (not effective).

The international peer review of SAFIR 2 under the auspices of the NEA acknowledged the maturity of the Belgian scientific programme and endorsed the conclusion of ONDRAF/NIRAS to pursue the research, development and demonstration (RD&D) programme on poorly indurated clay. However, the International Review Team noted the need for ONDRAF/NIRAS to update and strengthen the systematism of its scenario development methodology.

In the framework of the SFC1 preparation dedicated to poorly indurated clays (Boom Clay and Ypresian clays), ONDRAF/NIRAS has re-evaluated its methodology in order to improve several aspects: The safety functions concept is made now more visible through the use of the safety statements tools. They form a bridge between the mechanistic description of the system ("how it works") and the safety demonstration ("how it ensures safety"). Elements guiding scenario development such as traceability of the decisions, consistency of the safety models with respect to the knowledge, quantification of the uncertainties have been also revisited. Last, reconsidering the methodology has given rise to a reflexion on organisational aspects to ensure constructive feedback between safety assessors and subject experts.

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Scenarios for safety assessment of underground repositories

Soňa Konopásková, Radioactive waste repository authority, Czech Republic

Czech Republic is operating three subsurface repositories, two of them are situated underground, in the depth of some tens of meters below surface. The programme of geological repository development is in the phase of siting, there have been identified seven potential sites in granite structure, and geological research is planned for next period.

The types and the extent of scenarios used in safety assessment correspond to operational experience of subsurface repositories and to the stage of geological repository programme.

Generally, safety assessment is provided as a support of safety case in the frame of license application, in all phases of repository existence, i.e. siting, construction, operation and closure. Scenarios evaluated in the safety assessment have to provide information on relevant potential effects in normal evolution and alternative evolution of the disposal system, and in potential inadvertent intrusion.. Radiohygienical limits are specified by Regulation on radiation protection and are set to 0,25 mSv/yr. for the consequences of normal and alternative evolution scenarios and 1 mSv/yr. for the consequences of intrusion scenario. The optimization of radiation protection is an imperative even in cases that do not exceed limits.

Scenarios describe relevant processes that could affect required compliance with safety functions of the disposal system. Safety functions are specified separately for near field and far field components regarding possible time frames of their duration. The objective of scenario evaluation is effective dose – it is very desirable to demonstrate the maximum value of the calculated curve. With regard to this requirement the time frame of scenario evaluation is up to 106 yrs.

Normal evolution scenario, which describes the projected state of disposal system, has been developed for both types of repositories, subsurface and geological. Near field safety functions were containment and backfill life time, reduction of advective flow and isolation. The time frames for these safety functions are different: up to 5,000 years for advective flow prevention (backfill lifetime) for both types of repositories and 100,000 years for containment and isolation function in the case of geological repository. Far field safety functions are retention and dilution. Their values are radionuclide specific and depend on host structure properties. Alternative evolution assumes the failure of one of safety functions.

Recently, a set of criteria for geological repository siting has been developed. Most of them are in the form of qualitative indicators, because there are not yet available real data from potential sites. From the part of regulation body, there exist particular requirements that should be implemented in siting process. Actually, two candidate sites have to be selected till 2020, using *criteira* derived from safety assessment.

More options for basic scenarios are to be developed with respect to new information in the geological repository programme and planned reconstruction of subsurface repositories.

Posiva's Scenario Methodology

Nuria Marcos[1], Barbara Pastina[2], Lasse Koskinen[2], Paul Smith[3]

[1]Saanio & Riekkola Oy, Finland; [2]Posiva Oy, Finland; [3]Safety Assessment Management (Switzerland) GmbH, Switzerland

The following methodology was originally developed for use in Posiva's safety case TURVA-2012, but has recently been further developed, e.g. to include more thoroughly the impact of human error, taking into account the feedback of the Finnish regulator STUK on TURVA-2012.

The formulation of scenarios takes into account the safety functions of the main barriers of the repository system, the potential deviations in the initial state of the disposal system components, including those arising from human error, and the uncertainties in the features, events, and processes (FEPs) that may affect the entire disposal system (i.e. repository system plus the surface environment) from the emplacement of the first canister until the far future.

The uncertainties in the FEPs and evolution of the surface environment are taken into account in formulating the surface environment scenarios used ultimately in estimating radiation exposure. Consistent with the Finnish regulatory and international guidance (Guide YVL D.5; and IAEA 2009, 2011, 2012), Posiva distinguishes between the expected evolution of the disposal system and unlikely events and processes. Posiva's methodology for the formulation of radionuclide release scenarios relating to the repository system follows a top-down approach. The starting point for the methodology is the disposal concept, safety concept and the defined safety functions for the EBS and the host rock with their respective performance targets (PTs) target properties (TPs), all these considering the regulatory framework. The PTs and TPs are then evaluated against the FEPs affecting the system in the performance assessment and the lines of evolution (in fact, scenarios) resulting in deviations from the PTs are then formulated. In the scenario formulation, the effects of single potentially detrimental FEPs or combinations of FEPs on the safety functions are considered systematically. This systematic approach is designed to promote transparency and comprehensiveness. The methodology can be summarised as follows:

- FEPs that could adversely affect one or more safety functions at a given time or place or under specific conditions within the repository are identified (i.e. FEPs that are scenario drivers affecting the evolution of the repository system in time and space).
- The effects of uncertainties in the occurrence of deviations in the initial state and in the expected evolution of the repository system are taken into account.
- Thus, lines of evolution that describe the evolution of the repository system and ultimately lead to canister failure form the basis for the definition of radionuclide release scenarios. Each line of evolution is then classified using STUK's scenario terminology.
- For each of the radionuclide release scenarios a set of deterministic calculation cases is defined to analyse the potential radiological impact. The calculation cases take into account uncertainties in model assumptions and data used to analyse the scenarios through variations in the models and parameter values. For at least some scenarios, the deterministic cases are complemented by probabilistic sensitivity analyses.

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Andra's Scenarios Development Methodology and Application for Cigeo Post-Closure Safety

L. GRIFFAULT, S. VOINIS, M. BURGIO, D. COELHO, J. de MEREDIEU, S. SY

The French National Radioactive Waste Management Agency, or Andra, has, among its roles, the role of ensuring the protection of man and the environment from all radioactive waste generated in France. In order to verify compliance to the safety objectives, radiological and chemical impacts must be assessed. When assessing the safety of a waste disposal facility, development of scenarios constitutes the fundamental basis for the quantitative evaluations (along with the choice of related data and models).

In accordance with the regulatory requirements, the system representation for the safety model thus developed is based on a reference scenario, the "Normal Evolution Scenario" (NES), on "Altered Evolution Scenarios" (AES), and on "What-if" scenarios. The objective of the paper is to present the overall approach for scenario development and its application for Cigeo (Industrial Center for Geological Disposal) post closure safety.

The NES addresses several complementary objectives. The main one is to verify that the repository, as designed and to the extent that its evolution over time is understood by contemporary science, fulfils the safety objectives assigned to it. That means, to confirm that the performances are achieved, as indicated by the chosen indicators) and are consistent with the predefined threshold values. Calculation results based on the AES and what-if scenarios aim at evaluating overall repository robustness.

Establishing scenarios requires calling on many disciplines and implementing specific methods at the interface between those disciplines. One key element to establishing scenarios is the handling of uncertainties. The repository does not undergo a unique evolution because uncertainties remain, therefore a qualitative safety analysis (QSA) is conducted, in which there is a systematic analysis of uncertainties on Features Events and Processes (FEPs) and their effects on safety functions. This approach is in response to the 2008 Nuclear Safety Authority guide, which sets among the objectives of the post closure safety analysis, the identification and classification of uncertainties according to their consequences in the functioning of the repository, making sure that none is omitted.

Based on the post-closure safety functions and the scientific and technological knowledge with their associated uncertainties on FEPs, the QSA studies each uncertainty that may either:

I. Affect a component's ability to perform a safety function, or

II. Have an influence on another component's ability to perform a post-closure safety function.

QSA then proposes management of uncertainties:

III. By design measures which reduce their effect, or

IV. By the definition of bounding calculation cases in scenarios.

Based on the analysis including exchanges between scientist, engineers and safety people, a set of scenarios is at first selected and then each of them is developed to provide a description of the safety choices in relation to the uncertainties or events (internal or external) which affect the safety functions. Once each scenario is described including reference and sensitivity cases to be quantified, the models and parameters are set according the level of knowledge in such a way that they do not result in the repository's impact being underestimated. A set of indicators (which may include transfer pathways, radionuclides flows through component, etc, dose) are evaluated for compliance with performance and safety objectives. Both reference and sensitivity cases within the NES and AES are conducted to evaluate the overall repository performance and robustness, as well as the individual contribution of each component to the safety functions to be fulfilled by the disposal system. These results may influence the requirements and/or the specification of one or a set of repository’s components and may require additional, complementary investigations or characterization of its environment.

The “QSA” offers an integrated and structured vision of state of knowledge and associated uncertainties regarding major components of the disposal system and its surroundings, their impact on post-closure safety functions and how those uncertainties are managed. Since its application in the Dossier 2005 Argile, the QSA has continued its development, integrating a more advanced scenario development approach using the international FEPs database. The QSA contributes to the evaluation of the robustness of the repository by exploring possible dysfunctions of the disposal system (for instance, waste packages defects, seal failures, crosscut of the Callovo-Oxfordian formation etc.). This approach is being applied to Cigeo post-closure safety assessment.

Scenario Development: The German Strategy

A repository for high-level waste (HLW) will undergo exactly one evolution, which will be governed both by climatic and geological processes at the site and processes induced by the repository construction and the emplacement of the waste. Since this evolution cannot be predicted in all details, scenarios are used to manage uncertainties about the evolution of a repository system: The objectives of a scenario development are to ensure comprehensiveness in the safety assessment (by identifying relevant features, events and processes (FEP)) and to provide a consistent, transparent and reproducible way to describe possible future evolutions for very long time frames (up to 106 years).

In Germany, there is the regulatory requirement (Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste, BMU 2010) for a comprehensive identification and analysis of safety-relevant scenarios and their allocation to three probability categories: probable, less probable and improbable. Since Germany is at the beginning of a site selection process considering several different types of host rocks, it is useful to develop a method, the fundamentals and basic ideas of which are independent of a selected host rock type, disposal concept, or site. A systematic and formalized approach is considered important to achieve transparency and reproducibility and thus increase stakeholder confidence in the scenario development process.

The requirement to develop scenarios that can be allocated to probability classes is encountered by a method allowing the combination of FEP to derive one reference scenario and a number of alternative scenarios. The required FEP are documented in a FEP catalogue. Within this catalogue all FEP may influence other FEP or may be influenced by other FEP. These interdependencies, which are systematically recorded in the catalogue, are used to derive scenarios: The reference scenario is derived from the interaction of probable FEP with probable characteristics (parameter values) and some basic assumptions (about reference climate, undetected QA failure etc.). The alternative scenarios are generated from variation of the basic assumptions, from less probable FEP and from probable FEP with less probable characteristics. The methodology allows straightforwardly the assignment of the derived scenarios to the given probability classes according to the regulatory framework.

According to the Safety Requirements only the probable and less probable scenarios must be analyzed regarding their radiological consequences: for a probable scenario an additional effective dose in the range of 10-5 Sv/a, for a less probable scenario of 10-4 Sv/a is permissible. For improbable evolutions, reasonable risks or reasonable radiation exposure have not been quantified. A second safety indicator is the assessment of radiological consequences without modeling the dispersion of substances in the overburden and adjoining rock. According to the Safety Requirements, the implementer has to define a containment-providing rock zone (CRZ). This rock zone is part of the repository system which, in conjunction with the technical seals, ensures containment of the waste. The main goal of the German safety concept is the containment of the radionuclides in the CRZ. Consequences of radionuclides released from the CRZ are calculated using a generic exposure model. It is permitted to use this safety indicator instead of the above mentioned dose indicator for compliance demonstration.

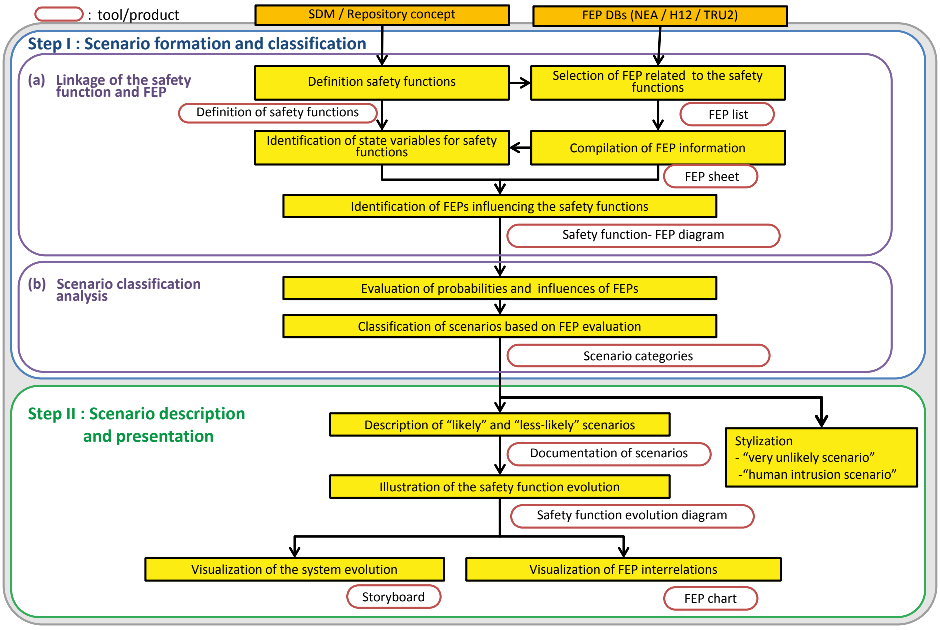
For calculating the consequences of scenarios, the developed scenarios have to be transferred to numerical models for safety demonstration. This transfer requires a high degree of abstraction and a strong collaboration of scenario developers and modelers. Confidence building in the consistency and comprehensiveness of the transfer process is one of the most challenging tasks of the whole safety analysis.

Scenario development for the risk-informed safety assessment of geological disposal

A. Makiuchi[1], K. Ishida[1], S. Kurosawa[1], M. Inagaki[1], K. Ishiguro[1], H. Umeki[1] T. Ebashi[2], K. Wakasugi[2], H. Makino[2], and M. Shibata[2]

[1] Nuclear Waste Management Organization of Japan, NUMO; [2] Japan Atomic Energy Agency, JAEA

NUMO and JAEA are now jointly developing a holistic methodology for scenario development to be applied for an updated safety case for co-disposal of vitrified High Level Waste (HLW) and TRU waste, and a first safety case for spent nuclear fuel (SNF) direct disposal, respectively. The methodology of scenario development, which results from a desire to combine a more conventional, bottom-up, FEP-based approach and a top-down method based on safety functions, appropriate to a risk-informed assessment. The scenarios examined that are considered to be “likely” are developed to be as realistic as possible, representing best current understanding of relevant FEPs in terms of extent and rate of impact on radionuclide containment and eventual release and transport. This is closely linked to representation of potential sites as 4D site descriptive models (SDMs), which integrate understanding of both the current characteristics of sites and how these evolve with time. The drive for realism is essential to allow the pros and cons of potential sites to be identified and the appropriateness of particular repository concepts to such sites to be evaluated. It is also necessary to assess less likely/very unlikely scenarios and also those associated with human intrusion. For these, more idealized representations of bounding scenarios are needed but, here again, emphasis is on incorporating realism to the extent possible, to assure that any inherent differences between different sites or concepts are captured. The methodology consisting of overall procedure and associated toolkits is aiming to increase traceability and transparency, and by clearly reflecting the purpose and context of SA/safety case and state-of-the-art knowledge, to provide appropriate degrees of completeness, comprehensiveness and sufficiency in the scenario development process.



Development of complex scenarios for the risk-based safety assessment of a geological repository

Jongtae Jeong, Jung-Woo Kim, Dong-Keun Cho, Nak-Youl Ko, Min Hoon Baik

Korea Atomic Energy Research Institute, 989-111 Daedeokdaero, Yuseong-Gu, Daejeon, Korea

The regulatory body in Korea made a draft guideline for the safe disposal of high-level wastes in 2012. According to the guideline, the primary safety goal is expressed as risk, that is, the total annual risk for the representative person resulting from the radiation exposure should not exceed 1.0x10-6/yr. Therefore, we developed a methodology for complex scenarios to perform the risk-based safety assessment of a HLW repository. The complex scenarios are combinations of reference scenario and alternative scenarios such as earthquake and well intrusion. The methodology consists of event characterization, influence evaluation, scenario combination, scenario assessment, and a convergence check. The methodology was applied to a reference repository system considering the combination of a reference scenario and an earthquake scenario for illustration. We found that the suggested methodology could be used to perform the risk-based safety assessment for the complex scenarios with various external events in the long-term safety assessment of a radioactive waste repository. We can make various risk profiles by making various kinds of complex scenarios with this methodology, and they can be used to support the development of safety cases for acquiring public acceptance.

The characterizations of alternative scenarios and their impacts on a repository system must be preliminarily determined for the successful application of risk-based safety assessment with this method. Therefore, we perform the characterization and prediction of earthquake and well intrusion by analyzing earthquake and well development data in Korea. With these prediction methodologies and the further study on their impacts on the repository system, the reliability of the long-term safety assessment will be improved.

Scenarios in the safety assessment SR-Site; Methodology and application

Allan Hedin

Swedish Nuclear Fuel and Waste Management Co., SKB

The safety assessment SR-Site forms a central part of SKB's application for a licence to build a final repository of the KBS-3 type for spent nuclear fuel at the Forsmark site in south central Sweden, filed in March 2011. The application has been reviewed by the NEA and the thorough review by the Swedish Radiation Safety Authority, SSM, is on-going (June 2015). In the KBS-3 method, copper canisters with a cast iron insert containing spent nuclear fuel are surrounded by bentonite clay and deposited at approximately 500 m depth in groundwater saturated, granitic rock. The primary safety function of the repository is to contain the fuel within the canisters throughout the one million year assessment period. Should containment be breached, the secondary safety function of the system is to retard a potential release from the repository.

The following five aspects of the methodology applied in SR-Site form key elements in the scenario methodology used in the assessment.

1. The establishment of a number of more differentiated safety functions under the two principal functions containment and retardation. In particular the canister safety functions of providing a corrosion barrier and of withstanding isostatic loads and shear loads play central roles in the scenario methodology.

2. The analysis of a reference evolution, forming also the basis for a main scenario. Here, a reasonable development of the repository system is analysed in different time frames, assuming that the long-term external conditions during the last 120,000 year glacial cycle are repeated. The analysis is characterised by extensive modelling of THMC aspects of the evolution, and by the inclusion of all relevant FEPs related to containment from a preceding FEP screening. This analysis is focused on the containment function of the repository.

3. The selection of a number of additional scenarios based on key safety functions related to containment. This results in a total of six scenarios related to containment. (Hypothetical scenarios to illustrate barrier functions and scenarios related to future human actions are also selected.)

4. The analysis of the containment potential for each of the six scenarios related to safety functions. The analysis is a combination of top-down and bottom-up approaches. For each scenario, a loss of its corresponding safety function is considered. This constitutes the top-

down aspect of the analysis. All conceivable routes to the loss of the safety function are then examined. This treatment is based on the understanding of the repository evolution gained in the analysis of the reference evolution and of the uncertainties affecting the safety function in question. The aim is to exhaustively investigate all possible ways in which the safety function in question can be lost. Detailed understanding of all relevant FEPs and their interplay is required in this step and the approach is of a bottom-up nature. The result is either a quantification of the extent of canister failures or the conclusion that canister failures can be ruled out in the scenario under consideration. When all scenarios have been analysed, combinations of scenarios are considered.

5. Quantification of dose and risk consequences for those containment scenarios for which canister failures could not be ruled out. The extents of canister failures are propagated from the previous step.

Scenario Development in the United States

Geoff Freeze[1], Ross Kirkes[2], and Christi Leigh[1]

[1]Sandia National Laboratories; [2]Piru Associates Inc.

Scenario development supporting performance assessment modeling has been performed as part of multiple radioactive waste disposal programs in the U.S. These programs include: the disposal of transuranic (TRU) waste at the Waste Isolation Pilot Plant (WIPP) managed by the U.S. Department of Energy Office of Environmental Management (DOE-EM); the submittal of a license application for disposal of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) at Yucca Mountain (YM), Nevada by the DOE Office of Civilian Radioactive Waste Management (OCRWM); and research and development (R&D) of SNF and HLW disposal in a variety of geologic media and generic repository concepts (mined disposal in salt, clay/shale, and granite formations, and deep borehole disposal in granite formations) by the DOE Office of Nuclear Energy (DOE-NE) Office of Used Nuclear Fuel Disposition (UFD).

This presentation will describe the scenario development approach in each of these three programs. For each program the discussion will include: the role of features, events, and processes (FEPs); scenario development methods; resulting scenarios; uncertainty quantification; implementation of scenarios in performance assessment (PA) models; and the effect of governing regulations and interactions with regulators.

This abstract is Sandia publication SAND2015-3648A. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the

U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Scenario Completeness in the United States

Geoff Freeze[1], Ross Kirkes[2], and Christi Leigh[1]

[1]Sandia National Laboratories; [2]Piru Associates Inc.

Scenario development supporting performance assessment modeling has been performed as part of multiple radioactive waste disposal programs in the U.S. These programs include: the disposal of transuranic (TRU) waste at the Waste Isolation Pilot Plant (WIPP) managed by the U.S. Department of Energy Office of Environmental Management (DOE-EM); the submittal of a license application for disposal of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) at Yucca Mountain (YM), Nevada by the DOE Office of Civilian Radioactive Waste Management (OCRWM); and research and development (R&D) of SNF and HLW disposal in a variety of geologic media and generic repository concepts (mined disposal in salt, clay/shale, and granite formations, and deep borehole disposal in granite formations) by the DOE Office of Nuclear Energy (DOE-NE) Office of Used Nuclear Fuel Disposition (UFD).

This presentation will discuss the completeness, comprehensiveness, and sufficiency of scenario development in each of these three programs. For each program the discussion will include: the evolution of the features, events, and processes (FEPs) and scenarios; methods used to demonstrate completeness and comprehensiveness; and interactions with regulators.

This abstract is Sandia publication SAND2015-3649A. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Appendix C. Compilation of workshop presentations

OECD Nuclear Energy Agency NEA

IGSC Scenario Development Workshop
June 1 – 3, 2015

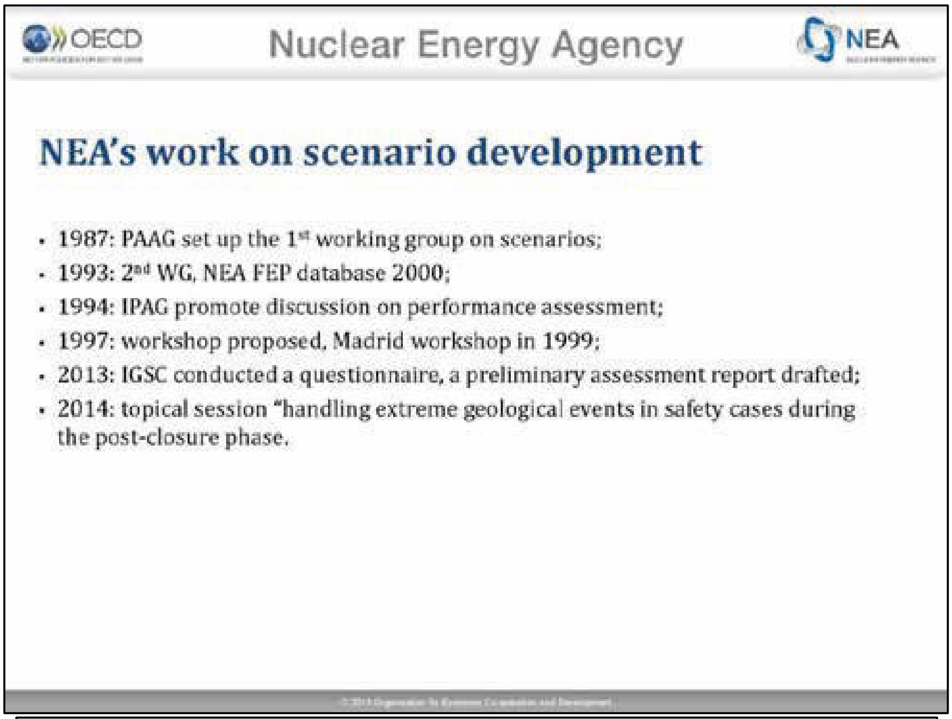
Gloria Kwong

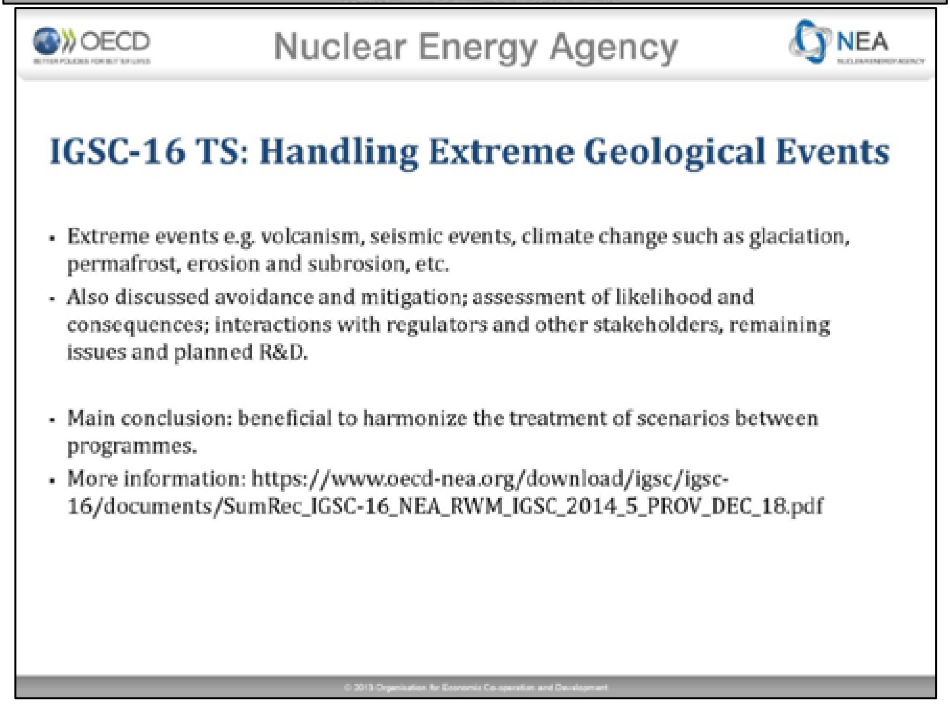
OECD Nuclear Energy Agency NEA

Program Committee & workshop organization

Program Committee	Moderators & Rapporteurs
Sylvie Voinis, *Andra* [Chair]	Jaakko Leino, *STUK*
Abe van Luik, *US WIPP*	Doug Ilett, *EA*
Christi Leigh, *SNL* [also a moderator]	Matthias Niemeyer, *AF Consult*
Hitoshi Makino, *JAEA*	Jens Wolf, *GRS*
Lucy Bailey, *RWM*	Jean De Meredieu, *Andra*
Lise Griffault, *Andra*	Christophe Depaus, *Ondraf/Niras*
Manuel Capouet, *Ondraf/Niras*	Sarah Watson, *Quintessa*
	Bettina Franke, *LBEG-Niedersachsen*
Paul Smith – General rapporteur	Barbara Pastina, *Posiva*
Hiroomi Aoki, *NEA*	Ross Kirkes, *SNL*
Katia-Karina LeBot, *NEA*	Eef Weetjens, *SCK CEN*

THANKS!


OECD
Nuclear Energy Agency
NEA
NEA's work on scenario development
• 1987: PAAG set up the 1st working group on scenarios;
• 1993: 2nd WG, NEA FEP database 2000;
• 1994: IPAG promote discussion on performance assessment;
• 1997: workshop proposed, Madrid workshop in 1999;
• 2013: IGSC conducted a questionnaire, a preliminary assessment report drafted;
• 2014: topical session "handling extreme geological events in safety cases during the post-closure phase.


OECD
Nuclear Energy Agency
NEA
IGSC-16 TS: Handling Extreme Geological Events
• Extreme events e.g. volcanism, seismic events, climate change such as glaciation, permafrost, erosion and subrosion, etc.
• Also discussed avoidance and mitigation; assessment of likelihood and consequences; interactions with regulators and other stakeholders, remaining issues and planned R&D.
• Main conclusion: beneficial to harmonize the treatment of scenarios between programmes.
• More information: https://www.oecd-nea.org/download/igsc/igsc-16/documents/SumRec_IGSC-16_NEA_RWM_IGSC_2014_5_PROV_DEC_18.pdf


ANDRA
NEA 2015 Scenario development Workshop
S. VOINIS, Andra, France
NEA Workshop Scenario , June 1-3-2015
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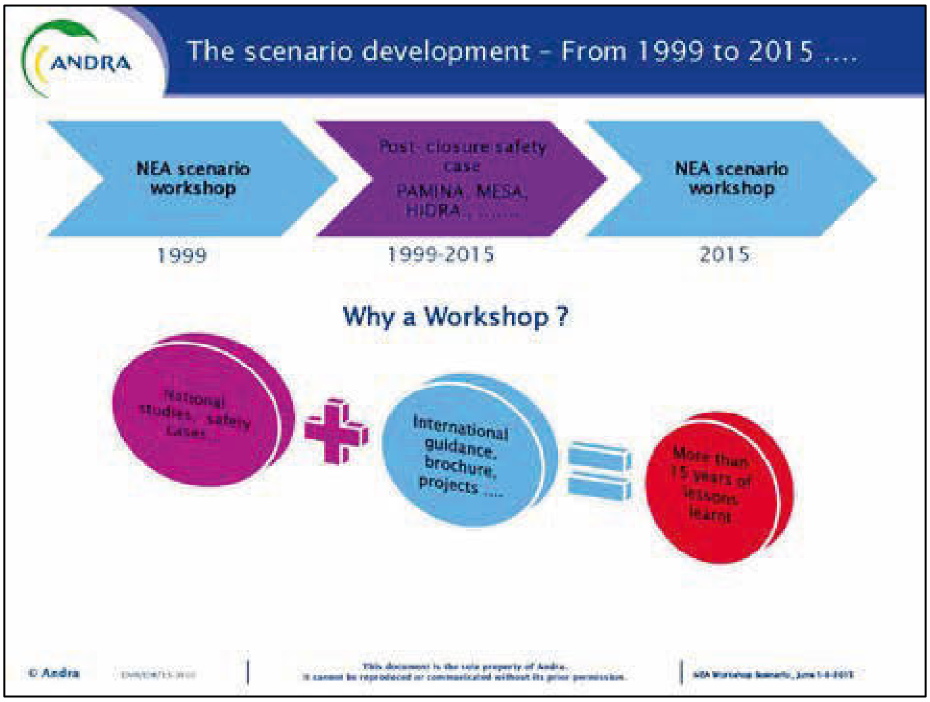
ANDRA
The scenario development - From 1999 to 2015 ....
NEA scenario workshop
Post-closure safety case
PAMINA, MESA, HIDRA, ...
NEA scenario workshop
1999
1999-2015
2015
Why a Workshop ?
National studies, safety cases
International guidance, brochure, projects ....
More than 15 years of lessons learnt
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Key conclusions of Workshop on « scenario Development Methods and Practice' in Madrid on 10-12 May 1999

40 representatives of 26 organisations from 12 NEA countries.

What were the mains conclusions?

- Showed progress since the NEA FEP's database of 1993 and the 1992 NEA report " safety assessment of radioactive waste repositories : systematic approaches to scenario development":
  - In their practice
  - Use of FEP list, comprehensive documentation..
  - Hierarchical approaches, such as event trees and directed diagrams..
- Challenges
  - Full traceability of information and judgements
  - Communication to wider audience
  - Difficulty to justify the assignment of probabilities

Key conclusions of Workshop on « scenario Development Methods and Practice' in Madrid on 10-12 May 1999

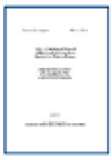
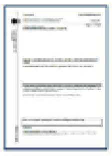
What were the mains conclusions?

- Methods used for scenario development were :
  - Generally sufficient to fulfill their technical function within PA
  - Use of graphic tools, databases, tables
  - As scenario development depends very heavily on the judgement of PA and technical specialists => importance to allow sufficient resource an time
- Scenarios should be a tool to communicate to wider audiences
  - May be a basis to explain the scope of the assessment , the performance of the disposal system, and its sensitivity to future conditions..
- Differences observed between methods applied and terminology
  - Tools used, level of formality
  - National and project stage contexts

The scenario development - From 1999 to 2015 ....
What happened?

National safety cases, international peer reviews

- ONDRAF
- NAGRA
- ANDRA
- SKB...

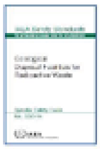
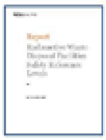
International exercises/projects:

- INTESC
- MeSA
- PAMINA

......


International standards/guidance/ brochure ....

- NEA post closure safety brochures
- IAEA standards/guides : SSG-14, SSG-23
- WENRA reference levels : SRL 2014

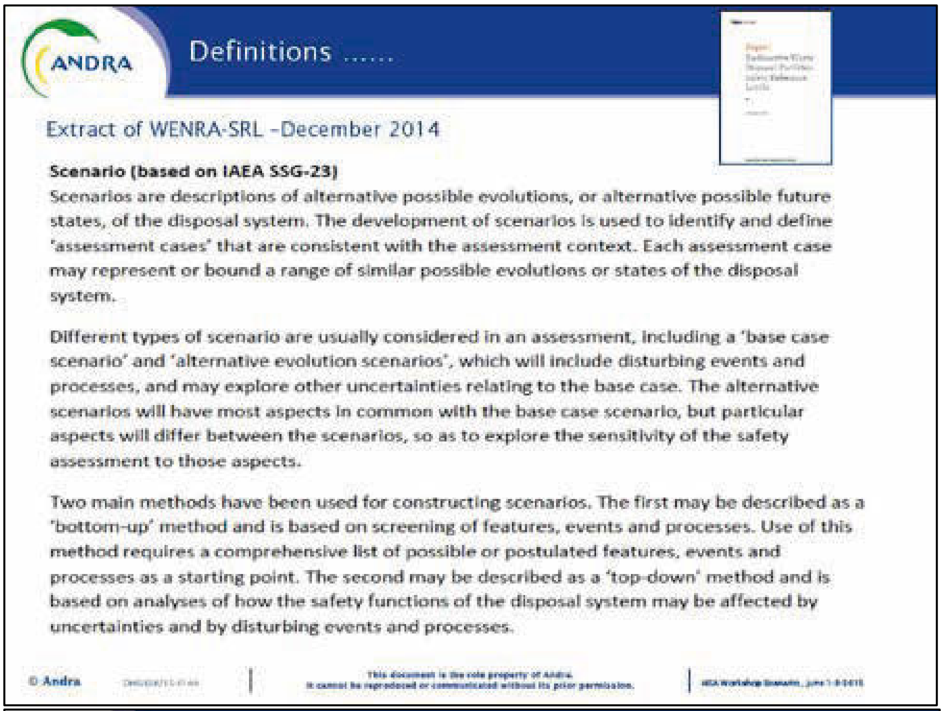
Definitions....

IAEA Glossary [IAEA, 2007]:

Scenario is defined as "a postulated or assumed set of conditions and/or events. Most commonly used in analysis or assessment to represent possible future conditions and/or events to be modelled, such as possible accidents at a nuclear facility, or the possible future evolution of a repository and its surroundings. A scenario may represent the conditions at a single point in time or a single event, or a time history of conditions and/or events (including processes)."

OECD/NEA post closure safety [NEA, 2013]:

A "scenario" is understood as a simplified description of a potential evolution of the repository system from a given initial state. Scenarios are a fundamental basis for the assessment of post closure safety which includes assessing the potential consequences on humans and the environment.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Definitions ……
Extract of WENRA-SRL –December 2014
Scenario (based on IAEA SSG-23)
Scenarios are descriptions of alternative possible evolutions, or alternative possible future states, of the disposal system. The development of scenarios is used to identify and define 'assessment cases' that are consistent with the assessment context. Each assessment case may represent or bound a range of similar possible evolutions or states of the disposal system.
Different types of scenario are usually considered in an assessment, including a 'base case scenario' and 'alternative evolution scenarios', which will include disturbing events and processes, and may explore other uncertainties relating to the base case. The alternative scenarios will have most aspects in common with the base case scenario, but particular aspects will differ between the scenarios, so as to explore the sensitivity of the safety assessment to those aspects.
Two main methods have been used for constructing scenarios. The first may be described as a 'bottom-up' method and is based on screening of features, events and processes. Use of this method requires a comprehensive list of possible or postulated features, events and processes as a starting point. The second may be described as a 'top-down' method and is based on analyses of how the safety functions of the disposal system may be affected by uncertainties and by disturbing events and processes.
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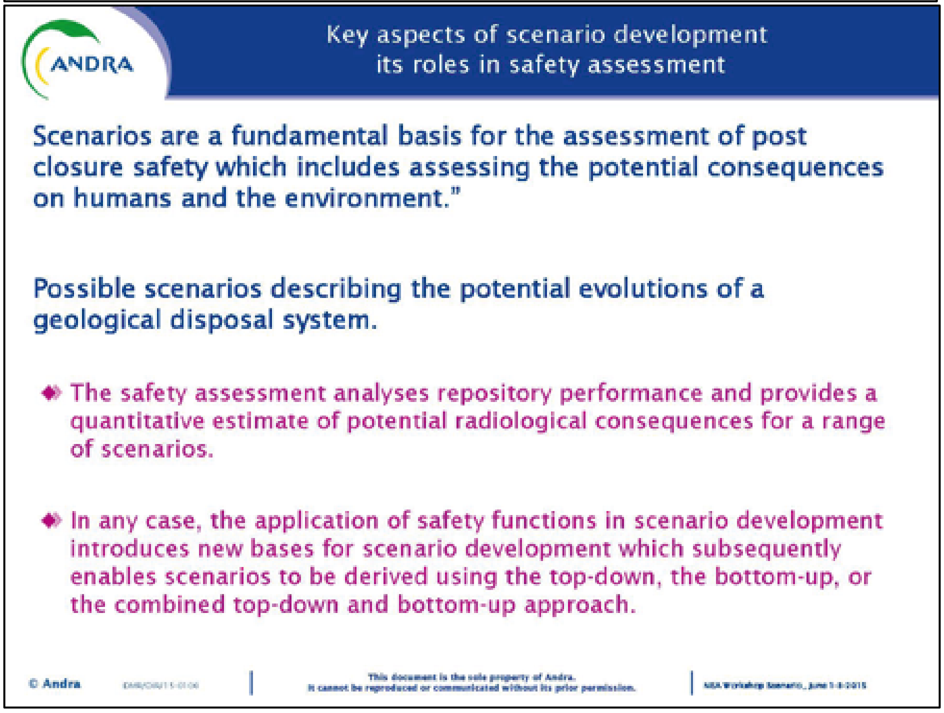
ANDRA
Key aspects of scenario development
its roles in safety assessment
Scenarios are a fundamental basis for the assessment of post closure safety which includes assessing the potential consequences on humans and the environment."
Possible scenarios describing the potential evolutions of a geological disposal system.
The safety assessment analyses repository performance and provides a quantitative estimate of potential radiological consequences for a range of scenarios.
In any case, the application of safety functions in scenario development introduces new bases for scenario development which subsequently enables scenarios to be derived using the top-down, the bottom-up, or the combined top-down and bottom-up approach.
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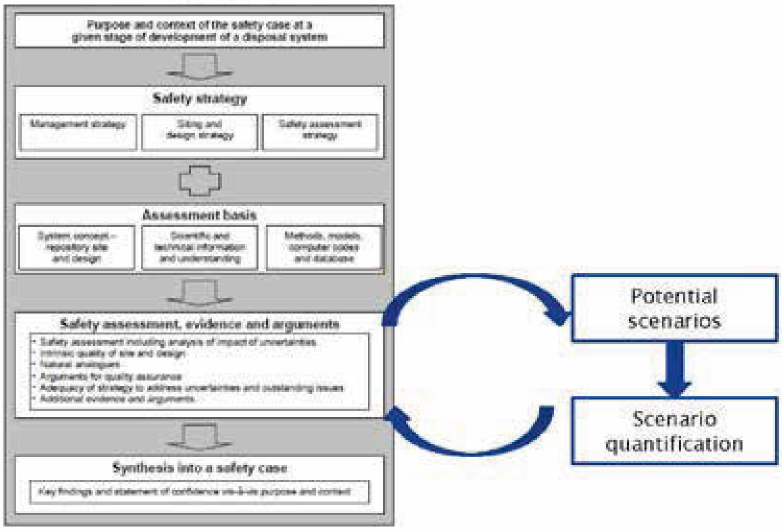
Key aspects of scenario development its roles in safety assessment



Scenarios - Development Approaches

There are various methods to derive and develop scenarios.

- Top-down
- Botton-Up

Methods aim at logic, consistency, clarity, traceable documentation of decisions, comprehensiveness, flexibility within an iterative assessment, and involvement of multiple disciplines.

Comprise the compilation and arrangement of safety-relevant FEP as well as mapping them to the system safety concept and component safety functions, taking into account safety-relevant phenomena and uncertainties.

A set of scenarios : Expected evolution and alternated scenarios, Human Intrusion, "What-if"

.......See National presentations

Particularity of Human intrusion scenarios

Emplacement of the waste in deep geological formations in itself can be seen as a powerful countermeasure against potential human intrusion

BUT, it is generally accepted that human actions have to be taken into account when assessing the safety of the disposal system.

Attempts at predicting human intrusion activity over an extensive period will be speculative, though, owing to the inability to discern the likely evolution of current technology, society and future human behaviour in general.

…….See IAEA- HIDRA presentation

NEA Workshop Scenario, June 1-3-2015

Key findings of Project and exercices

NEA Workshop Scenario, June 1-3-2015

OECD/NEA Project MeSA

OECD/NEA Project on Methods for Safety Assessment for Geological Disposal Facilities for Radioactive Waste (MeSA)

Motivation

- Review and summarises developments of the last decades: a state of the art

The project: 2008-2010

- 18 waste management, research, regulatory, and technical support organisations in 11 NEA member countries
- 7 reports + synthesis
  - Overall Regulatory Perspective
  - Safety Assessment in the Context of the Safety Case
  - Safety Case and Safety Assessment Flowcharts
  - System description and scenarios
  - Modelling Strategy
  - Indicators for Safety Assessment
  - Treatment of Uncertainties

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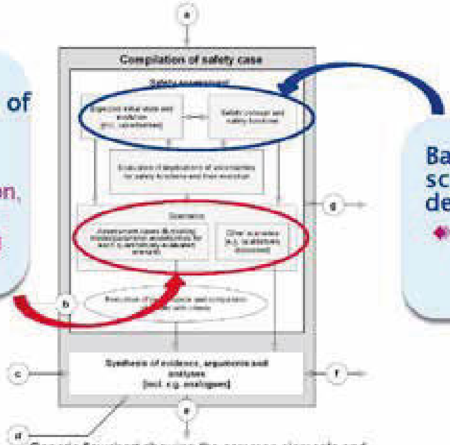
Results - Safety assessment and safety case

Generic flowcharts developed in Mesa

A better integration of scenario into the safety case

- Their categorization,
- Evaluation of their performance using some indicators



Generic flowchart showing the common elements and linkages when carrying out safety assessments (Schneider et al. 2010. MeSA project)

Basis for scenario development:

- More link with safety function

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Results - Regulatory perspectives

Evolution at national and international level accounting for:

- Evolving safety case concept
  → role of assessment as one of several lines of argument
  → roles of demonstrating robustness and understanding
  → roles of development and optimisation
- Timescales
- Quality issues (QA, confidence building, traceability, transparency)

Regulatory guidance about handling specific uncertainties (e.g. human intrusion, biosphere)

Balance needed: Being prescriptive vs. leaving freedom for optimisation

Independent regulatory assessment (and other) capabilities

Balance needed: Early exchange with regulator vs. independence

Results – System description and scenarios

Scenarios

- Key element of the management of uncertainties
- Comprehensive set of scenarios
- Expected evolution and alternated scenarios, Human Intrusion, "What-if"

Scenario Development Methodology

- Not a straight forward Top-Down or Bottom-Up approach but a combination of both
- Relies on a comprehensive list of relevant and specific Features Events and Processes (FEP)
- Scenario supported by detailed description and organization of the FEP
  + *New approaches in structuring the scientific knowledge in time and space have emerged*

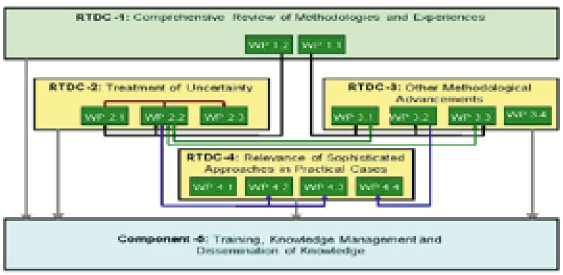
Significant interactions between safety assessment and other aspects of the repository development notably site and waste characterisation, repository design, knowledge on expected initial state and evolution (including uncertainties)

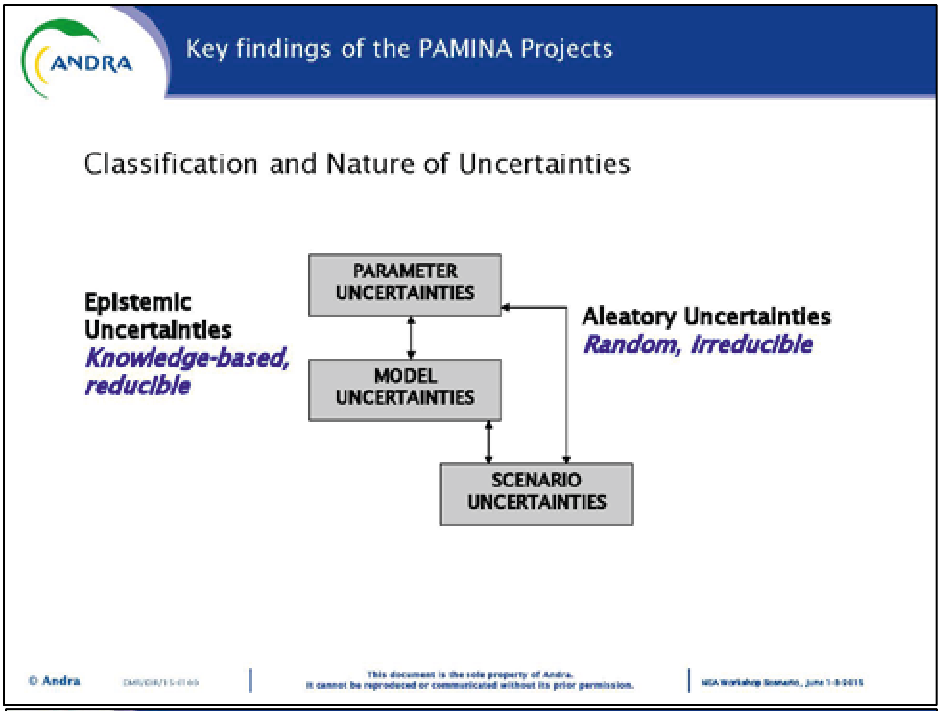
Main Outcomes

- Assessment central but to be put into safety context/Case
- Interaction with site characterisation, R&D, engineering → information flow
- Generic flowchart developed within MeSA
- Wide consensus on the modelling strategies
- Both deterministic and probabilistic methods
- Evolution concerning indicators, but terminology internationally not consistent
- Consensus on the types and sources of uncertainties
- Strategies for treating uncertainties well established
- Regulatory expectations going far beyond pure numerical compliance demonstration

Key findings of the PAMINA Projects

PAMINA : Performance Assessment Methodologies in Application to Guide the Development of the Safety Case- www.ip-pamina.eu

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Key findings of the PAMINA Projects
Classification and Nature of Uncertainties
Epistemic Uncertainties
Knowledge-based, reducible
PARAMETER UNCERTAINTIES
MODEL UNCERTAINTIES
SCENARIO UNCERTAINTIES
Aleatory Uncertainties
Random, irreducible
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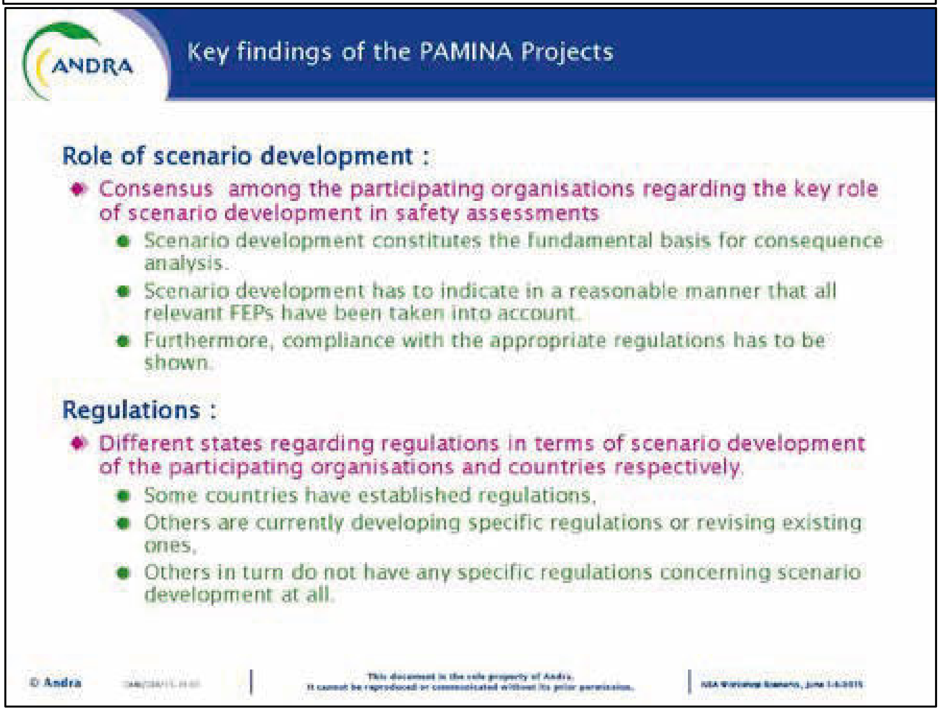
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Key findings of the PAMINA Projects
Role of scenario development :
Consensus among the participating organisations regarding the key role of scenario development in safety assessments
Scenario development constitutes the fundamental basis for consequence analysis.
Scenario development has to indicate in a reasonable manner that all relevant FEPs have been taken into account.
Furthermore, compliance with the appropriate regulations has to be shown.
Regulations :
Different states regarding regulations in terms of scenario development of the participating organisations and countries respectively.
Some countries have established regulations,
Others are currently developing specific regulations or revising existing ones,
Others in turn do not have any specific regulations concerning scenario development at all.
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Key findings of the PAMINA Projects

Methodology:

- A wide range of methods and approaches in terms of scenario development are in use.
  - The general basis for many of the procedures is the international OECD/ NEA FEP database.
- Another fixed element of scenario development constitutes expert judgement.
  - The general opinion arose that systematic approaches should be used whenever possible.
  - Expert judgement implies some subjective influences which finally cannot be avoided.
- Traceability of decisions by expert judgement is of paramount importance.
  - Regarding the matter of comprehensiveness in terms of scenarios and / or FEPs, comprehensiveness can be achieved but it cannot be proved.

Key findings of the PAMINA Projects

Application and Experience:

- Several international projects, studies, working groups and initiatives as well as national projects and working programmes with respect to scenario development.
- Safety functions seem to play a great role in connection with scenario development in future. Furthermore the role of expert judgement appears to be a subject for discussion in
- some nations concerning high effort as well as strong and subjective influence.

Developments:

- The main developments identified focus more or less to the consideration of safety functions either in existing methodologies by modifications or by developing new approaches.
- Developments related to regulation comprise the current revision of existing safety criteria and safety requirements, respectively.

Summary of the 2014 questionnaire responses – 4 parts, each to be discussed in more details in following sessions

The questionnaire was sent to IGSC Members in preparation to the Workshop

Four main topics :

- General/Context/Regulatory requirement
- Changes since the 1999 NEA Scenario Workshop held in Madrid
- Detail regarding a scenario approach currently in use by project
- Discuss why the current scenario definition and analysis approach is appropriate for this project at present.

☺ A success !

- Fourteen completed questionnaires received by the NEA relating to eleven different national programmes
  - (seventeen organisations responded in total, with three of the questionnaires were joint responses).

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Questionnaire

Seventeen organizations responded

- Three of the questionnaire were joint responses
- Eleven different national programmes

Organisation	Country	Role	Notes
Federal Agency for Nuclear Control (FANC)	Belgium	Regulator	
Ondraf/Niras	Belgium	Implementer	
Nuclear Waste Management Organisation (NWMO)	Canada	Implementer	
Radioactive Waste Repository Authority (RAWRA)	Czech Republic	Implementer	
POSIVA Oy	Finland	Implementer	
Agence nationale pour la gestion des déchets radioactifs (Andra)	France	Implementer	
Bundesamt für Strahlenschutz (BfS)	Germany	Implementer	Joint response with GRS
Gesellschaft für Anlagen- und Reaktorsicherheit mbH (GRS)	Germany	Research Organisation	Joint response with BfS
Japan Atomic Energy Agency (JAEA)	Japan	Research Organisation	Joint response with NUMO
Nuclear Waste Management Organisation of Japan (NUMO)	Japan	Implementer	Joint response with JAEA
Korea Atomic Energy Research Institute (KAERI)	South Korea	Research Organisation	
Swedish Nuclear Fuel and Waste Management Co. (SKB)	Sweden	Implementer	
Swedish Radiation Safety Authority (SSM)	Sweden	Regulator	
Environment Agency (EA)	UK (England, Wales, and Northern Ireland)	Regulator	Response appended to that of RWMD
Radioactive Waste Management Limited (RWM, NDA)	UK	Implementer	
US Department of Energy Office of Nuclear Energy (US DOE NE) (for spent nuclear fuel and high level waste)	USA	Implementer	Joint response with US DOE EM/CBFO
US Department of Energy Office of Environmental Management Carlsbad Field Office (US DOE EM/CBFO) (for transuranic waste)	USA	Implementer	Joint response with US DOE NE

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A questionnaire with the following aims:

- To review the current status and on-going discussions on the handling issues related to scenario development methodologies
- To provide a clear overview of scenario development since 1999
- To obtain feedback and reveal lessons learned from scenario development and its application
- To identify areas where further international co-operations are beneficial and in safety cases
- To develop a state-of-the-art report documenting the outcomes of the 2015 workshop

Questionnaire and Four Main Questions

Q1 - General Context/Regulatory Requirement

- Stage of the national program and disposal concept
- Legal and/or regulatory requirements on the definition and consideration of scenarios in safety evaluations

Q2 - Summaries of Change since the 1999 NEA Scenario Workshop held in Madrid

Q3 - Details Regarding Scenario Approach Currently in use by Project

Q4 - Discuss Why the Current Scenario Definition and Analysis Approach is Appropriate for this Project at Present

Questionnaire: a preliminary analysis

A report providing preliminary analysis of the collected responses

- Communalities/Differences among National Program
- Identification of some key issues

Questionnaire: a preliminary analysis
Regulatory perspectives

Considerable changes since 1999

- As a consequence of projects advance into different stages

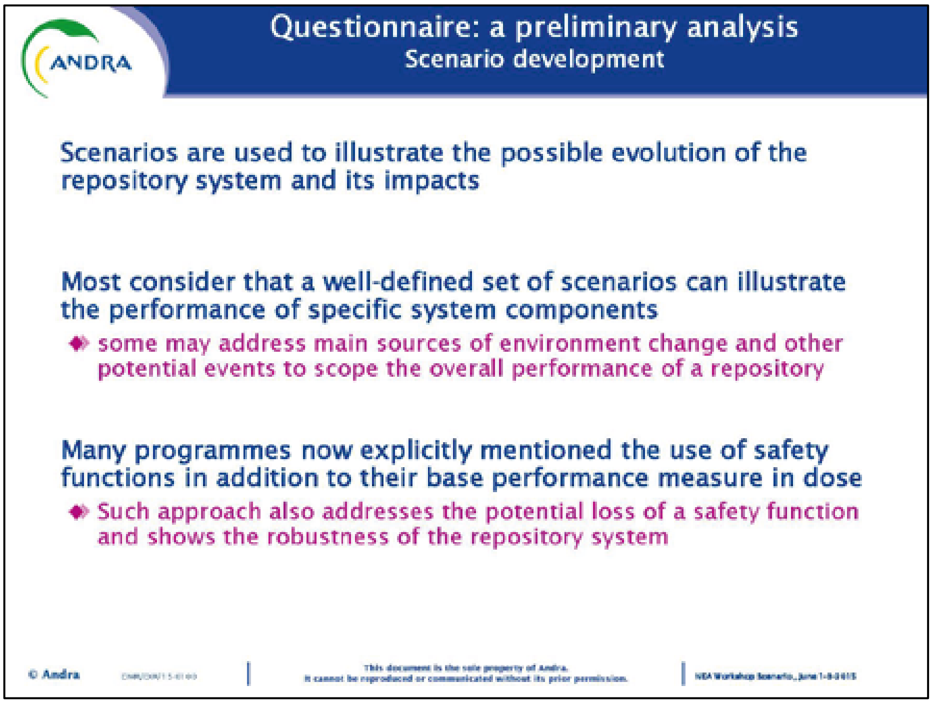
Many regulations now have requirements for scenario development

- their classification, FEPs which need to be considered (internal and external), probability of events, safety functions, demonstration of relevant process understanding, uncertainty management, and compliance indicators

Most regulations also require human intrusion to be addressed despite the different level of requirements

Level of requirement regarding scenario development varies

- However most regulations consider the classification of scenarios, e.g. "base / reference case / main / likely / normal evolution" scenario supplemented by "altered / additional / disruptive / less probable" or "disruptive" scenarios


ANDRA
Questionnaire: a preliminary analysis
Scenario development
Scenarios are used to illustrate the possible evolution of the repository system and its impacts
Most consider that a well-defined set of scenarios can illustrate the performance of specific system components
some may address main sources of environment change and other potential events to scope the overall performance of a repository
Many programmes now explicitly mentioned the use of safety functions in addition to their base performance measure in dose
Such approach also addresses the potential loss of a safety function and shows the robustness of the repository system
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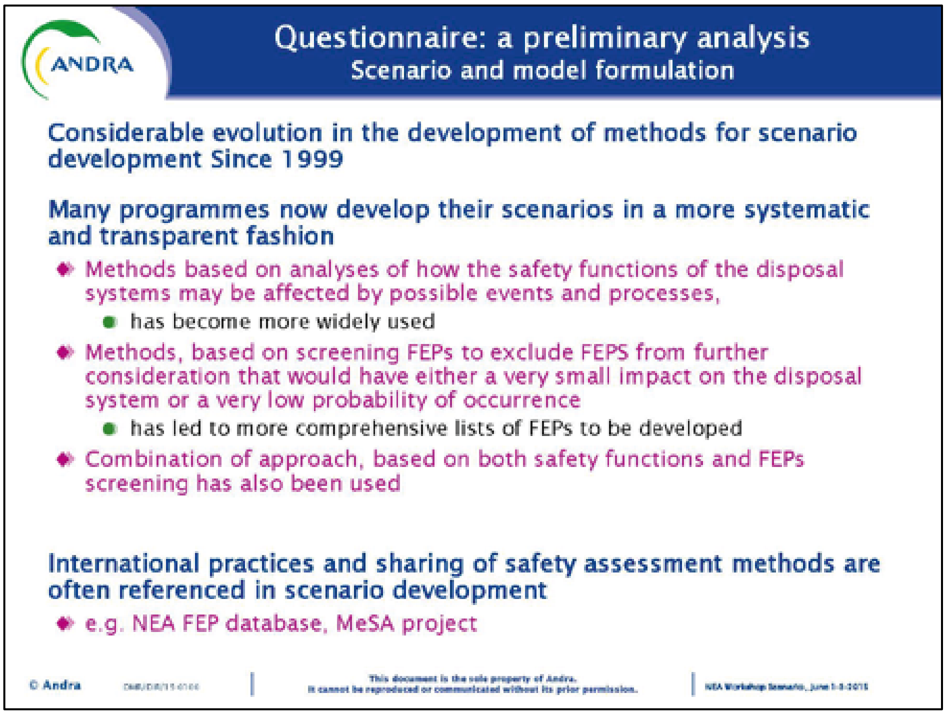
ANDRA
Questionnaire: a preliminary analysis
Scenario and model formulation
Considerable evolution in the development of methods for scenario development Since 1999
Many programmes now develop their scenarios in a more systematic and transparent fashion
Methods based on analyses of how the safety functions of the disposal systems may be affected by possible events and processes,
has become more widely used
Methods, based on screening FEPs to exclude FEPS from further consideration that would have either a very small impact on the disposal system or a very low probability of occurrence
has led to more comprehensive lists of FEPs to be developed
Combination of approach, based on both safety functions and FEPs screening has also been used
International practices and sharing of safety assessment methods are often referenced in scenario development
e.g. NEA FEP database, MeSA project
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Questionnaire: a preliminary analysis
Completeness, Comprehensiveness, and Sufficiency

Recent safety cases have used internal reviews, expert judgment, international peer reviews

- to verify the completeness, comprehensiveness and sufficiency of their FEP lists and scenarios

Many programmes reported the importance of transparency in their formal expert elicitation process which led to formal documentation of their methods and results

Analyses of uncertainties and propagation of uncertainties are also formally managed in some programmes

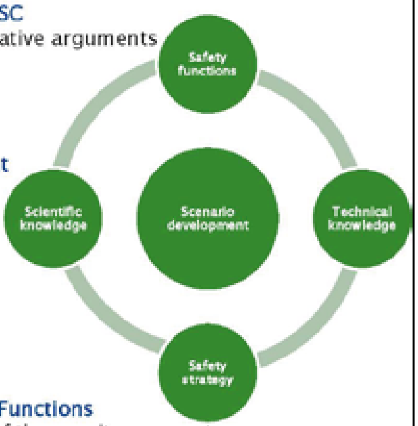
Summary of progress in scenario development since 1999 – evolution of safety cases, use of safety functions, etc.

- Most of the participating organisations have a lot of experience with systematic scenario development due to the former and / or current application of own, modified or adapted methodologies in safety assessments.
- Previous international projects have also increased knowledge and experiences
- The scenario development is a useful exercise to describe the compilation and arrangement of both scientific and technical information as a fundamental basis for the assessment of long-term safety for a radioactive waste repository

Summary of progress in scenario development since 1999 – evolution of safety cases, use of safety functions, etc.

From PA to SC

- A more integration of qualitative and quantitative arguments



The central role of the scenarios development

- Link between FEP, component and safety functions
- Tool for communication
- Set of scenarios
- An input for quantification

The role of the safety Functions

- Play a central role in the safety case ⇔development of the repository concept
- Facilitate explanation of the functioning of the repository system in easily understandable terms.
- Useful tool for communication to non-technical audiences.

Organisation of the workshop

Programme committee

Lucy Bailey	NDA, UK
Manuel Capouet	Ondraf/Niras, Belgium
Lise Griffault	Andra, France
Gloria Kwong	NEA
Christi Leigh	SNL, USA
Hitoshi Makino	JAEA, Japan
Abe van Luik	DOE WIPP, USA
Sylvie Voinis	Andra, France (Chair)

Workshop purpose, structure and sessions

What are the key objectives of the workshop?

- **To provide a forum** to review and discuss methods for scenario development, and its contribution to the development of recent safety cases (since 1999)
- **To share experiences** and examine the latest methods and compare their scope, consistency and function within the overall safety assessment process, based on practical experience of applications
- **To provide a basis for producing a report** summarizing the current status of scenario methodologies, identifying where sufficient methods exist and any outstanding problem areas

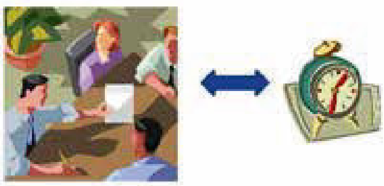
Workshop purpose, structure and sessions

Oral presentations :

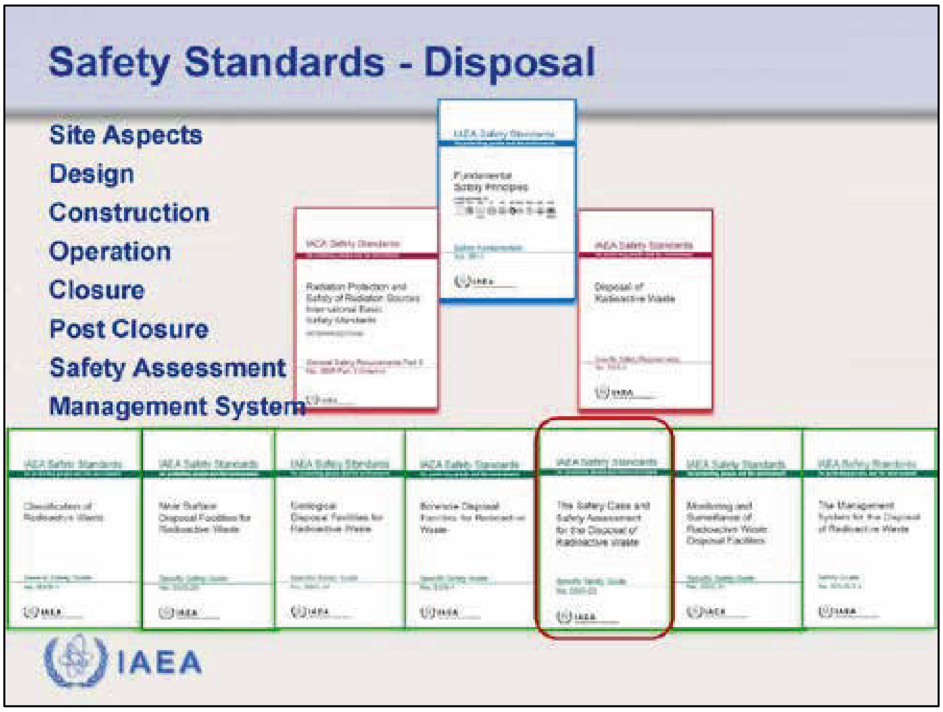
- National
- International

Working groups sessions in parallel:

- In line with the four topics of the questionnaire
- Same questions to all working groups at the same time per session
  - But order different => To guaranty that at the end of the workshop we will have covered all questions in case of not enough time per question!




HIDRA: IAEA project on Human Intrusion in the context of Disposal of Radioactive Waste
L. Bailey and Y. Kumano
2015 IGSC Scenario Development Workshop
1-3 June 2015
NEA Offices, Issy-les-Moulineaux, France
IAEA
International Atomic Energy Agency


Safety Standards - Disposal
Site Aspects
Design
Construction
Operation
Closure
Post Closure
Safety Assessment
Management System
IAEA

SSR-5 : Human Intrusion Context

CONCEPTS RELATING TO DISPOSAL OF RADIOACTIVE WASTE

1.10.

…The specific aims of disposal are:

(a) To contain the waste;

(b) To isolate the waste from the accessible biosphere and to reduce substantially the likelihood of, and all possible consequences of, inadvertent human intrusion into the waste;*

** 'Human intrusion' refers to human actions that affect the integrity of a disposal facility and which could potentially give rise to radiological consequences. Only those human actions that result in direct disturbance of the disposal facility (i.e. the waste itself, the contaminated near field or the engineered barrier materials) are considered.*

IAEA 3

SSG-23: Fundamentally different approaches to HI for near-surface and geological facilities

HUMAN INTRUSION (6.52-6.65)

Near surface disposal facility:

- *Inadvertent HI should be assumed to occur at some time following the loss of knowledge about the site*

  → Consequences of plausible intrusion scenarios should be assessed (but should not attempt to use a risk based concept)

Geological disposal facility:

- *Relevance of HI scenario is limited due to the depth and location*
- *Timeframes of concern are far too large to enable meaningful estimates*

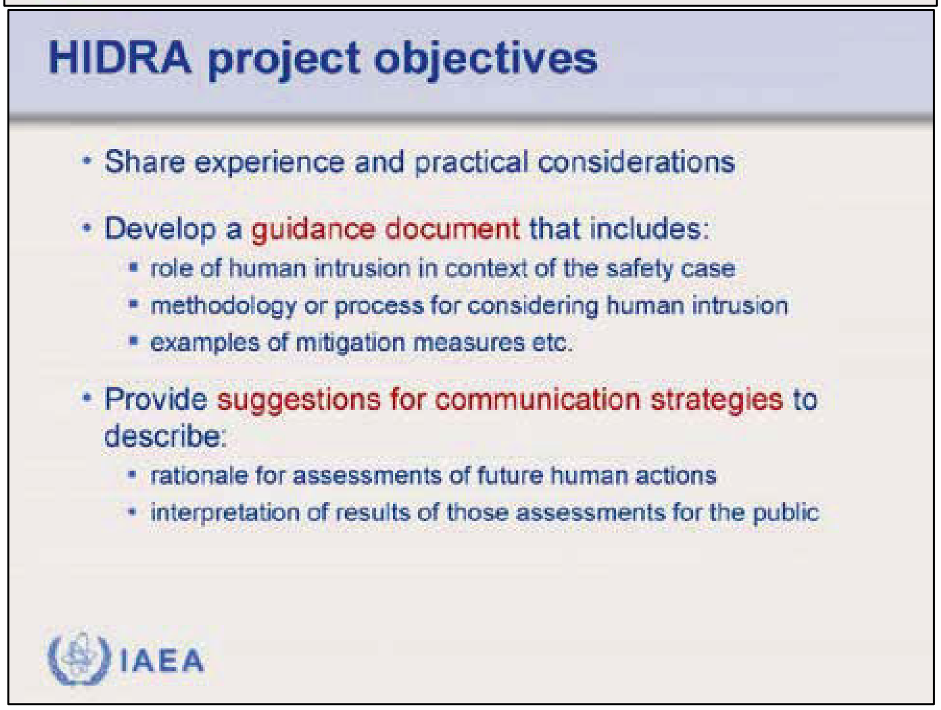
  → Assessment of HI scenario should be used to demonstrate the robustness of the disposal system

  ** avoid speculative scenarios / arbitrary boundary conditions*

  ** care should be taken regarding quantitative evaluation*

IAEA 4


Launch of HIDRA project
➢ Following initial technical meeting in Sept 2012 with 34 participants from 21 member States:
HIDRA:
Human Intrusion in the context of Disposal of RadioActive waste
➢ HIDRA project
•2-year project: annual plenary meeting & task group activities
•3 working groups: Scenarios / Societal / Measures
IAEA


HIDRA project objectives
• Share experience and practical considerations
• Develop a guidance document that includes:
▪ role of human intrusion in context of the safety case
▪ methodology or process for considering human intrusion
▪ examples of mitigation measures etc.
• Provide suggestions for communication strategies to describe:
▪ rationale for assessments of future human actions
▪ interpretation of results of those assessments for the public
IAEA

HIDRA project scope

- Future human actions, emphasising inadvertent human intrusion
- Post-closure for a disposal facility, assuming loss of passive and active institutional controls
- Consider factors that influence timing of loss of institutional controls
- Geological and near-surface disposal facilities, including boreholes and intermediate depth facilities (VLLW, L/ILW, HLW, SF)

IAEA

HIDRA Work plan

Meetings

- Annual Plenary meetings
- WG meetings
- Coordinating Group meetings

Deliverables

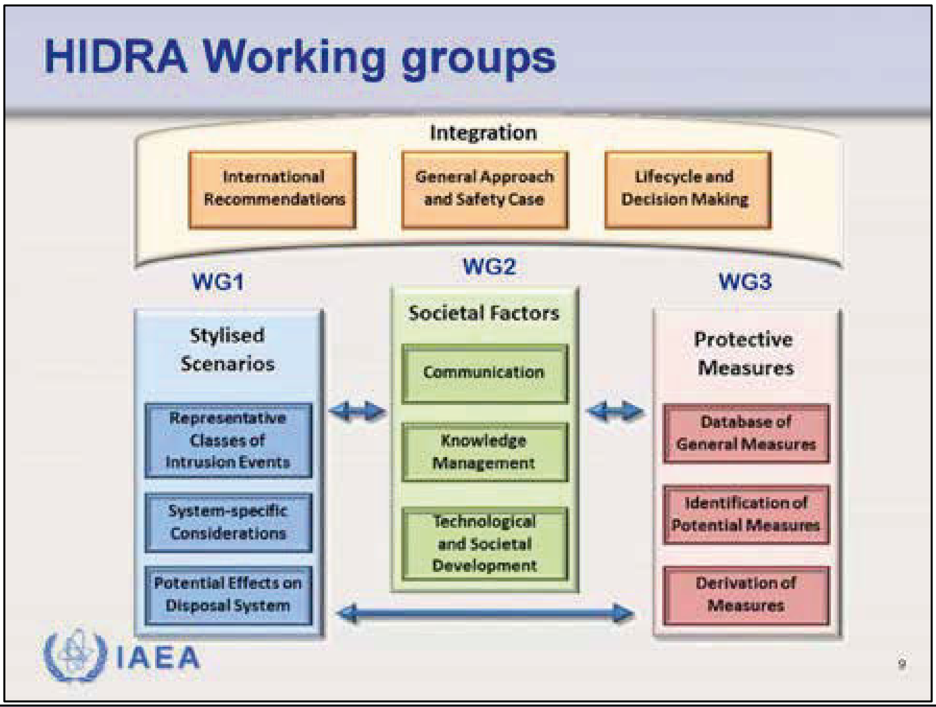
- Project report
- Brochure

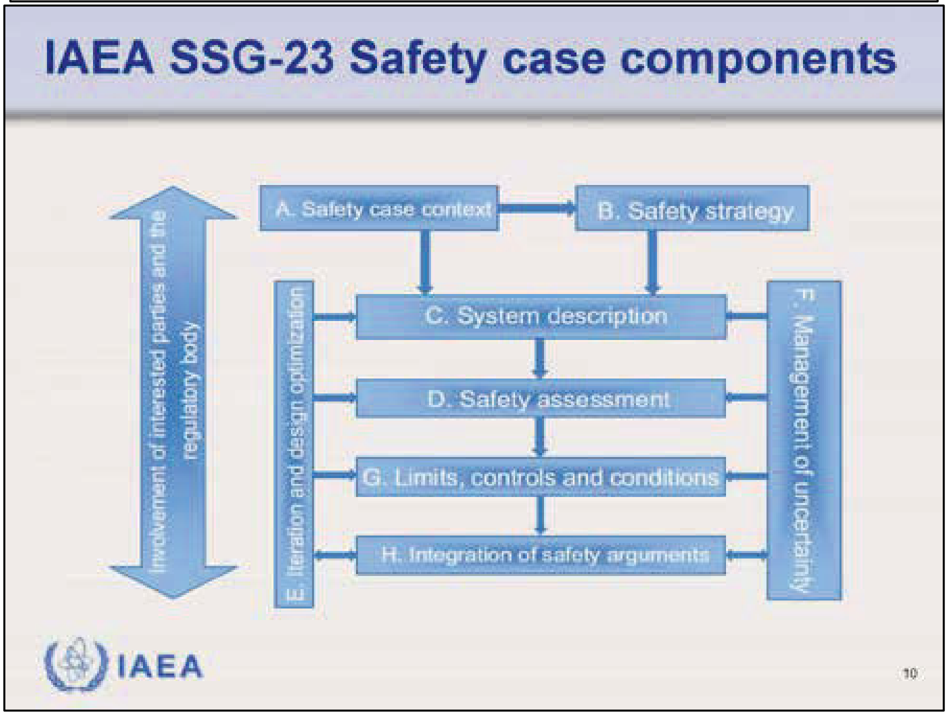
Webpage

- Latest news
- Terms of Reference
- Summary presentation

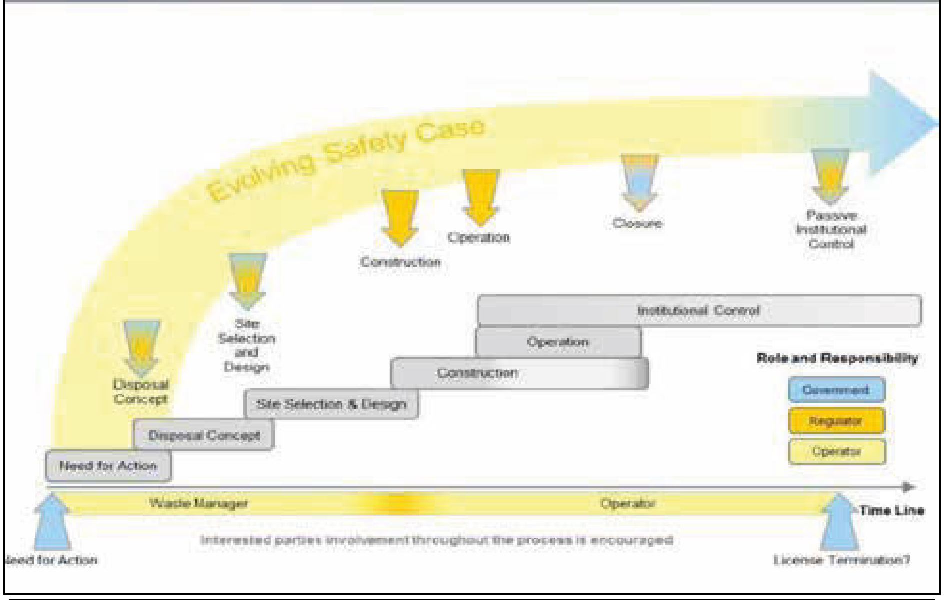
http://www-ns.iaea.org/projects/hidra/default.asp?s=8

IAEA


HIDRA Working groups
Integration
International Recommendations
General Approach and Safety Case
Lifecycle and Decision Making
WG1
WG2
WG3
Stylised Scenarios
Representative Classes of Intrusion Events
System-specific Considerations
Potential Effects on Disposal System
Societal Factors
Communication
Knowledge Management
Technological and Societal Development
Protective Measures
Database of General Measures
Identification of Potential Measures
Derivation of Measures
IAEA
9


IAEA SSG-23 Safety case components
A. Safety case context
B. Safety strategy
C. System description
D. Safety assessment
G. Limits, controls and conditions
H. Integration of safety arguments
E. Iteration and design optimization
F. Management of uncertainty
Involvement of interested parties and the regulatory body
IAEA
10

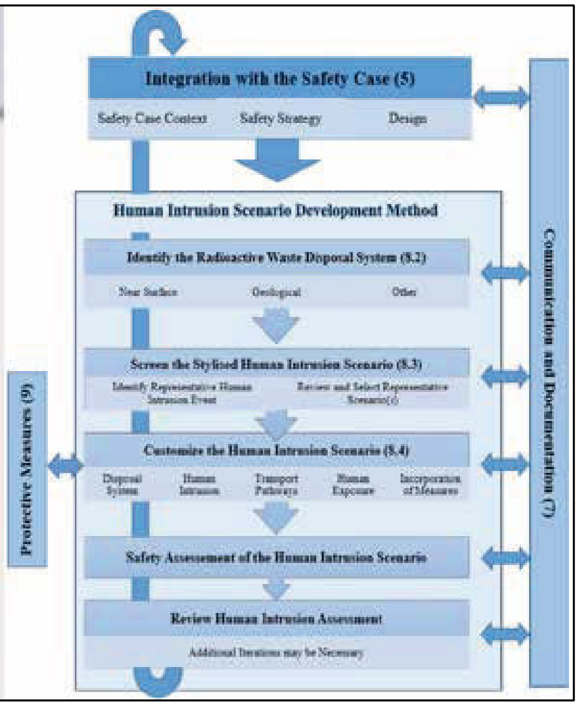
Safety case evolution over facility lifetime



Post-closure HI considerations

	Active Control	Passive Control	Loss of Memory
Societal control	Physical security at site, knowledge management, records, site markers	Knowledge management, records, site markers	No knowledge of hazardous nature of site
Design safety features	Depth of disposal, multi-barriers	Depth of disposal, multi-barriers	Depth of disposal, multi-barriers may be degrading
Implications for potential for HI	No inadvertent HI	Inadvertent HI extremely unlikely – safety case can justify exclusion of major HI scenarios	Inadvertent HI a possibility, may still be mitigated by enduring design features
Hazard of facility	Disposal inventory	Decaying inventory	Decay may be significant for near-surface, low-level waste facilities

Iterative approach for scenario development



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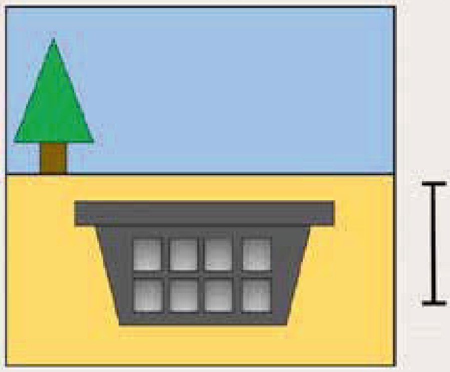
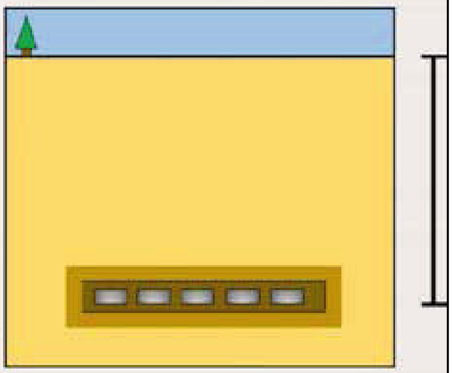
Near-surface and geological facilities



Hypothetical Near Surface Radioactive Waste Disposal Facility. The scale bar is of the order of tens of metres



Hypothetical Geological Radioactive Waste Disposal Facility. The scale bar is of the order of hundreds of metres.

IAEA

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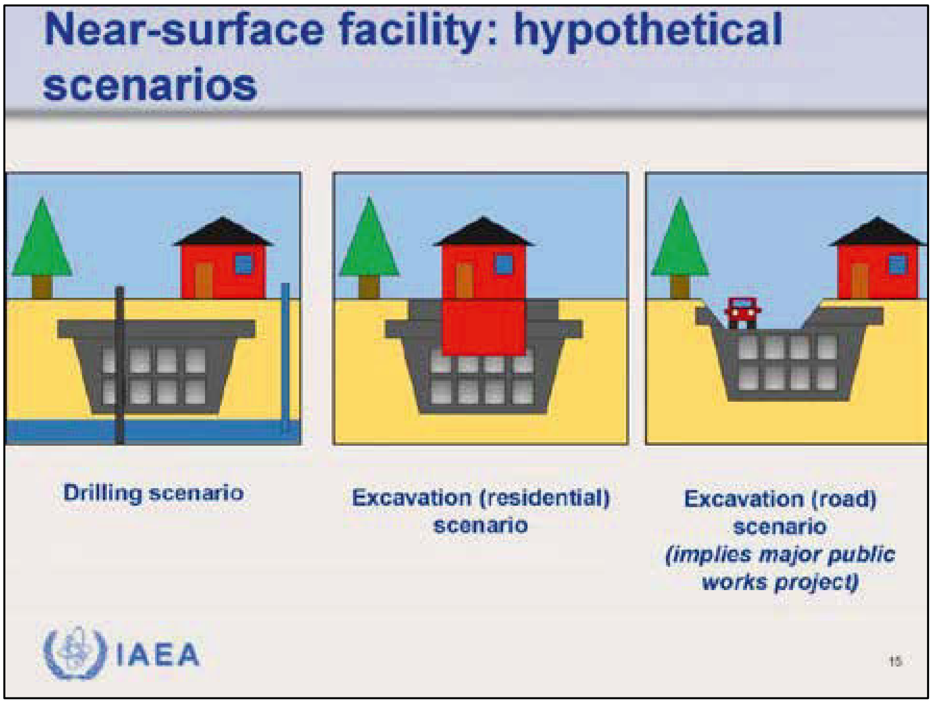
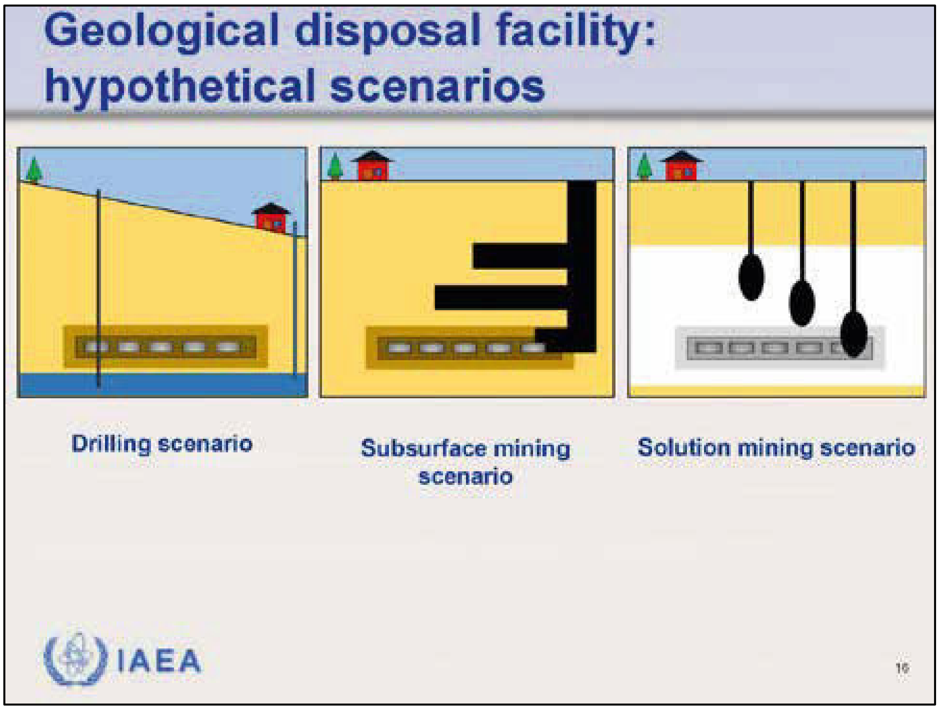
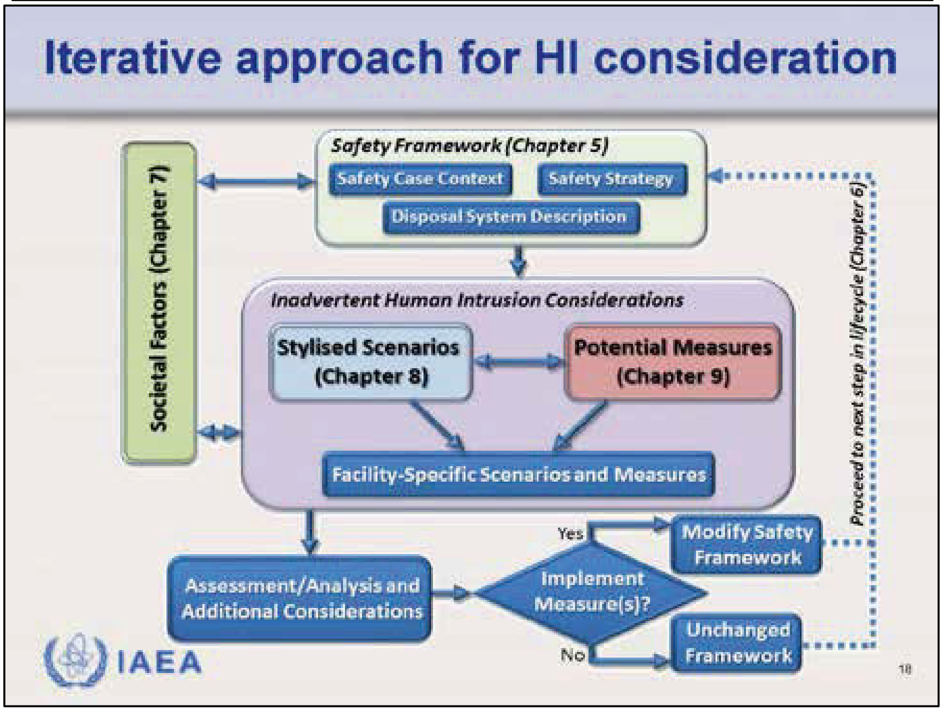

Near-surface facility: hypothetical scenarios
Drilling scenario
Excavation (residential) scenario
Excavation (road) scenario
(implies major public works project)
IAEA
15


Geological disposal facility: hypothetical scenarios
Drilling scenario
Subsurface mining scenario
Solution mining scenario
IAEA
16


Derivation of protective measures
Acts, rules and guidelines
Database
Site
Disposal concept
Design, Layout
Additional Considerations
1. Definition of the framework
2. Compilation of general measures
3. Identification of potential/ inherent measures
4. Derivation of protective measures
Agreements, conditions and provisions
Literature, Projects
Waste characterization
HI Scenarios
Analysis
Consulting experts
IAEA
17


Iterative approach for HI consideration
Societal Factors (Chapter 7)
Safety Framework (Chapter 5)
Safety Case Context
Safety Strategy
Disposal System Description
Inadvertent Human Intrusion Considerations
Stylised Scenarios (Chapter 8)
Potential Measures (Chapter 9)
Facility-Specific Scenarios and Measures
Assessment/Analysis and Additional Considerations
Implement Measure(s)?
Yes
No
Modify Safety Framework
Unchanged Framework
Proceed to next step in lifecycle (Chapter 6)
IAEA
18

Summary

- Near-surface and geological facilities have fundamentally different approaches to HI
    - Near-surface – active controls, WAC → delay HI until hazard reduces
    - Geological – passive safety, low HI potential, consider outside main safety assessment as part of optimisation and robustness demonstration
- Societal factors
    - Importance of maintaining site knowledge – records, markers
    - Communication throughout facility life-cycle
- Stylised scenarios
    - Scenarios proposed for both near-surface and geological facilities
    - Easily customised to specific settings
    - Not indications of site evolution
    - Provide basis for HI assessment and for consideration of potential mitigating measures
- Design and siting measures can be considered for both types of facility
    - Any HI mitigation measure should not compromise normal evolution of disposal facility
    - Implemented measures should be effective and beneficial

IAEA 19


Western European
WENRA
Nuclear Regulators Association
WENRA
Regulatory Perspectives on
Scenario Development
NEA IGSC SCENARIO DEVELOPMENT WORKSHOP
Paris, 1 June 2015
Bengt Hedberg, WENRA WGWD


Contents
NEA IGSC Scenario Development Workshop
Paris, 1 June 2015
01 WENRA
02 Approach
03 WENRA WGWD (Working Group on Waste and Decommissioning)
04 Safety Reference Levels for Disposal
05 On Scenario Development
06 Conclusions
2
NEA IGSC Scenario Development Workshop, Paris, 1 June 2015
WENRA

01
WENRA Basic Facts

3 NEA IGSC Scenario Development Workshop, Paris, 1 June 2015 WENRA

01 WENRA Basic Facts
Creation

- Association of the Heads of nuclear regulatory authorities of the EU countries with NPP and Switzerland
- Interested countries as observers
- Terms of Reference:
  - Signed on 4 February 1999 (10 members)
  - Revised on 14 March 2003 (17 members)
  - Revised on 26 March 2015 (18 members) ⇐
- Chairpersons:
  - 1999-2003: A.-C. Lacoste, French Nuclear Safety Authority
  - 2003-2006: J. Melin, Swedish Nuclear Power Inspectorate
  - 2006-2009: D. Drábová, Czech State Office for Nuclear Safety,
  - 2009-2011: J. Laaksonen, Finnish Rad. & Nuclear Safety Authority
  - 2011- : H. Wanner, Swiss Federal Nuclear Safety Inspectorate

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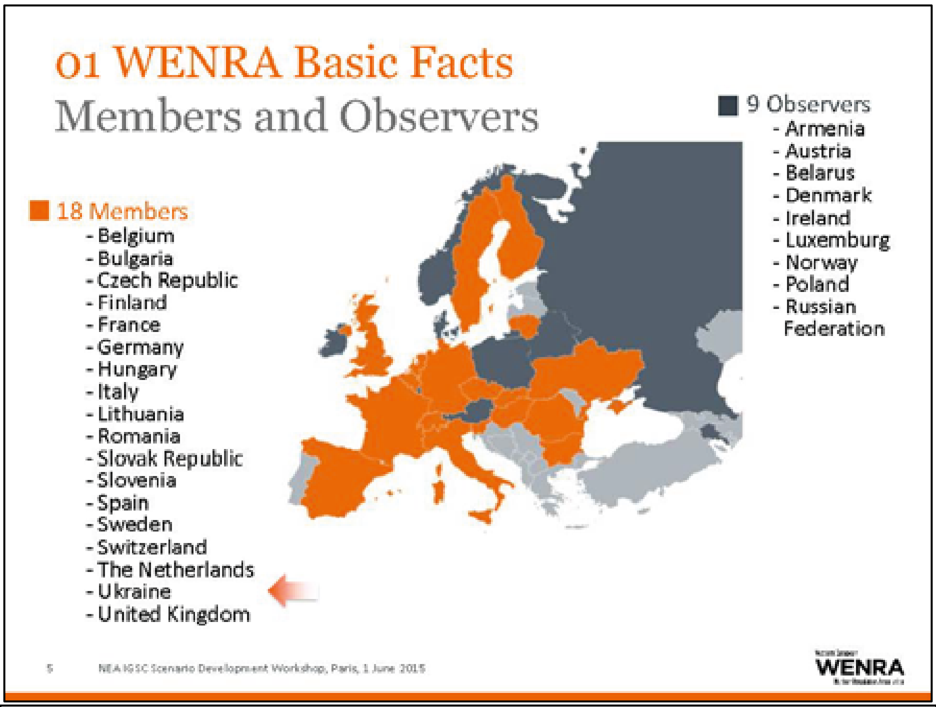
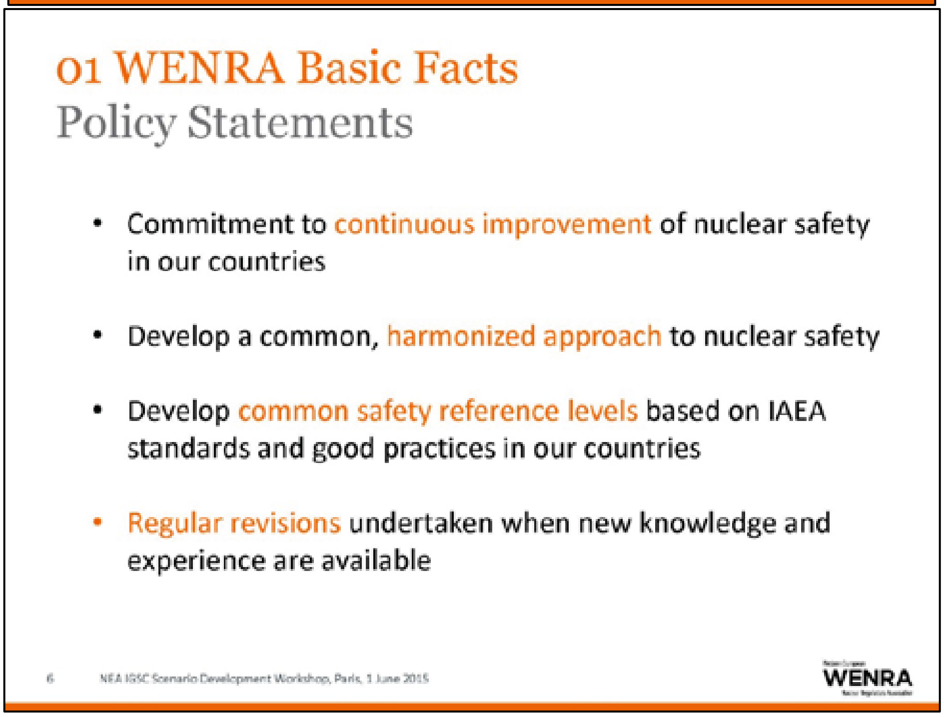

01 WENRA Basic Facts
Members and Observers
18 Members
- Belgium
- Bulgaria
- Czech Republic
- Finland
- France
- Germany
- Hungary
- Italy
- Lithuania
- Romania
- Slovak Republic
- Slovenia
- Spain
- Sweden
- Switzerland
- The Netherlands
- Ukraine
- United Kingdom
9 Observers
- Armenia
- Austria
- Belarus
- Denmark
- Ireland
- Luxemburg
- Norway
- Poland
- Russian Federation
5
NEA IGSC Scenario Development Workshop, Paris, 1 June 2015
WENRA


01 WENRA Basic Facts
Policy Statements
• Commitment to continuous improvement of nuclear safety in our countries
• Develop a common, harmonized approach to nuclear safety
• Develop common safety reference levels based on IAEA standards and good practices in our countries
• Regular revisions undertaken when new knowledge and experience are available
6
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WENRA

01 WENRA Basic Facts
Working Groups

Two technical Working Groups have been established to **harmonize safety approaches** with the aim to continuously improve nuclear safety:

RHWG Reactor Harmonisation Working Group

WGWD Working Group on Waste and Decommissioning

Ad-hoc Working Groups

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02
Approach

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02 Approach
Working Groups Mandate

- Analyse the current situation and the different safety approaches;
- Compare individual national regulatory approaches with selected requirements from the IAEA Safety Standards as defined in WENRA reports on various subjects;
- Identify any differences;
- Propose a way forward to possibly eliminate the differences;
- Proposals expected to be based on best practices among the most advanced requirements for existing power reactors and nuclear waste facilities

02 Approach
WGWD Harmonisation Process

02 Approach
Elaboration of SRLs

SRL are in general based on IAEA standards

	WENRA SRL (waste and SF storage)	IAEA SF-1; para 3.16
	The licensee shall carry out at regular intervals a review of the safety of the facility (PSR). The review shall be made periodically, at a frequency which shall be established by the national regulatory framework (e. g. every ten years).	The process of safety assessment for facilities and activities is repeated in whole or in part as necessary later in the conduct of operations in order to take into account changed circumstances (such as the application of new standards or scientific and technological developments), the feedback of operating experience, modifications and the effects of ageing. For operations that continue over long periods of time, assessments are reviewed and repeated as necessary. Continuation of such operations is subject to these reassessments demonstrating to the satisfaction of the regulatory body that the safety measures remain adequate. (SF-1; para 3.16)

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02 Approach
Benchmarking

Benchmarking and validation of national self-assessment

Assessment

- Group of 4 to 5 countries
- Notation system to be able to compare
  - A (Full compliance)
  - B (Difference exists, but justified from safety point of view)
  - C (Non compliance, to be addressed for harmonisation)

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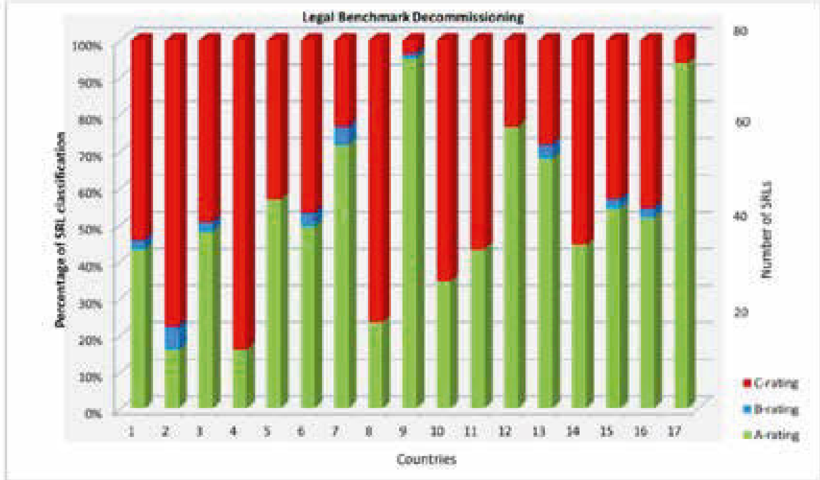
02 Approach
SRL implementation - Decommissioning



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02 Approach
National Action Plans

- Incorporation of SRL or missing part thereof in national regulatory systems
- Target duration of implementation: 3 years
- Implementation in regulations

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02 Approach
Monitoring of implementation

- Periodic reporting of progress of SRL implementation at WGWD meetings
- Experience feedback on update of regulations
- Ensuring non-divergence of interpretations

After completion of National Action Plan:
Re-benchmarking by WGWD to ensure full compliance

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03
WENRA WGWD

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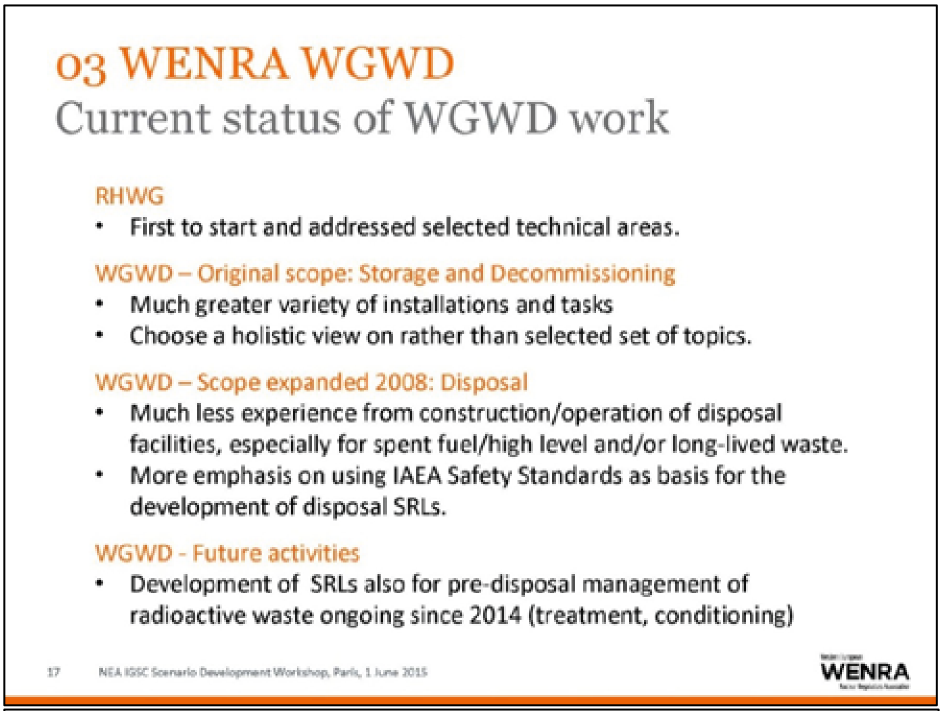
03 WENRA WGWD
Current status of WGWD work
RHWG
• First to start and addressed selected technical areas.
WGWD – Original scope: Storage and Decommissioning
• Much greater variety of installations and tasks
• Choose a holistic view on rather than selected set of topics.
WGWD – Scope expanded 2008: Disposal
• Much less experience from construction/operation of disposal facilities, especially for spent fuel/high level and/or long-lived waste.
• More emphasis on using IAEA Safety Standards as basis for the development of disposal SRLs.
WGWD - Future activities
• Development of SRLs also for pre-disposal management of radioactive waste ongoing since 2014 (treatment, conditioning)
17
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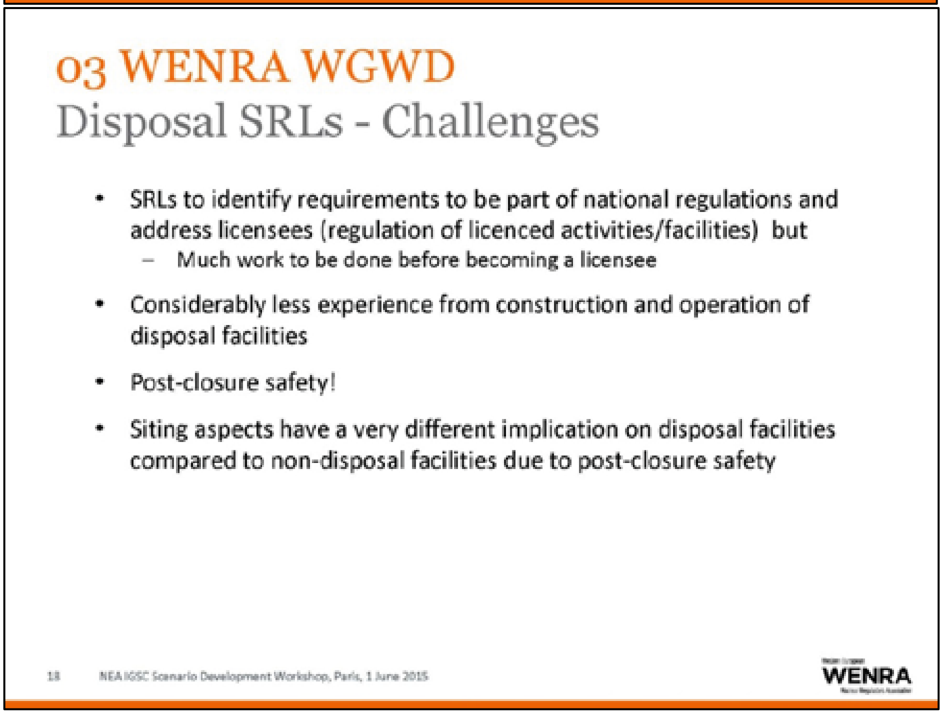
WENRA


03 WENRA WGWD
Disposal SRLs - Challenges
• SRLs to identify requirements to be part of national regulations and address licensees (regulation of licenced activities/facilities) but
– Much work to be done before becoming a licensee
• Considerably less experience from construction and operation of disposal facilities
• Post-closure safety!
• Siting aspects have a very different implication on disposal facilities compared to non-disposal facilities due to post-closure safety
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WENRA

03 WENRA WGWD
Disposal SRLs - Challenges (continued)

- Disposal is endpoint of long sequence of activities (generation – conditioning - storage - transport – disposal) and quite frequently involves different operators and licensees, but
  - Each licensee only responsible for activities within the envelope of the licensed activity
- Important that regulatory system ensures that interdependencies between different licensees are properly addressed
- Disposal facilities likely to be operated for many decades where construction, emplacement of waste and partial closure may be carried out in parallel

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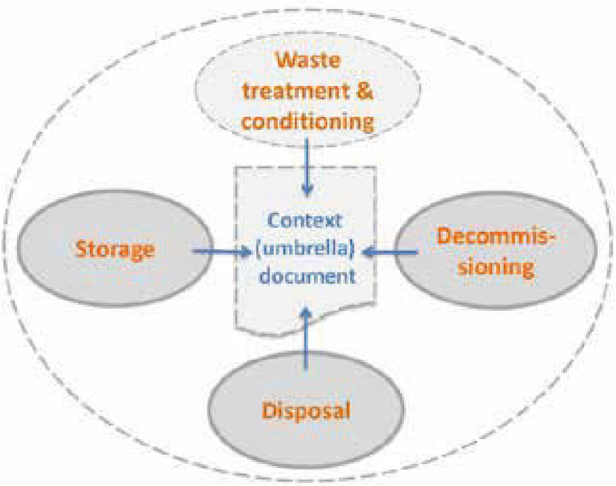
WENRA

03 WENRA WGWD
Context document to be developed



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04
Disposal SRLs

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04 Disposal SRLs
Disposal SRLs in perspective

- Scope of report:
  - Licensed activities – requires a licensee
    - Early activities including siting process not included
  - All types of disposal facilities
    - Near surface disposal facilities (monitoring after closure!)
    - Geological disposal facilities (monitoring after closure?)
- Other specificities:
  - Activities in sequence or activities in parallel
  - Disposal is endpoint of "cradle-to-grave" activity
    - Interdependencies other licensees(!)

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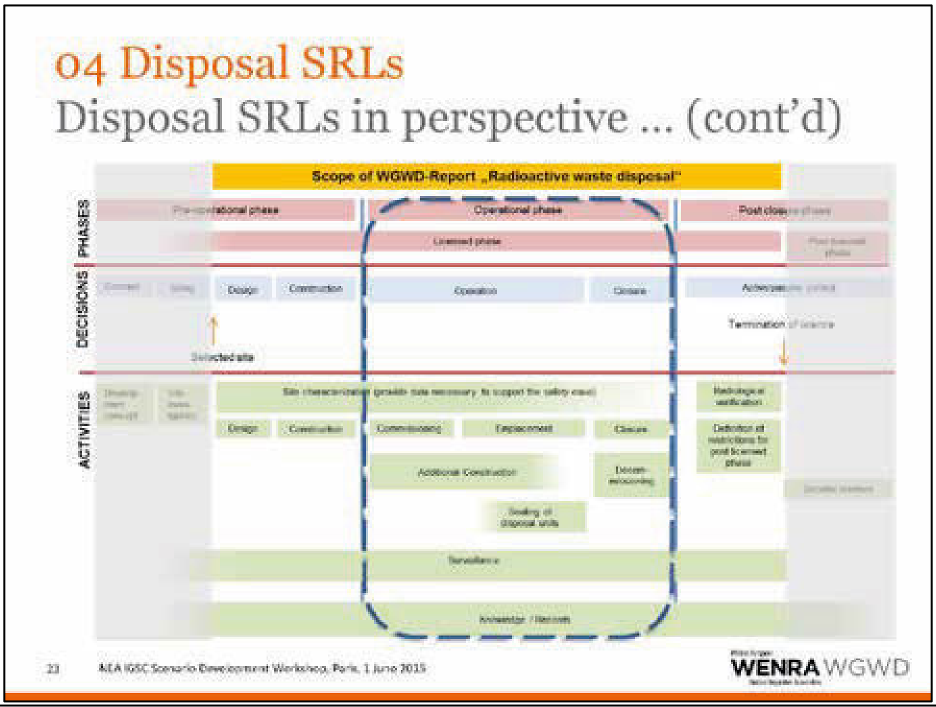
WENRA WGWD


04 Disposal SRLs
Disposal SRLs in perspective ... (cont'd)
Scope of WGWD-Report „Radioactive waste disposal"
PHASES
DECISIONS
ACTIVITIES
Operational phase
Licensed phase
Design
Construction
Operation
Closure
Termination of licence
Selected site
Design
Construction
Commissioning
Emplacement
Closure
Additional Construction
Sealing of disposal units
Surveillance
Knowledge / Records
23
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04 Disposal SRLs
Report published end of 2014
WENRA
European centre for competence for Nuclear Safety
Report
Radioactive Waste Disposal Facilities Safety Reference Levels
www.wenra.org
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04 Disposal SRLs
Disposal SRLs report structure

Safety Area	*Safety Issue*
Safety Management	Responsibility
	Organizational structure
	Management System
Site characterization and disposal facility development	General Requirements
	Site characterization
	Design (DI-36)
	Information gathering and monitoring
	Construction
	Operation
	Record and knowledge keeping
	Decommissioning and closure of disposal facility
	Post-closure phase and release from regulatory control
Waste acceptance	Derivation of waste acceptance criteria
	Revision of waste acceptance criteria
Safety verification	Scope and content of safety case (DI-86)
	Operational and post-closure safety assessment (DI-101)
	Periodic safety review (PSR)

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05 Scenario Development
... Glossary

Scenario (based on IAEA SSG-23)

Scenarios are descriptions of alternative possible evolutions, or alternative possible future states, of the disposal system. The development of scenarios is used to identify and define 'assessment cases' that are consistent with the assessment context. Each assessment case may represent or bound a range of similar possible evolutions or states of the disposal system.

Different types of scenario are usually considered in an assessment, including a 'base case scenario' and 'alternative evolution scenarios', which will include disturbing events and processes, and may explore other uncertainties relating to the base case. The alternative scenarios will have most aspects in common with the base case scenario, but particular aspects will differ between the scenarios, so as to explore the sensitivity of the safety assessment to those aspects.

Two main methods have been used for constructing scenarios. The first may be described as a 'bottom-up' method and is based on screening of features, events and processes. Use of this method requires a comprehensive list of possible or postulated features, events and processes as a starting point. The second may be described as a 'top-down' method and is based on analyses of how the safety functions of the disposal system may be affected by uncertainties and by disturbing events and processes.

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05 Scenario Development
... Safety issue: Design

DI-36	Related IAEA safety standards
The licensee shall design the disposal facility giving due consideration to both normal evolution of the disposal system after closure and scenarios involving events and processes that might disturb the normal evolution of the disposal system.	*The post-closure safety case should specify a range of credible scenarios for the evolution of the disposal facility and its surroundings over the time period for which the waste represents a potentially significant hazard or as specified in national regulations, some of which prescribe the timescale for the assessment. Consideration should be given to expected scenarios (normal evolution scenarios) and to less likely scenarios.(SSG-29, para 5.18)*

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05 Scenario Development
... Safety issue: Scope and contents of SC

DI-86	Related IAEA safety standards
The licensee shall include in the safety assessment for the operational and post-closure phases: • An evaluation of the performance and robustness of the disposal facility and system and its components; • An evaluation of the radiological impact.	*Robustness of a component of the disposal system means that it will continue to fulfil its expected safety function(s) irrespective of disturbances that may reasonably be expected to occur (see paras 4.33 and 4.51). Sites can be selected, for example, by choosing those that are little affected by natural processes such as flooding and earthquakes. Similarly, the engineered barriers can be designed for robustness, for example, by expanding the dimensioning of certain components beyond the necessary values to ensure their resilience to disturbances and uncertainties. (SSG-23, para 6.39)* *Robustness of the disposal system is evaluated through comparison of the results of analyses of the base case with those of a range of scenarios illustrating specific perturbations or uncertainties. Among the different types of perturbation, the most generally considered are those where one component or one of its characteristics is considered to have failed ('what if' scenarios). Scenarios involving such strong perturbations applied to the disposal system are distinguished from scenarios describing degraded behaviour of the disposal system. (SSG-23, para 6.41)*

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05 Scenario Development
... Safety issue: OP and PC SA

DI-101	Related IAEA safety standards
The licensee shall include in the post-closure safety assessment a scenario analysis that considers the possible features, events and processes that might affect the performance of the disposal system, including events of low probability.	*With regard to safety after closure, the expected range of possible developments affecting the disposal system and events that might affect its performance, including those of low probability, have to be considered in the safety case and supporting assessment by the following means:* *a) By presenting evidence that the disposal system, its possible evolutions and events that might affect it are sufficiently well understood;* *b) By demonstrating the feasibility of implementing the design;* *c) By providing convincing estimates of the performance of the disposal system and a reasonable level of assurance that all the relevant safety requirements will be complied with and that radiation protection has been optimized;* *d) By identifying and presenting an analysis of the associated uncertainties.*

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06
Conclusions

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06 Conclusions

- The WENRA (WGWD) concept for development of SRLs contributes to harmonised safety approaches, including development of safety cases for disposal.
- Disposal in geological disposal facilities involves specific challenges compared to "conventional" nuclear activities (e.g. storage, decommissioning)
- WENRA SRLs addresses licensed activities
  - Pre-license and post-closure activities addressed only indirectly
- WENRA SRL focuses on goals to be achieved, i.e.
  - Recognizes differences in national approaches
  - National responsibility to integrate appropriately in national regulations
- Scenario development important element and addressed

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WENRA

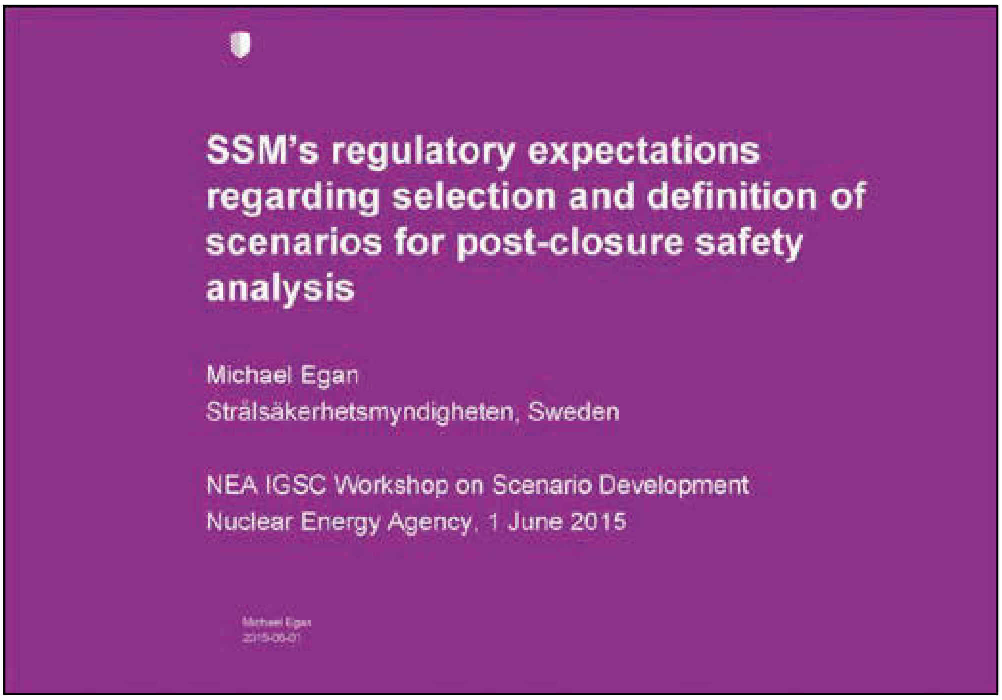
Western European
WENRA
Nuclear Regulators Association

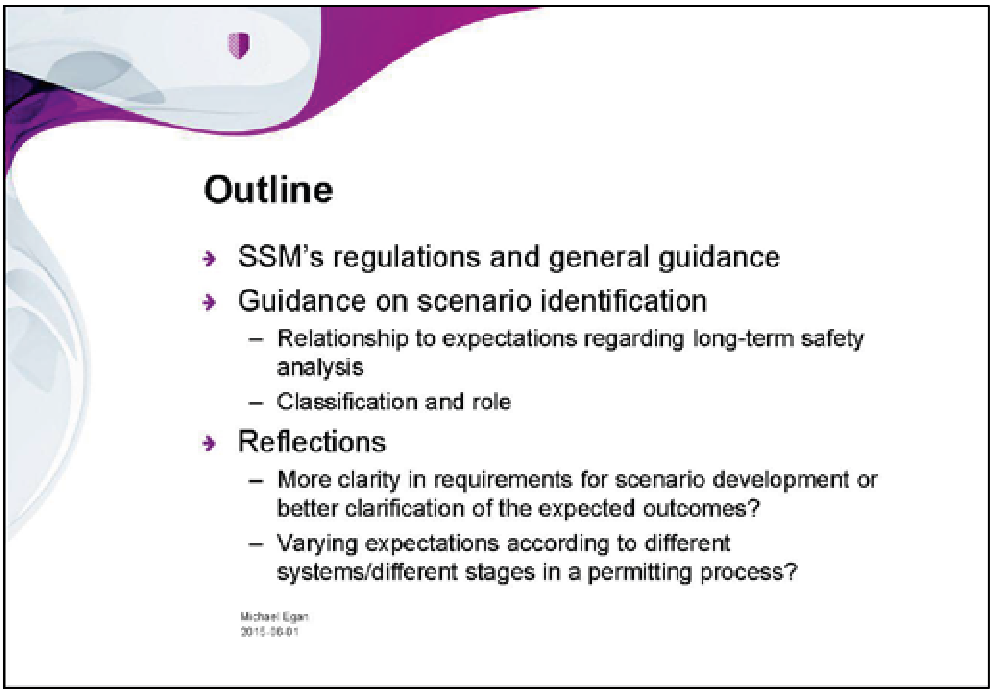
RHWG
REACTOR HARMONISATION WORKING GROUP

WGWD
WORKING GROUP ON WASTE AND DECOMMISSIONING

Thank you

WENRA WGWD
Bengt Hedberg *Bengt.Hedberg@ssm.se*


SSM's regulatory expectations regarding selection and definition of scenarios for post-closure safety analysis
Michael Egan
Strålsäkerhetsmyndigheten, Sweden
NEA IGSC Workshop on Scenario Development
Nuclear Energy Agency, 1 June 2015
Michael Egan
2015-06-01


Outline
SSM's regulations and general guidance
Guidance on scenario identification
– Relationship to expectations regarding long-term safety analysis
– Classification and role
Reflections
– More clarity in requirements for scenario development or better clarification of the expected outcomes?
– Varying expectations according to different systems/different stages in a permitting process?
Michael Egan
2015-06-01

SSM:s regulations on requirements for final disposal

- Two sets of requirements
- Originally developed by separate regulatory authorities under two regulatory regimes
  - Nuclear facility licensing
  - Radiation protection
- Focus on overall expectations regarding scope and purpose of safety assessments
  - High-level goals
  - Supported by related general guidance

Michael Egan
2015-06-01

Safety in connection with the disposal of nuclear material and nuclear waste

- SSMFS 2008:21
- Barriers and their functions
- Design and construction
  - Capability of barriers to withstand FEPs that may affect their function
- Post-closure safety analysis and reporting, including:
  - General definition and classification of scenarios
  - Time periods

Michael Egan
2015-06-01

Radiological protection in connection with final management of waste/spent fuel

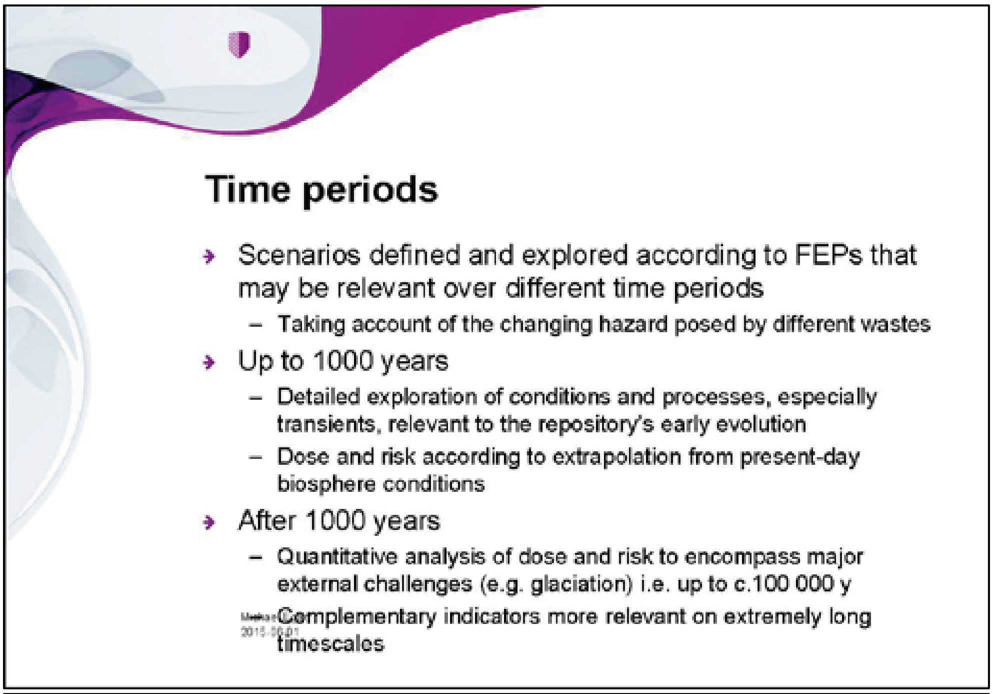
- SSMFS 2008:37
- Protection of human health
  - Estimated annual risk
  - Purpose and selection of scenarios
- Protection of the environment
- Time periods

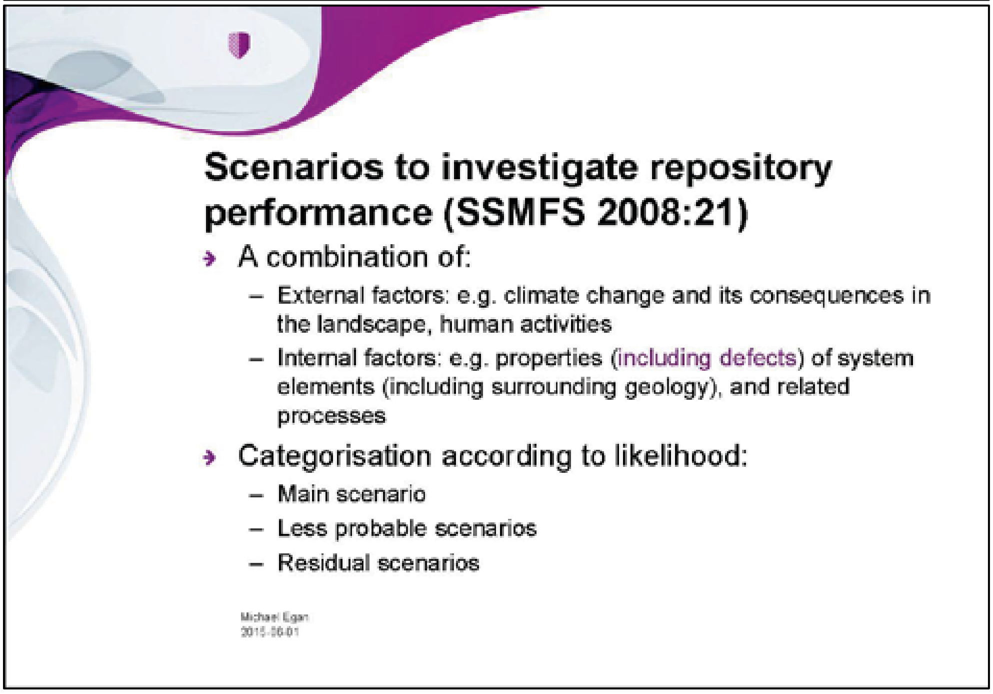
Michael Egan
2015-06-01

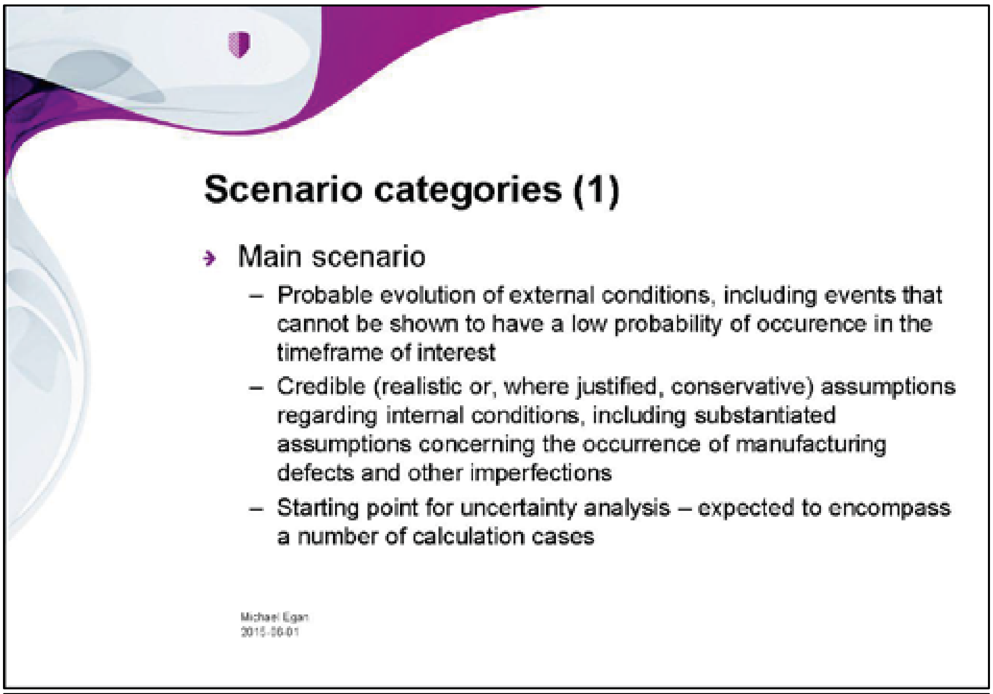
Scenarios

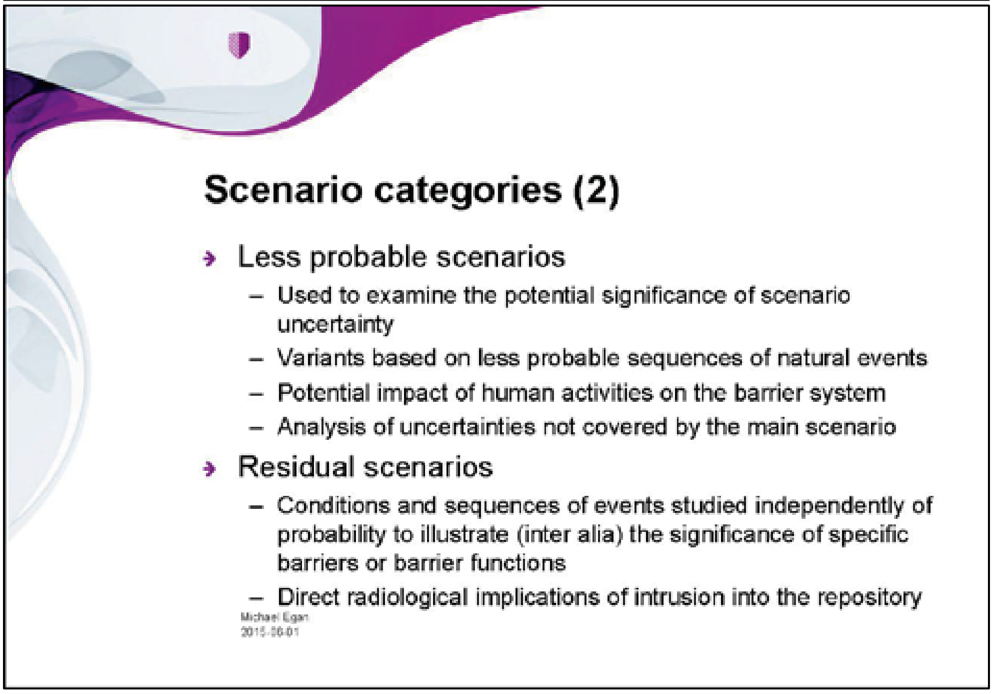
- "*… a description of how a given combination of external and internal conditions affects repository performance*" (SSMFS 2008:21 General guidance)
- "*… (a set) that together illustrate the most important courses of development of the repository, its surroundings and the biosphere*" (SSMFS 2008:37 General guidance)

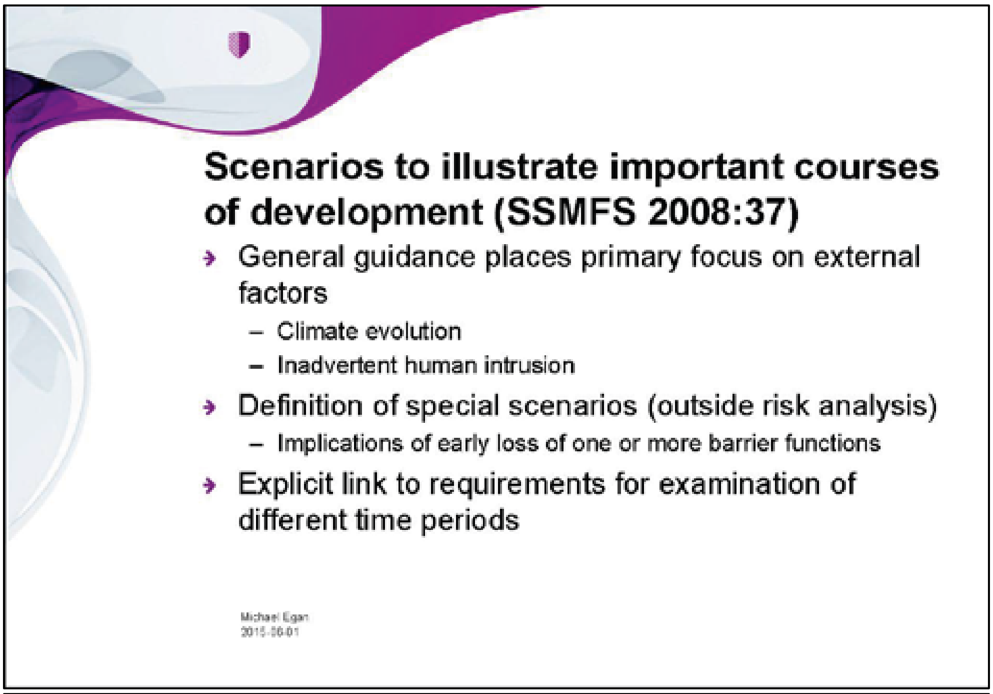
Michael Egan
2015-06-01

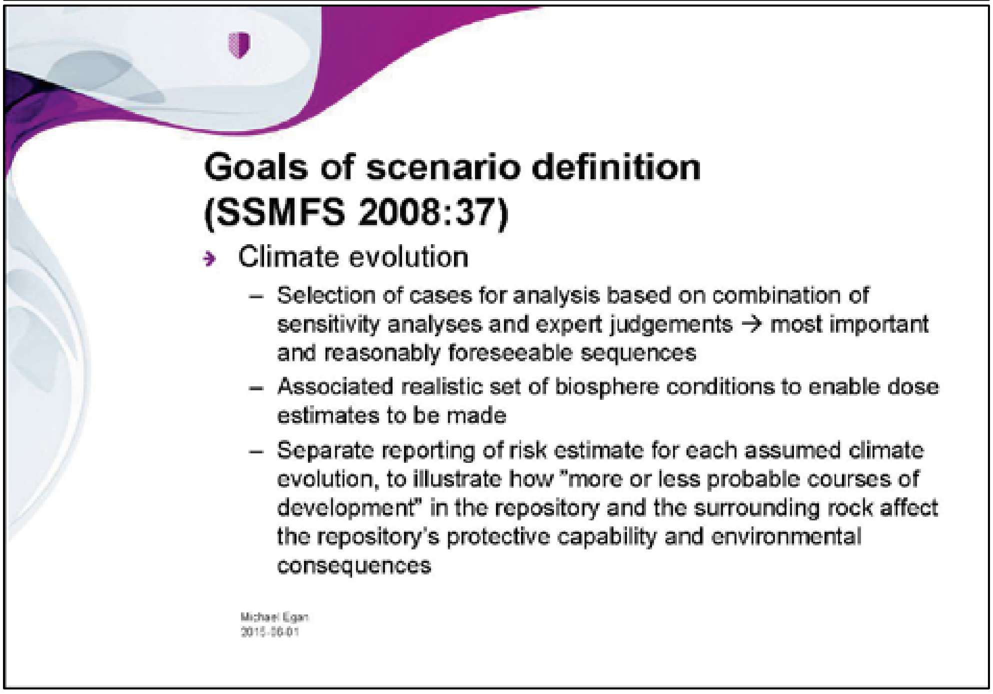

Time periods
Scenarios defined and explored according to FEPs that may be relevant over different time periods
– Taking account of the changing hazard posed by different wastes
Up to 1000 years
– Detailed exploration of conditions and processes, especially transients, relevant to the repository's early evolution
– Dose and risk according to extrapolation from present-day biosphere conditions
After 1000 years
– Quantitative analysis of dose and risk to encompass major external challenges (e.g. glaciation) i.e. up to c.100 000 y
– Complementary indicators more relevant on extremely long timescales

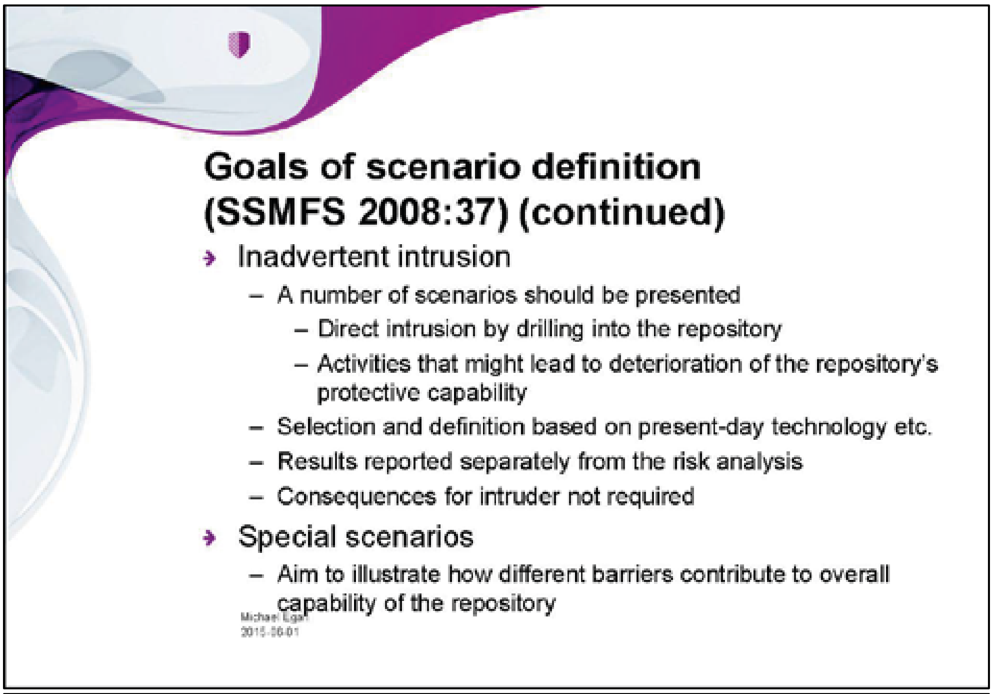

Scenarios to investigate repository performance (SSMFS 2008:21)
A combination of:
– External factors: e.g. climate change and its consequences in the landscape, human activities
– Internal factors: e.g. properties (including defects) of system elements (including surrounding geology), and related processes
Categorisation according to likelihood:
– Main scenario
– Less probable scenarios
– Residual scenarios

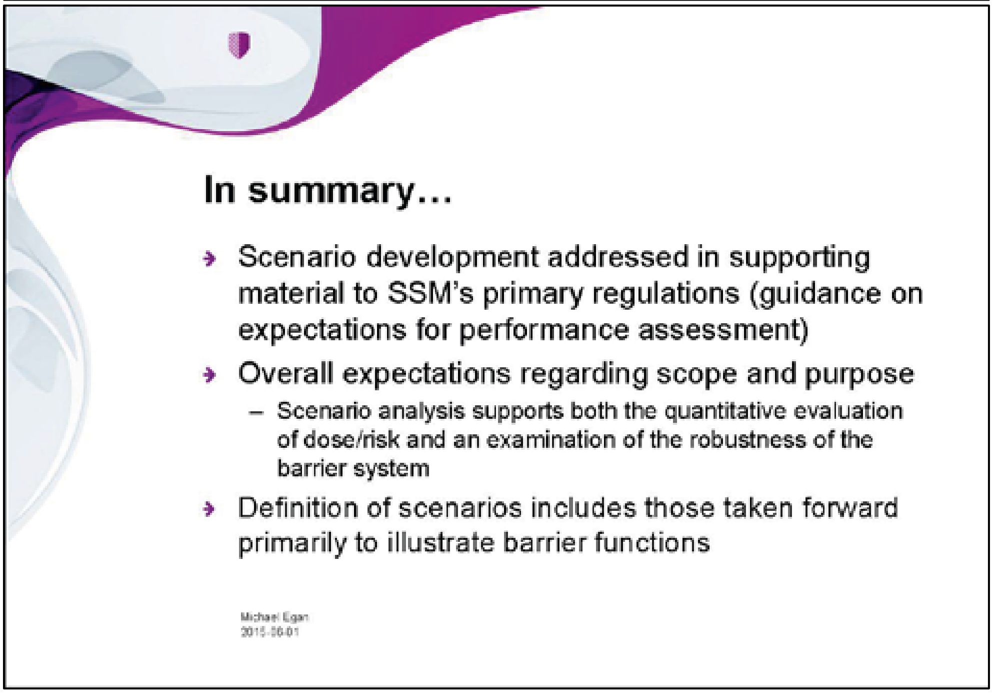

Scenario categories (1)
Main scenario
– Probable evolution of external conditions, including events that cannot be shown to have a low probability of occurence in the timeframe of interest
– Credible (realistic or, where justified, conservative) assumptions regarding internal conditions, including substantiated assumptions concerning the occurrence of manufacturing defects and other imperfections
– Starting point for uncertainty analysis – expected to encompass a number of calculation cases
Michael Egan
2015-06-01

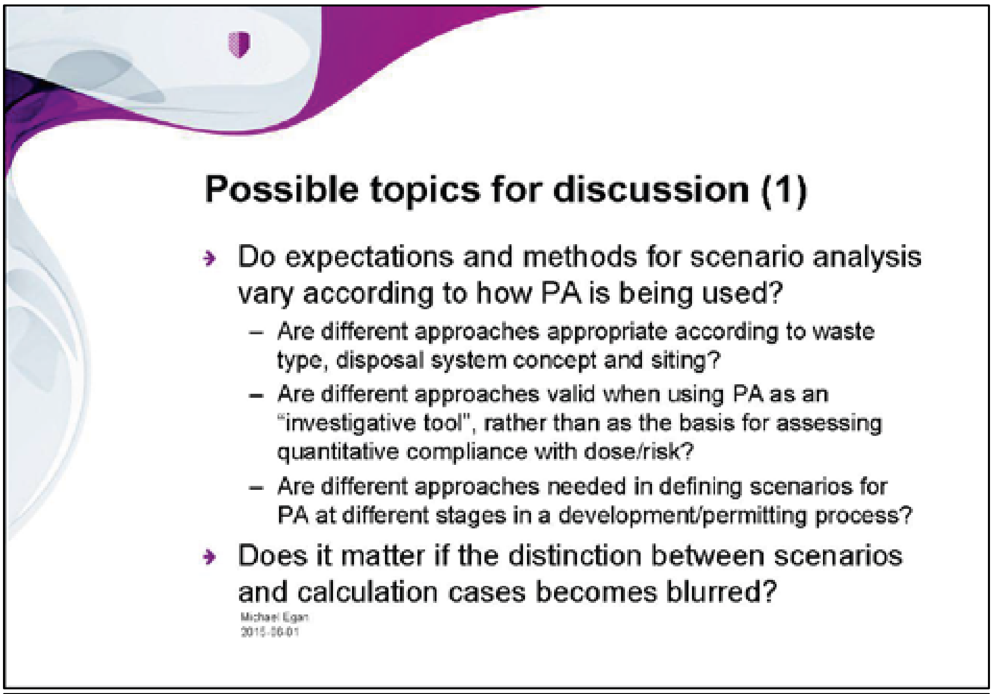

Scenario categories (2)
Less probable scenarios
– Used to examine the potential significance of scenario uncertainty
– Variants based on less probable sequences of natural events
– Potential impact of human activities on the barrier system
– Analysis of uncertainties not covered by the main scenario
Residual scenarios
– Conditions and sequences of events studied independently of probability to illustrate (inter alia) the significance of specific barriers or barrier functions
– Direct radiological implications of intrusion into the repository
Michael Egan
2015-06-01

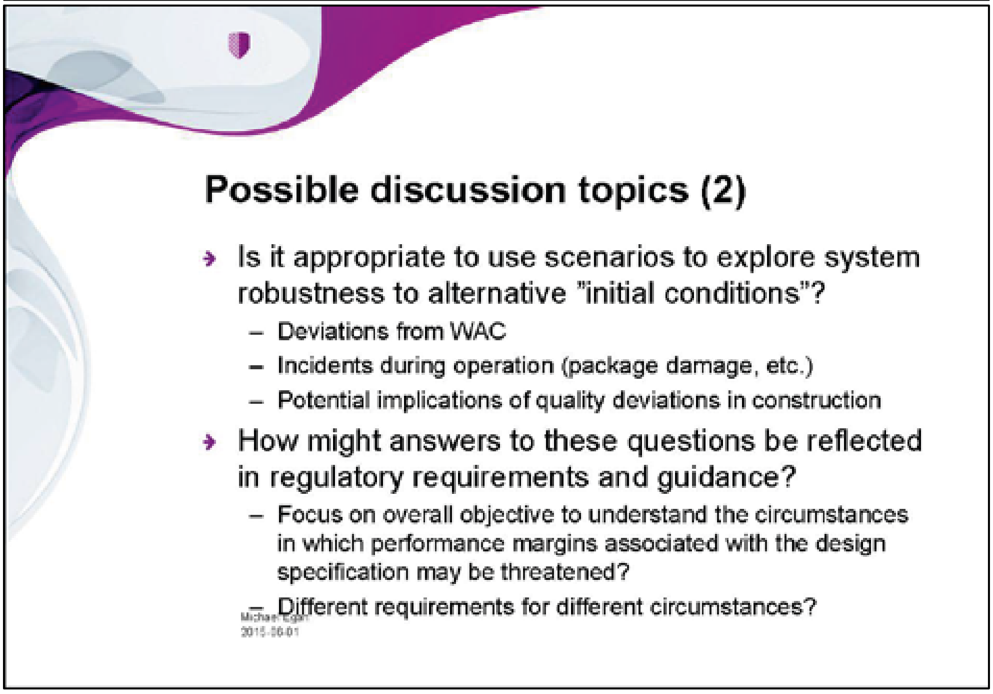

Scenarios to illustrate important courses of development (SSMFS 2008:37)
General guidance places primary focus on external factors
– Climate evolution
– Inadvertent human intrusion
Definition of special scenarios (outside risk analysis)
– Implications of early loss of one or more barrier functions
Explicit link to requirements for examination of different time periods
Michael Egan
2015-06-01

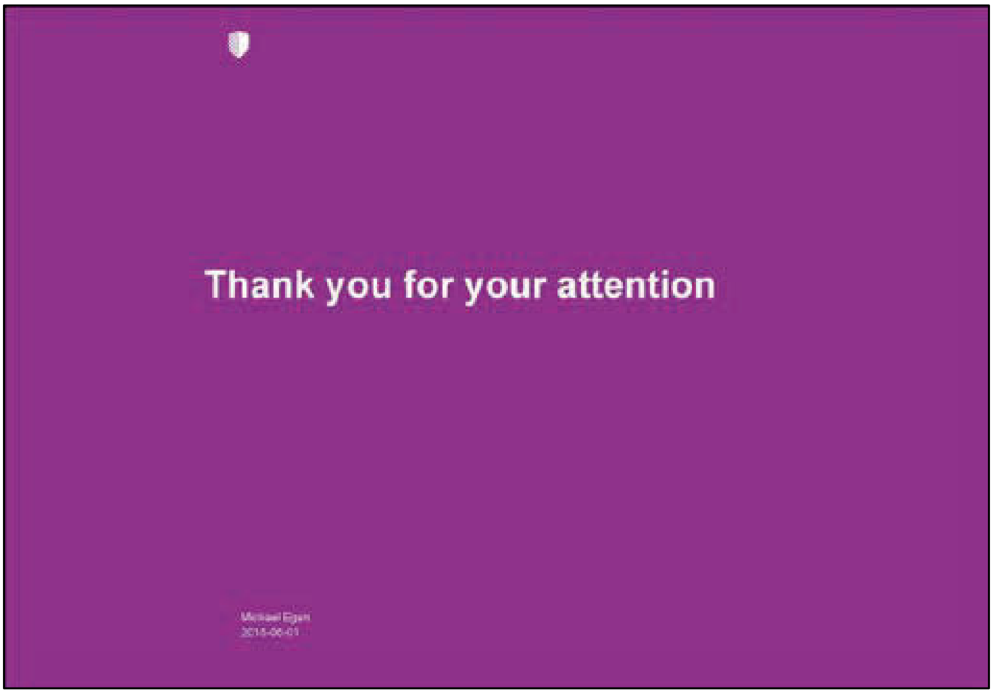

Goals of scenario definition (SSMFS 2008:37)
Climate evolution
– Selection of cases for analysis based on combination of sensitivity analyses and expert judgements → most important and reasonably foreseeable sequences
– Associated realistic set of biosphere conditions to enable dose estimates to be made
– Separate reporting of risk estimate for each assumed climate evolution, to illustrate how "more or less probable courses of development" in the repository and the surrounding rock affect the repository's protective capability and environmental consequences
Michael Egan
2015-06-01


Goals of scenario definition (SSMFS 2008:37) (continued)
Inadvertent intrusion
– A number of scenarios should be presented
– Direct intrusion by drilling into the repository
– Activities that might lead to deterioration of the repository's protective capability
– Selection and definition based on present-day technology etc.
– Results reported separately from the risk analysis
– Consequences for intruder not required
Special scenarios
– Aim to illustrate how different barriers contribute to overall capability of the repository
Michael Egan
2015-06-01


In summary…
Scenario development addressed in supporting material to SSM's primary regulations (guidance on expectations for performance assessment)
Overall expectations regarding scope and purpose
– Scenario analysis supports both the quantitative evaluation of dose/risk and an examination of the robustness of the barrier system
Definition of scenarios includes those taken forward primarily to illustrate barrier functions
Michael Egan
2015-06-01


Possible topics for discussion (1)
Do expectations and methods for scenario analysis vary according to how PA is being used?
– Are different approaches appropriate according to waste type, disposal system concept and siting?
– Are different approaches valid when using PA as an "investigative tool", rather than as the basis for assessing quantitative compliance with dose/risk?
– Are different approaches needed in defining scenarios for PA at different stages in a development/permitting process?
Does it matter if the distinction between scenarios and calculation cases becomes blurred?
Michael Egan
2015-06-01


Possible discussion topics (2)
Is it appropriate to use scenarios to explore system robustness to alternative "initial conditions"?
– Deviations from WAC
– Incidents during operation (package damage, etc.)
– Potential implications of quality deviations in construction
How might answers to these questions be reflected in regulatory requirements and guidance?
– Focus on overall objective to understand the circumstances in which performance margins associated with the design specification may be threatened?
– Different requirements for different circumstances?
Michael Egan
2015-06-01


Thank you for your attention
Michael Egan

ONDRAF/NIRAS

Methodological developments pertaining to scenario since SAFIR 2

2015 IGSC Scenario Development Workshop

1-3 June 2015

M. Capouet[1], C. Depaus[1], E. Weetjens[2] &P. Smith[3]

[1] Belgian Agency for Radioactive Waste and Enriched Fissile materials (ONDRAF/NIRAS), Belgium
[2] Institute of Environment, Health and Safety, Belgian Nuclear Research Centre (SCK•CEN), Belgium.
[3] Safety Assessment, Switzerland

Belgian Agency for Radioactive Waste and Enriched Fissile Materials

Plan of the presentation

- Situating the geological disposal programme
- Scenario development in SAFIR 2
- Methodological development for SFC1
- Conclusions

ONDRAF/NIRAS

Situating the geological disposal programme

1st and 2nd RD&D phase (1974-1990-2001) : SAFIR 2

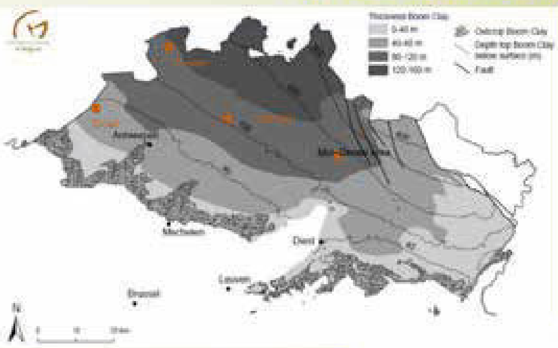
- Safety Assessment and Feasibility Interim Report
- Combined the knowledge accumulated by 2000 into an safety assessment format
- Focus:
  - Boom Clay and the Mol-Dessel nuclear zone as reference host rock and site
  - Ypresian Clays as alternative formation
- International Review Team (2002), on behalf of the Belgian Government

3d RD&D phase (2001): paving the way to the first Safety Case (SFC1)

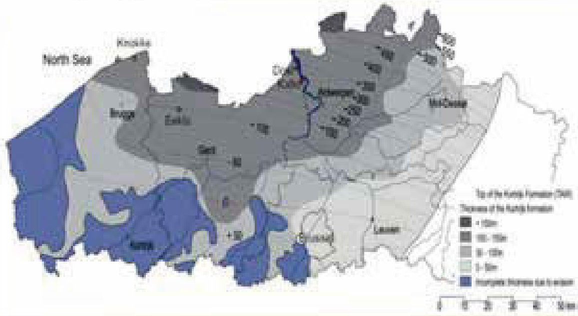
- SEA (2010) & Waste plan (2011)
- RD&D plan (2014)
- Aim: Safety Case dedicated to the poorly indurated clays in well defined assessment zones
- To date: No political decision regarding a potential geological disposal in Belgium

3

The assessment zones

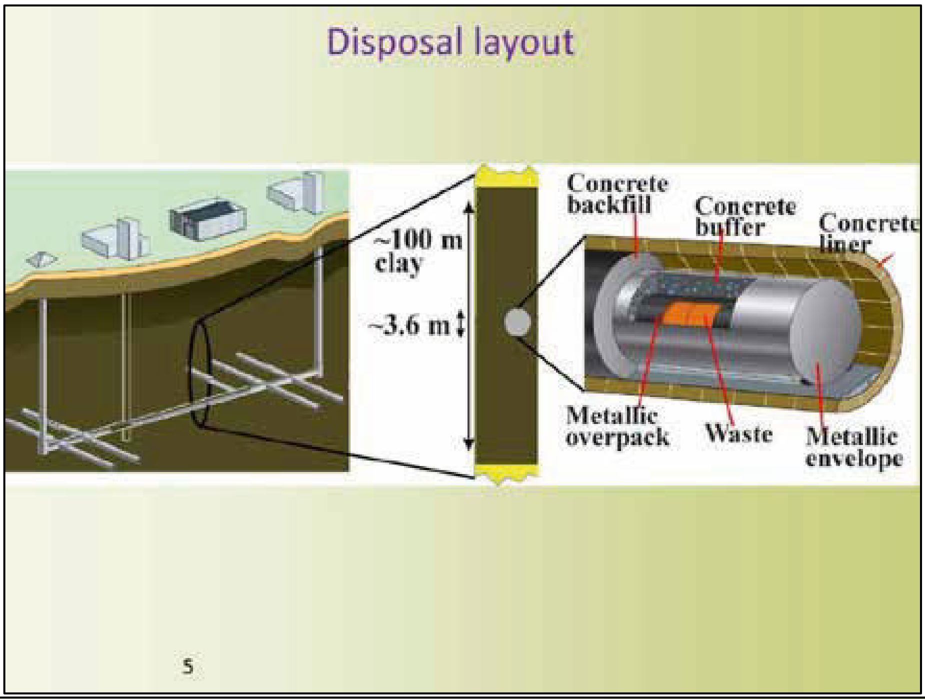


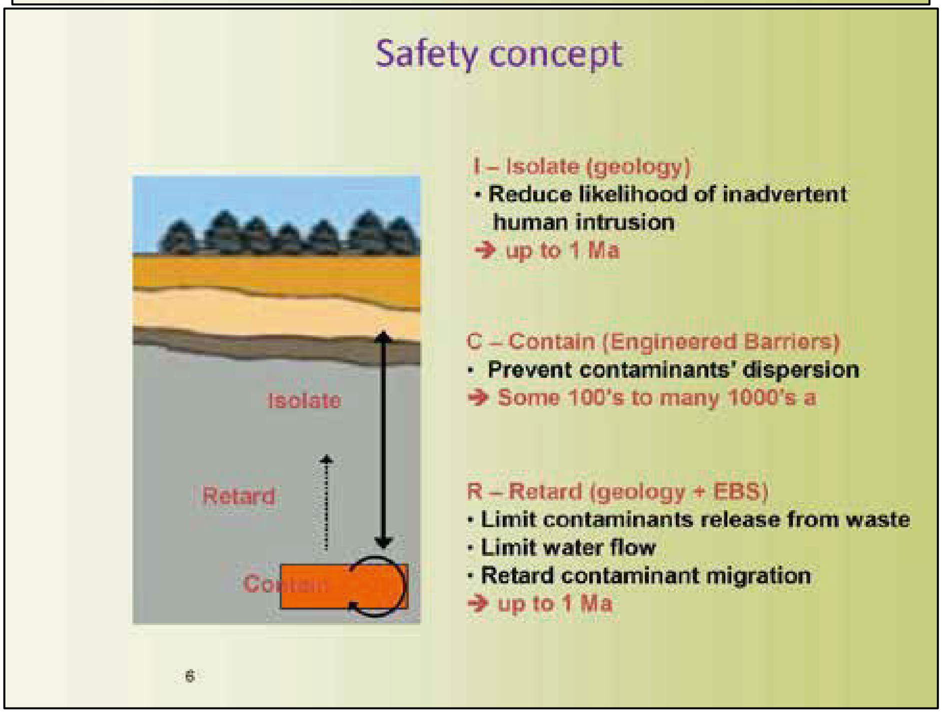
Boom Clay



Ypresian Clays

4


Disposal layout
~100 m clay
~3.6 m
Concrete backfill
Concrete buffer
Concrete liner
Metallic overpack
Waste
Metallic envelope
5


Safety concept
Isolate
Retard
Contain
I – Isolate (geology)
• Reduce likelihood of inadvertent human intrusion
➔ up to 1 Ma
C – Contain (Engineered Barriers)
• Prevent contaminants' dispersion
➔ Some 100's to many 1000's a
R – Retard (geology + EBS)
• Limit contaminants release from waste
• Limit water flow
• Retard contaminant migration
➔ up to 1 Ma
6

Scenario development at the time of SAFIR2 (1)

Based on the so-called FEP approach:

1/ A FEP catalogue dedicated to disposal in Boom Clay (Mol site) is compiled:

- Based on the NEA's FEP list (1992)
- The NEA FEP list being exhaustive, only few FEPs typical to clay is added.

7

Scenario development at the time of SAFIR2 (2)

2/ Systematic screening & analysis of the FEP table according to the following criteria:

Code	Reasons for screening out
R1	Low probability
R2	negligible consequences
R3	not relevant for clay formations
R4	not relevant for the Mol site
R5	not relevant for the considered repository design
R6	responsibility of future generations
R7	administrative reasons (mostly multiple entries)

code	Components that might be influenced by the FEPs
n	Near field
c	Clay layer
a	Aquifer
b	Biosphere

8

Scenario development at the time of SAFIR2 (1)

3/ Combination of FEPs to form the altered evolution scenarios:

- FEPs that cannot be considered in the normal evolution scenario can be classified according to the state of the disposal system (prosa methodology)

Table 11.5.2-2: *Classification of FEPs according to the state of the disposal system.*

The second column indicates the barrier or component that is compromised by the FEP. E: engineered; G: geological; H: hydrogeological; 1: intact; 0: compromised.

State	E	G	H	FEPs
1	1	1	1	**Normal evolution scenario**
2	1	1	0	[illegible] fault activation
				2.3.2 exploitation drilling
				2.4.8 anthropogenic climate changes
3	1	0	1	1.2.4 fault activation
				1.6.3 gas-driven transport
				3.3.4 gas effects
				2.1.1 failure of backfill material in shaft and gallery
				2.2.3 poor sealing
4	1	0	0	1.3.5 glaciation
5	0	1	1	1.2.3 seismicity
				2.1.2 material defect
				2.1.3 poor-quality construction
				3.3.4 gas effects
6	0	1	0	–
7	0	0	1	1.2.4 fault activation
				1.6.3 gas-driven transport
				3.3.4 gas effects
8	0	0	0	2.3.1 exploratory drilling
				2.3.3 archaeological research

9

IRT& ONDRAF/NIRAS review

Good points:

- Systematic approach !
- Premise of a coupled bottom-up /top-down approach

Less good points:

- The link with RD&D is missing
- The methodology does not rely on the defence in depth
- Good tool to identify classes of scenarios but not how they are shaped. Different realisations might be possible for one scenario.
- Need to explore further some uncertainties, more insight calculations to illuminate the key features determining the performance of the system.
- Need to develop alternative indicators

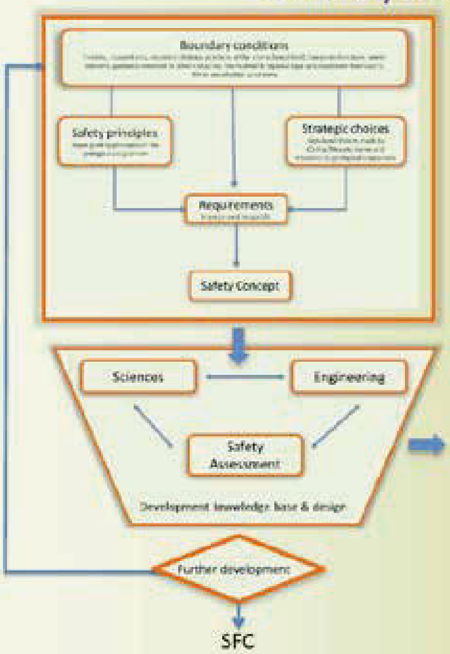
10

Development of the regulatory framework since SAFIR 2

- AFCN (2012), Technical guide on post-closure analysis of the radiaoctive waste disposal system (« Analyse de la sûreté post-fermeture des établissements de stockage définitif des déchets radioactifs ». Note externe 2012-02-28-FLE-5-4-4-FR, Rév. 0)
  - The scenarios must have an appropriate level of realism
  - The disposal system must be known and understood
  - Its expected evolution sufficiently known (basis for the scenario development)
  - The perturbations must be identified and characterised
  - Treatment of uncertainties must be transparent, traceable and appropriate. Three types of uncertainties:
    - Associated to FEPs bound to initial state and evolution of the disposal system
    - Associated to the completeness of FEPs
    - Associated to tools and methods used in the assessment
  - A set of scenarios representative and bounding of the possible evolutions of the system must be developed:
    - A scenario representative of the expected evolution;
    - Unexpected (but possible) scenari
    - Human intrusion scenari
    - Penalising scenari to represent the evolution of the system when the performances of the disposal system can no more be assessed correctly.
  - Robustness of the system must be evaluated

11

Ondraf/Niras Safety Strategy



Revisiting the scenario methodology was carried out with an examination of the overall strategy:

• To connect each activity with the safety case objective.

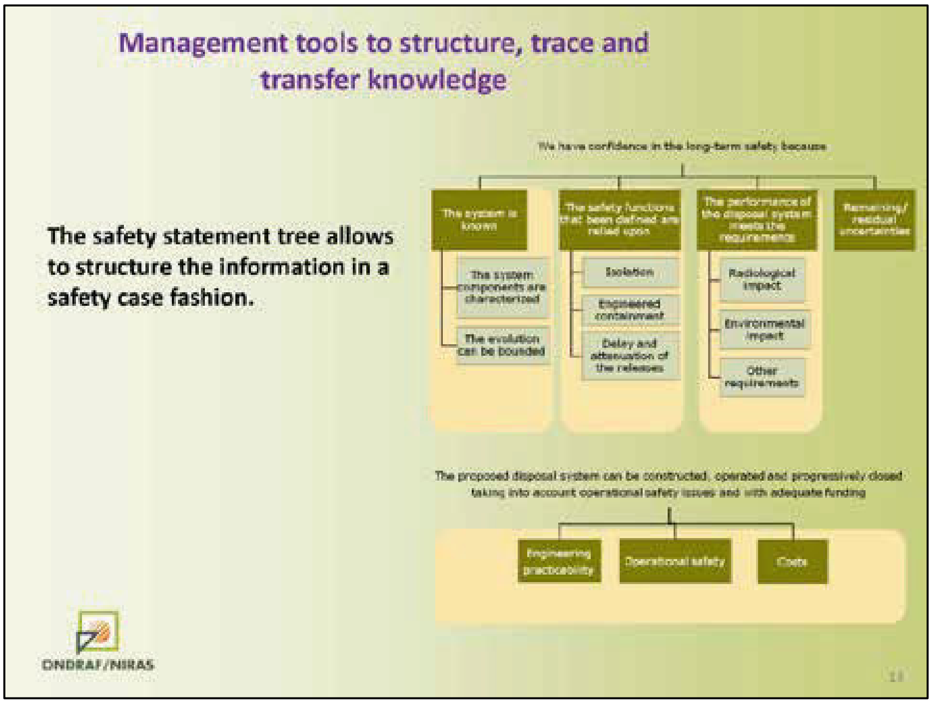
•To implement the link between the assessment basis and the safety assessment

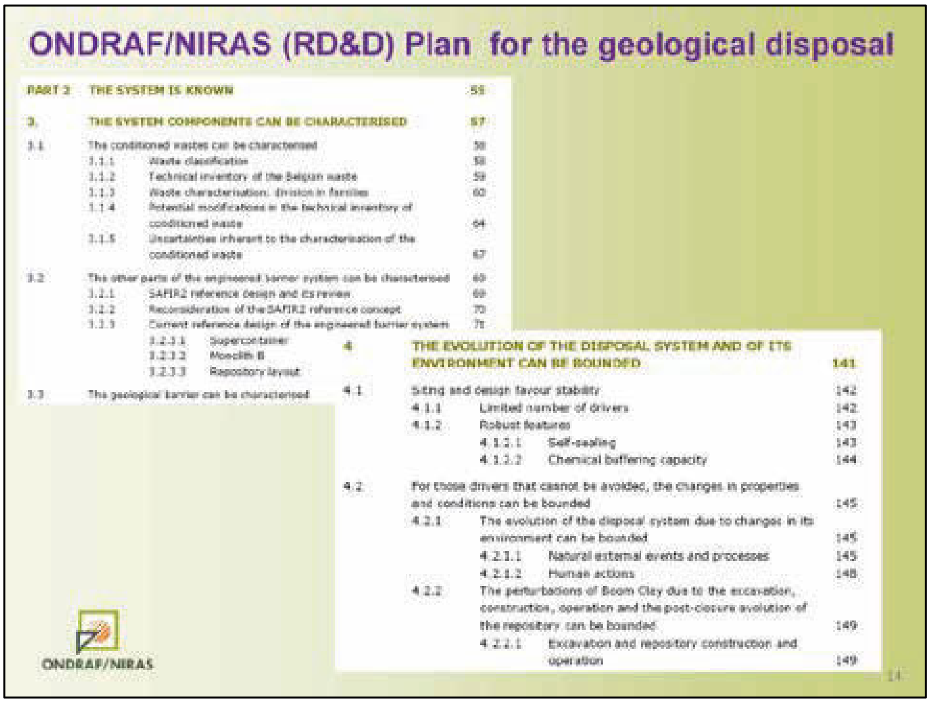
•Scenarios are developed iteratively through the interactions between the three poles of activity.

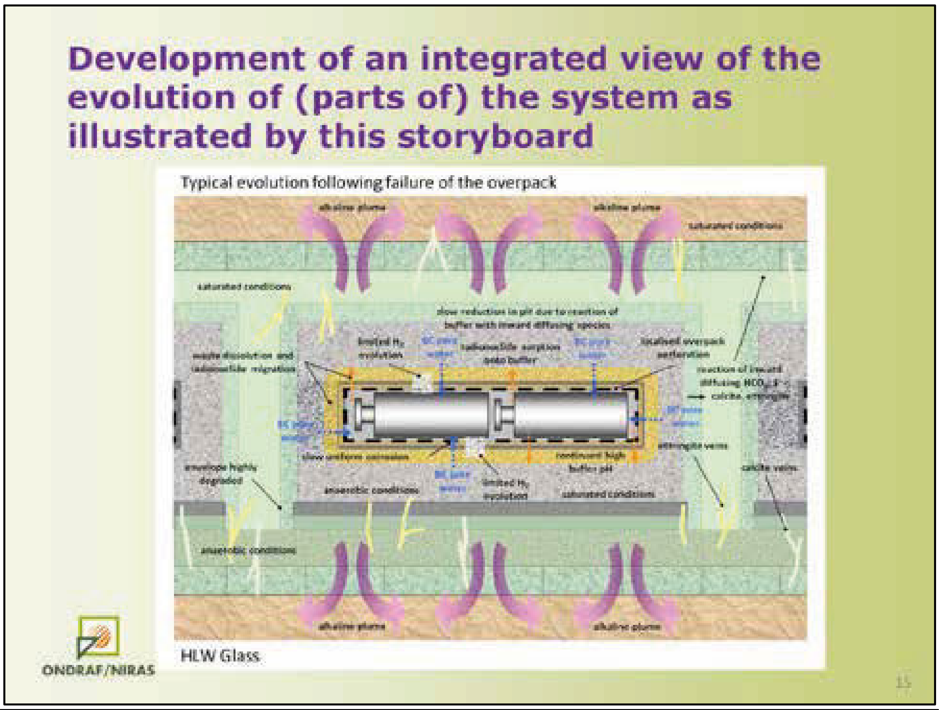
System knowledge

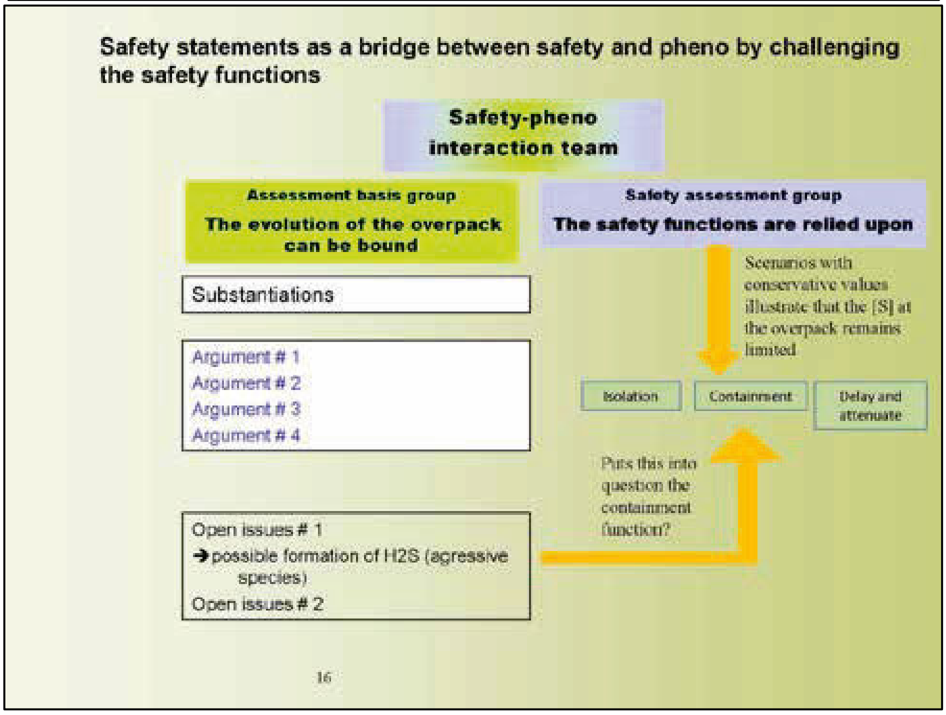
Scenarios

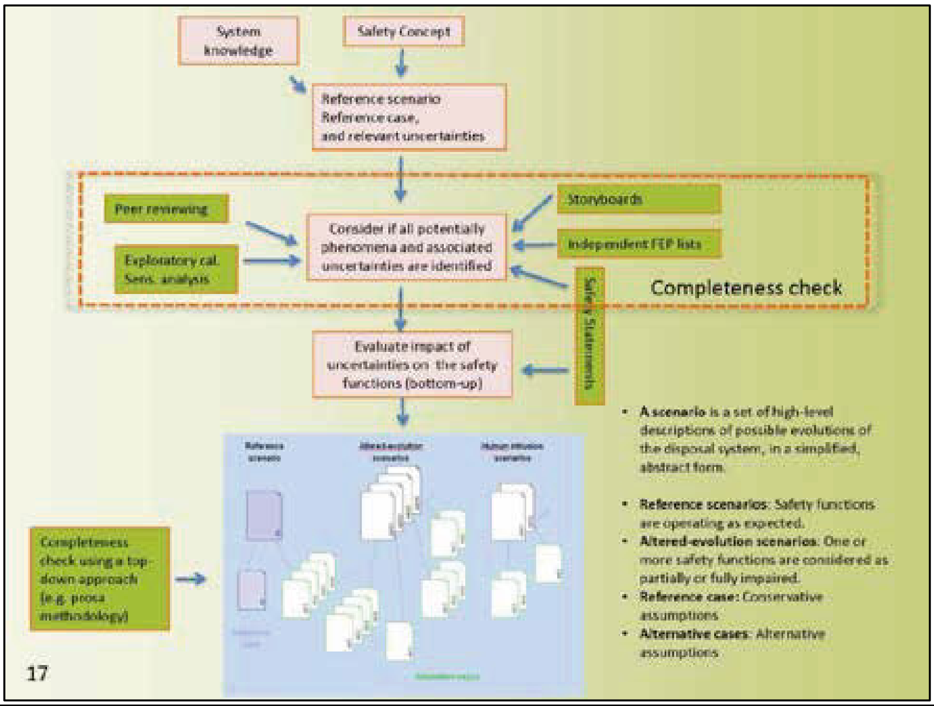
12


Management tools to structure, trace and transfer knowledge
The safety statement tree allows to structure the information in a safety case fashion.
We have confidence in the long-term safety because
The system is known
The system components are characterized
The evolution can be bounded
The safety functions that been defined are relied upon
Isolation
Engineered containment
Delay and attenuation of the releases
The performance of the disposal system meets the requirements
Radiological impact
Environmental impact
Other requirements
Remaining/ residual uncertainties
The proposed disposal system can be constructed, operated and progressively closed taking into account operational safety issues and with adequate funding
Engineering practicability
Operational safety
Costs
ONDRAF/NIRAS
13


ONDRAF/NIRAS (RD&D) Plan for the geological disposal
ONDRAF/NIRAS
14


Development of an integrated view of the evolution of (parts of) the system as illustrated by this storyboard
Typical evolution following failure of the overpack
alkaline plume
alkaline plume
saturated conditions
saturated conditions
anaerobic conditions
saturated conditions
anaerobic conditions
alkaline plume
alkaline plume
HLW Glass
ONDRAF/NIRAS
15


Safety statements as a bridge between safety and pheno by challenging the safety functions
Safety-pheno interaction team
Assessment basis group
The evolution of the overpack can be bound
Safety assessment group
The safety functions are relied upon
Substantiations
Argument # 1
Argument # 2
Argument # 3
Argument # 4
Scenarios with conservative values illustrate that the [S] at the overpack remains limited
Isolation
Containment
Delay and attenuate
Puts this into question the containment function?
Open issues # 1
➔possible formation of H2S (agressive species)
Open issues # 2
16

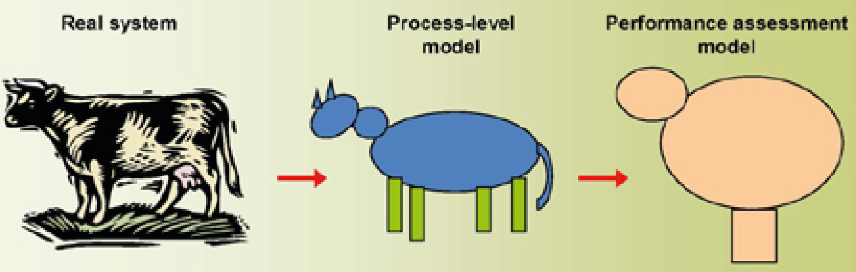


How do we make safety assessment scenarios ?

The need for simplification:

- Large amount of information from pheno.
- Complex geometric situations & processes
- All processes together and on high spatial resolution cannot be implemented in one model – and if, it could so, it would be difficult to verify the model (QA issue)
- **Focus is on the modelling of the safety consequences rather than the representation of the evolution of the system.**

PA Abstraction



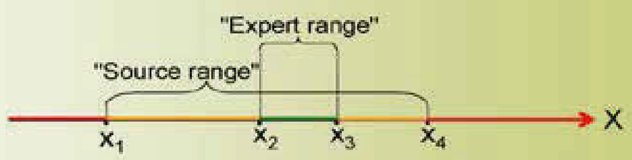
- **PA abstraction:** *The process of developing a safety assessment model from relevant phenomenological knowledge, taking into account the limits of, and uncertainties in, this knowledge, as well as requirements that may include :*
  - *the types of safety and performance indicators to be calculated,*
  - *the need of conservatism : simplification without undermining safety*
    - *Intentionally ignore beneficial processes that are difficult to characterise*
    - *Intentionally bind detrimental processes that are difficult to characterise*
  - *The ease of verification of the computer code used to implement the model.*
- ***Through this process some conceptual model uncertainties are translated into safety parameter uncertainties***

Characterisation of the uncertainties of the safety relevant parameter

Two ranges are estimated:

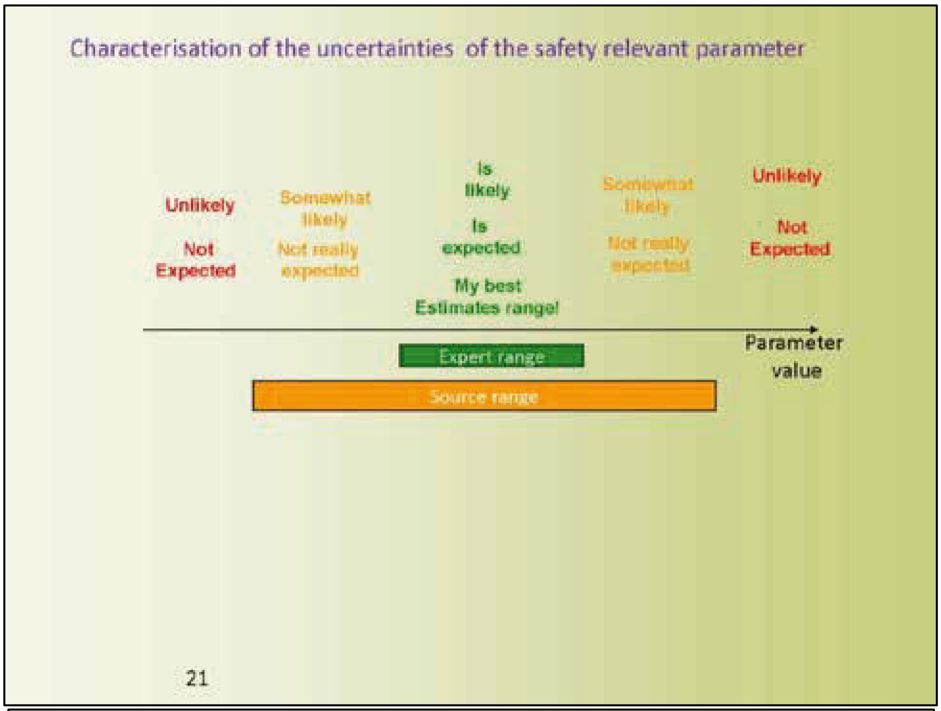
The expert range: is the range within which experts expect the parameter value to lie considering current knowledge.

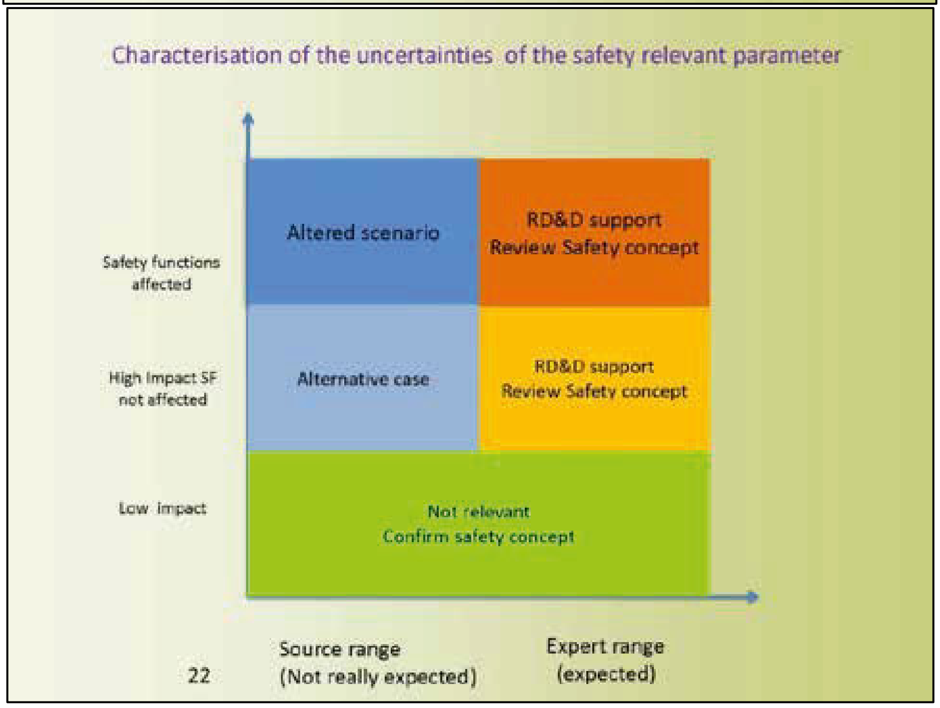
The source range : is the range outside of which the experts do not expect the parameter value to lie considering current knowledge.



Legend:
[x2,x3] = range within which the value of X should lie, according to experts i.e. "(fully)realistic values"
\ ]x1,x4[= range of values that should be ruled out for X, according to experts i.e. "unrealistic" 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"

20


Characterisation of the uncertainties of the safety relevant parameter
Unlikely
Not Expected
Somewhat likely
Not really expected
Is likely
Is expected
My best Estimates range!
Somewhat likely
Not really expected
Unlikely
Not Expected
Parameter value
Expert range
Source range
21


Characterisation of the uncertainties of the safety relevant parameter
Safety functions affected
High Impact SF not affected
Low impact
Altered scenario
RD&D support
Review Safety concept
Alternative case
RD&D support
Review Safety concept
Not relevant
Confirm safety concept
Source range
(Not really expected)
Expert range
(expected)
22

Methodological developments pertaining to scenario since SAFIR 2

Conclusions

- Scenario is also a tool to steer RD&D and to test robustness.
- Scenario development follows a top down/bottom up approach.
- Increasing importance of the sensitivity analysis since SAFIR 2.
- Importance of a traceable and transparent simplification process to capture sytem knowledge in SA model.
- Importance of the completeness process

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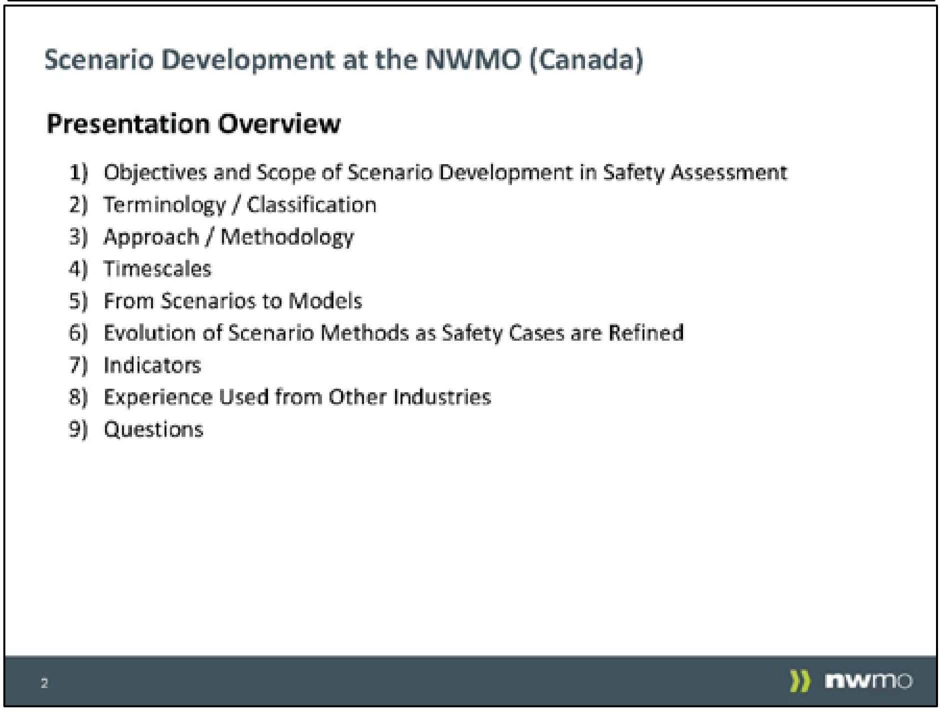
Scenario Development at the NWMO (Canada)
Neale Hunt
NEA IGSC Scenario Development Workshop
June 1-3, 2015
Paris

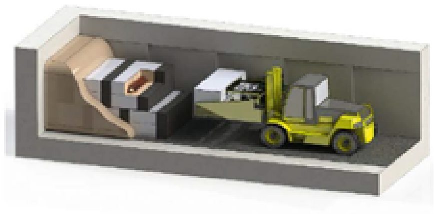

Scenario Development at the NWMO (Canada)
Presentation Overview
1) Objectives and Scope of Scenario Development in Safety Assessment
2) Terminology / Classification
3) Approach / Methodology
4) Timescales
5) From Scenarios to Models
6) Evolution of Scenario Methods as Safety Cases are Refined
7) Indicators
8) Experience Used from Other Industries
9) Questions
2

Objectives and Scope of Scenario Development

Scenarios are specified to define the scope of the postclosure safety assessment

Regulatory guidance for the postclosure safety assessment is available in CNSC Regulatory Guide G-320 *Assessing the Long Term Safety or Radioactive Waste Management*

CNSC Regulatory Guide G-320 specifies that scenarios be developed in a systematic, transparent and traceable manner through a structured analysis of FEPs



3

Terminology / Classification

Taken / adapted from CNSC Regulatory Guide G-320

Scenario:

- Assumed set of future conditions to be modelled in an assessment. Includes information on timeframes and receptors

Normal Evolution Scenario:

- Reasonable extrapolation of present day site features and receptor lifestyles. Includes expected evolution of site and degradation of components
- In practice, the NWMO adopts a Reference Normal Evolution Scenario together with a series of sensitive studies that challenge barrier effectiveness

Disruptive Event Scenarios:

- Postulate the occurrence of unlikely events leading to possible penetration of barriers and abnormal loss of containment
- Assessed separately from the Normal Evolution Scenario

4

Approach / Methodology

Consistent with CNSC Regulatory Guide G-320, NWMO scenarios are identified through a structured analysis of the FEPs

- NWMO FEP list is based on the NEA 2000 FEP list with revisions incorporated to address some of the changes in the draft NEA FEP list currently under development → will align in the future
- Maintained as a Word document with Description, Screening Analysis and Inclusion Statement

Structure of NWMO FEP List:

0. Assessment Basis
1. External Factors
2. Waste Package Factors
3. Repository Factors
4. Geosphere Factors
5. Biosphere Factors
6. Contaminant Factors

More information available on the NWMO website:

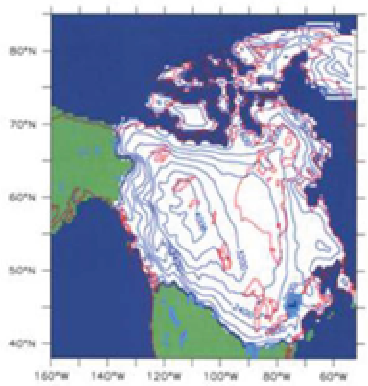
- NWMO TR-2012-14: FEPs for illustrative postclosure safety assessment for crystalline rock
- NWMO TR-2013-06: FEPs for illustrative postclosure safety assessment for sedimentary rock

5 nwmo

Approach / Methodology (cont'd)

General approach for scenario identification is to consider 'internal' FEPs and 'external' FEPs

- *Internal FEPs* (e.g., waste package, repository, geosphere, biosphere, contaminant factors) primarily aid in defining the expected evolution of the repository and in determining which features and processes to include in the conceptual model
- *External FEPs* (e.g., climate, earthquakes, human influence) provide the system with boundary conditions and include influences from outside the repository that might cause change. They include decisions on design, operation and closure



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Approach / Methodology (cont'd)

For the Normal Evolution Scenario:

- *External FEPs* and *Internal FEPS* are reviewed to identify those that are likely to occur and could potentially affect the repository → included in scenario definition
- Examples of inclusions are placement of some containers with undetected defects, glaciation and its effects, earthquakes, human influence (climate, land use, water management, etc.)

For Disruptive Event Scenarios:

- *External FEPs* and *Internal FEPs* are compared against high level safety features that have been specified for the geology, the waste characteristics, the design and for institutional control. Any FEP that could compromise the safety feature is potentially scenario generating

7 nwmo

Approach / Methodology (cont'd)

Example of assessment approach for Disruptive Scenario Identification

Safety Feature	Potentially Compromised by	Consider as Failure Mechanism
1. The depth of the host rock formation should be sufficient for isolating the repository from surface disturbances and changes caused by human activities and natural events.	Near-surface design adopted (FEP 1.1.02).	**No**, only a deep design is being considered for the repository.
	Meteorite impact (FEP 1.5.01).	**No**, due to low probability of meteor impact capable of compromising safety due to the relatively small repository footprint (~6 km^2) and depth of repository (~500 m). See Garisto (2013) for further discussion of probabilities.
	Exploration borehole penetrates into repository providing enhanced permeability pathway to surface environment and potential for direct exposure to waste (FEP 1.4.04).	**Yes**, although the absence of economically exploitable resources, and the depth (~500 m) and relatively small repository footprint (~6 km^2) mean that the probability of such a borehole intruding into the repository would be very low during the period of greatest potential hazard.
	Mining and other underground activities resulting in excavation in the vicinity of the repository (FEP 1.4.05).	**No**, due to assumption of the absence of commercially viable mineral resources near or below repository level. Shallow quarrying or tunnelling activities are unlikely to affect the repository because of repository depth (~500 m). Also, most underground activities would likely be preceded by exploration boreholes, as addressed above.

Potentially compromising FEPs are grouped to define Disruptive Event Scenarios

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Approach / Methodology (cont'd)

Grouping resulted in eight Disruptive Scenarios for the recent Illustrative Sedimentary Rock Postclosure Safety Assessment

1. Inadvertent Human Intrusion
   - Exploration borehole inadvertently drilled into the repository
2. All Containers Fail
   - Unexpected poor mechanical or chemical performance of copper shell
   - Beyond design basis ice sheet causes collapse of containers
3. Shaft Seal Failure
   - Poor construction leads to large excavation damage zone around shafts
   - Poor installation of shaft seals
   - Long-term performance of shaft seals is much worse than expected
4. Partially Sealed Repository
   - Repository not closed as planned after monitoring period due to unknown reasons (e.g., societal collapse)

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Approach / Methodology (cont'd)

5. Poorly Sealed Borehole
   - Site characterization or monitoring borehole poorly sealed
   - Long-term performance of borehole seals is much worse than expected
6. Undetected Fault
   - Site characterization does not identify permeable feature near repository
   - Large seismic event results in reactivation of an existing fracture zone or fault
7. Severe Erosion
   - Glacial erosion is much more extensive than expected
8. Container Failure
   - Seismic events cause shearing along existing fracture zone passing through placement room, damaging containers near the fracture
   - Unexpected poor chemical performance of some copper shells
   - Beyond design basis ice sheet causes collapse of some containers

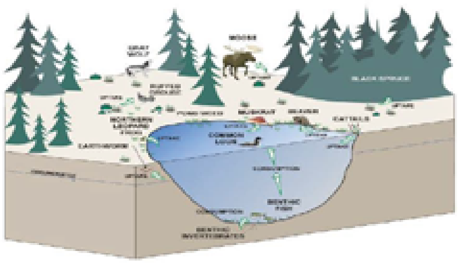
10 nwmo

Approach / Methodology (cont'd)

Other Disruptive Scenarios ruled out on various grounds (e.g., no volcanic activity in area) or very low probability (e.g., meteor strike)

More information on scenario identification available on the NWMO website :

- NWMO TR-2012-16: Illustrative postclosure safety assessment for crystalline rock
- NWMO TR-2013-06: Illustrative postclosure safety assessment for sedimentary rock



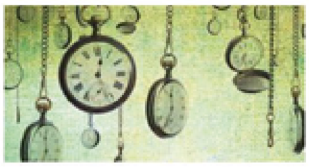
11 nwmo

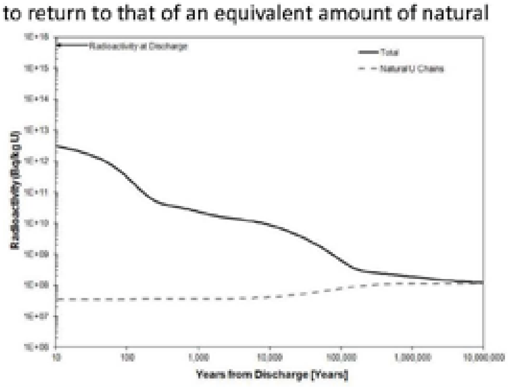
Timescales

CNSC Regulatory Guide G-320 specifies that there is no time limit on the statutory objective to prevent unreasonable risk to the environment and the health and safety of persons

General expectation is that the assessment of future impact include the period of time during which the maximum impact is anticipated to occur

The NWMO typically considers a 1 My time period because this is roughly the time required for the radioactivity level to return to that of an equivalent amount of natural uranium

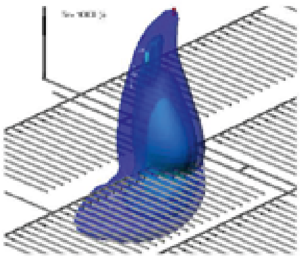


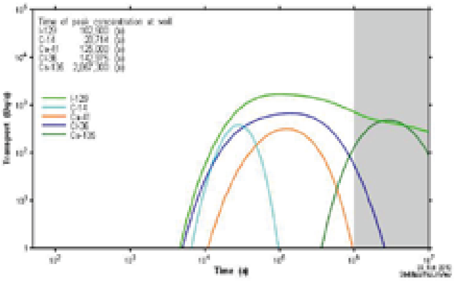


12 nwmo

From Scenarios to Models

- *Internal FEPS* are important aids in defining the expected evolution of the repository and in determining which features and processes to include in the conceptual model
- Conceptual model then converted to a computer model
- Models and approaches used by other organizations are also considered
- Conservative methods are used when applying simplifying assumptions
- Data used are sourced and documented
- Default data are used until site-specific data become available
- Disruptive Event Scenarios are considered separately from the Normal Evolution Scenario





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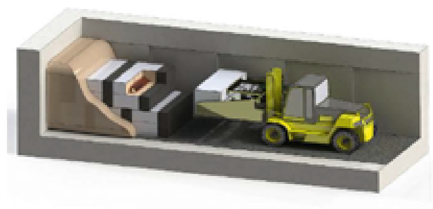
Evolution of Scenario Methods as Safety Cases are Refined

- Changes in the NWMO conceptual design and hypothetical geosphere have resulted in changes to the NWMO illustrative safety assessment
- Such changes are addressed through the existing process of defining scenarios
- Scenario identification has been given a higher priority and more visibility in recent illustrative assessments than previously → specific chapter
- Have better integration between Engineering, Safety Assessment and Geoscience when considering essential features of the Normal Evolution Scenario and the Disruptive Event Scenarios



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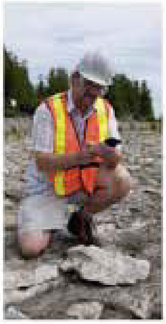
Indicators

Safety assessment uses complementary indicators:

- Radiotoxicity concentration in a water body
- Radiotoxicity transport from the geosphere



15 nwmo

Experience Used from Other Industries

Disruptive Scenarios are compared with, and rationalized against, similar scenarios from other organizations, including those from SKB, Posiva, Andra, Nagra, Ondraf/Niras, the US DOE and others

16 nwmo

Questions

17

SÚRAO

Scenarios for safety assessment of underground repositories

Radioactive Waste Repository Authority
Soňa Konopásková
www.surao.cz

SÚRAO

Contents

2

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Operated Repositories

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Subsurface repositories underground

- ❑ Waste containing natural radionuclides – disposed off in Bratrství repository
- ❑ Waste containing artificial radionuclides – disposed off in Richard repository

Operation and volumes

- ❑ Richard – since 1964, 11 000 m³
- ❑ Bratrství – since 1973, 1 200 m³
- ❑ Hostím – 1959 – 1964, 1 700 m³, closed 1998

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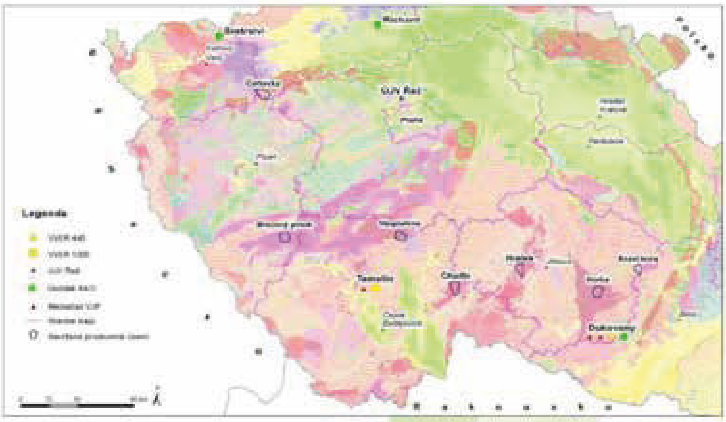
Potential sites for geological repository



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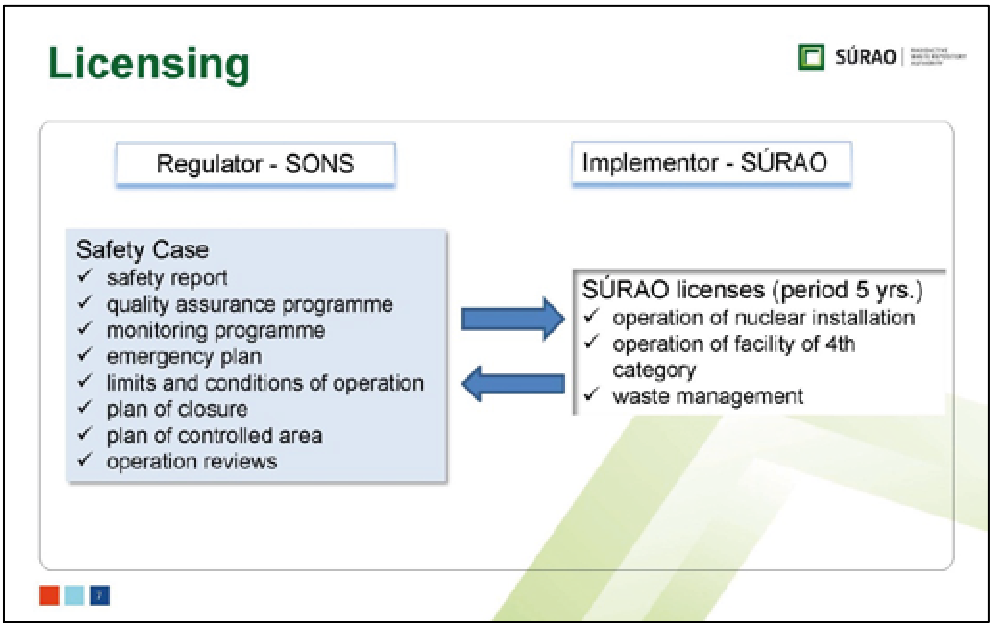
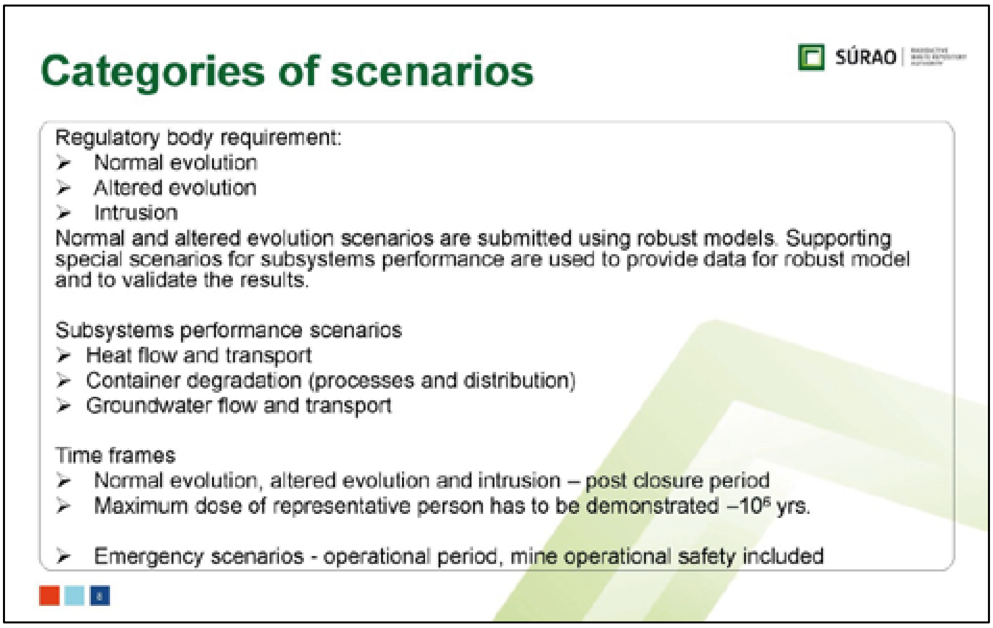
Objectives of safety assessment

- Re-licensing in accordance with Atomic Act – a new wording of the Act should be valid in 2016
- Support of the safety case
- Safety criteria development
- Limits and conditions of operation development
- Derivation of acceptance conditions
- Support of monitoring programme
- Evaluation of potential emergency situations

6


Licensing
SÚRAO
Regulator - SONS
Implementor - SÚRAO
Safety Case
✓ safety report
✓ quality assurance programme
✓ monitoring programme
✓ emergency plan
✓ limits and conditions of operation
✓ plan of closure
✓ plan of controlled area
✓ operation reviews
SÚRAO licenses (period 5 yrs.)
✓ operation of nuclear installation
✓ operation of facility of 4th category
✓ waste management


Categories of scenarios
SÚRAO
Regulatory body requirement:
➢ Normal evolution
➢ Altered evolution
➢ Intrusion
Normal and altered evolution scenarios are submitted using robust models. Supporting special scenarios for subsystems performance are used to provide data for robust model and to validate the results.
Subsystems performance scenarios
➢ Heat flow and transport
➢ Container degradation (processes and distribution)
➢ Groundwater flow and transport
Time frames
➢ Normal evolution, altered evolution and intrusion – post closure period
➢ Maximum dose of representative person has to be demonstrated –10⁶ yrs.
➢ Emergency scenarios - operational period, mine operational safety included

Considered safety functions

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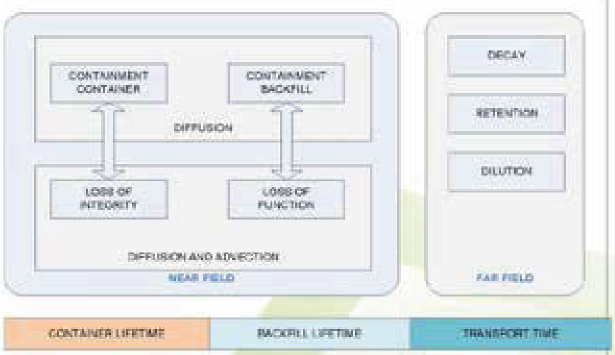
Near field
- containment and decay
- reduction of advective flow
- isolation

Far field
- retention
- dilution
- decay



Temporal sequences

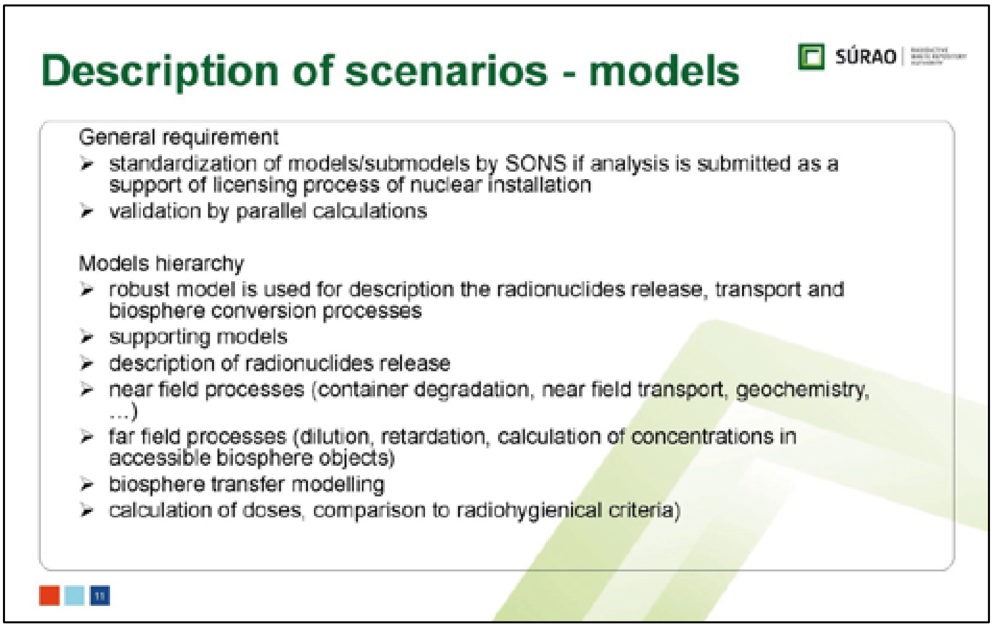
SÚRAO

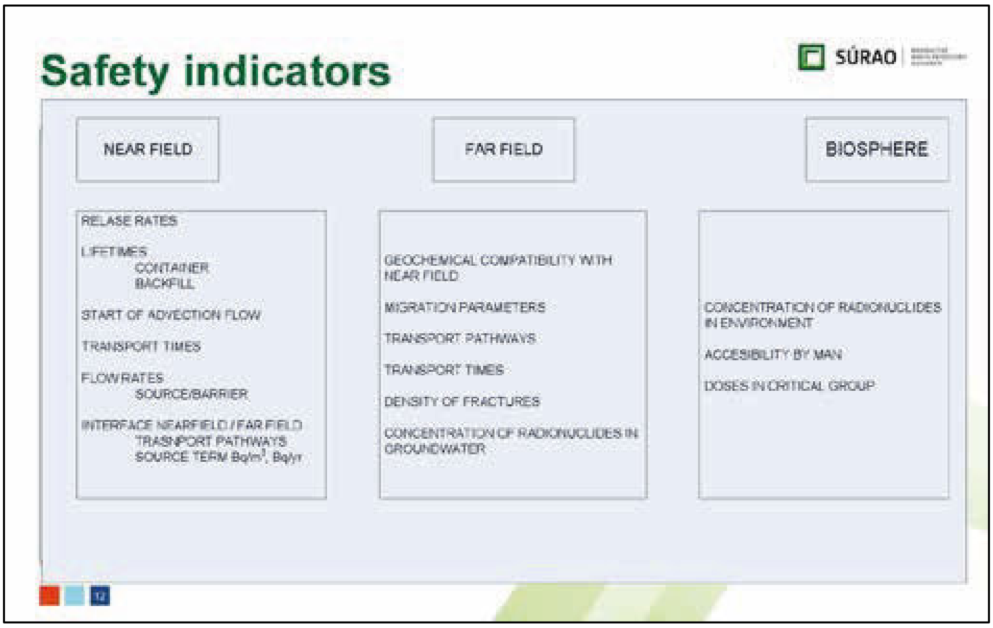
Container life time
- not considered in subsurface repositories (some tenths of yrs.)
- 10^5 yrs. for HLW and SF container

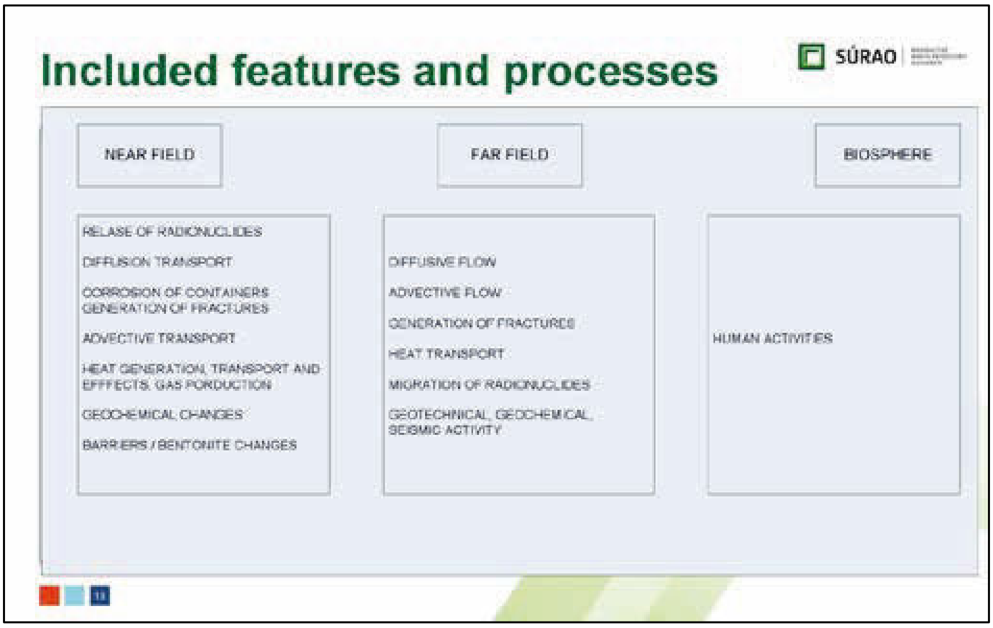
Backfill and buffer
- 3 000 – 5 000 yrs. In subsurface repositories (prevention of advective flow)
- it is to be verified for geological repository

Host rock safety function
- 10^5 – 10^6 yrs. for subsurface repository – dilution capacity 0,01 – 0,1, retention radionuclide sensitive
- not yet estimated for geological repository – four options for hydrogeology indicate time frame up to 10^6 yrs., dilution is considered to be 0,01 – 0,001 for normal evolution scenario

Biosphere
- maximum dose is to be demonstrated – 10^6 yrs. Is a sufficient period


Description of scenarios - models
SÚRAO
General requirement
➢ standardization of models/submodels by SONS if analysis is submitted as a support of licensing process of nuclear installation
➢ validation by parallel calculations
Models hierarchy
➢ robust model is used for description the radionuclides release, transport and biosphere conversion processes
➢ supporting models
➢ description of radionuclides release
➢ near field processes (container degradation, near field transport, geochemistry, …)
➢ far field processes (dilution, retardation, calculation of concentrations in accessible biosphere objects)
➢ biosphere transfer modelling
➢ calculation of doses, comparison to radiohygienical criteria)
11


Safety indicators
SÚRAO
NEAR FIELD
FAR FIELD
BIOSPHERE
RELASE RATES
LIFETIMES
CONTAINER
BACKFILL
START OF ADVECTION FLOW
TRANSPORT TIMES
FLOW RATES
SOURCE/BARRIER
INTERFACE NEARFIELD / FAR FIELD
TRASNPORT PATHWAYS
SOURCE TERM Bq/m³, Bq/yr
GEOCHEMICAL COMPATIBILITY WITH NEAR FIELD
MIGRATION PARAMETERS
TRANSPORT PATHWAYS
TRANSPORT TIMES
DENSITY OF FRACTURES
CONCENTRATION OF RADIONUCLIDES IN GROUNDWATER
CONCENTRATION OF RADIONUCLIDES IN ENVIRONMENT
ACCESIBILITY BY MAN
DOSES IN CRITICAL GROUP
12


Included features and processes
SÚRAO
NEAR FIELD
FAR FIELD
BIOSPHERE
RELASE OF RADIONUCLIDES
DIFFUSION TRANSPORT
CORROSION OF CONTAINERS GENERATION OF FRACTURES
ADVECTIVE TRANSPORT
HEAT GENERATION, TRANSPORT AND EFFFECTS, GAS PORDUCTION
GEOCHEMICAL CHANGES
BARRIERS / BENTONITE CHANGES
DIFFUSIVE FLOW
ADVECTIVE FLOW
GENERATION OF FRACTURES
HEAT TRANSPORT
MIGRATION OF RADIONUCLIDES
GEOTECHNICAL, GEOCHEMICAL, SEISMIC ACTIVITY
HUMAN ACTIVITIES
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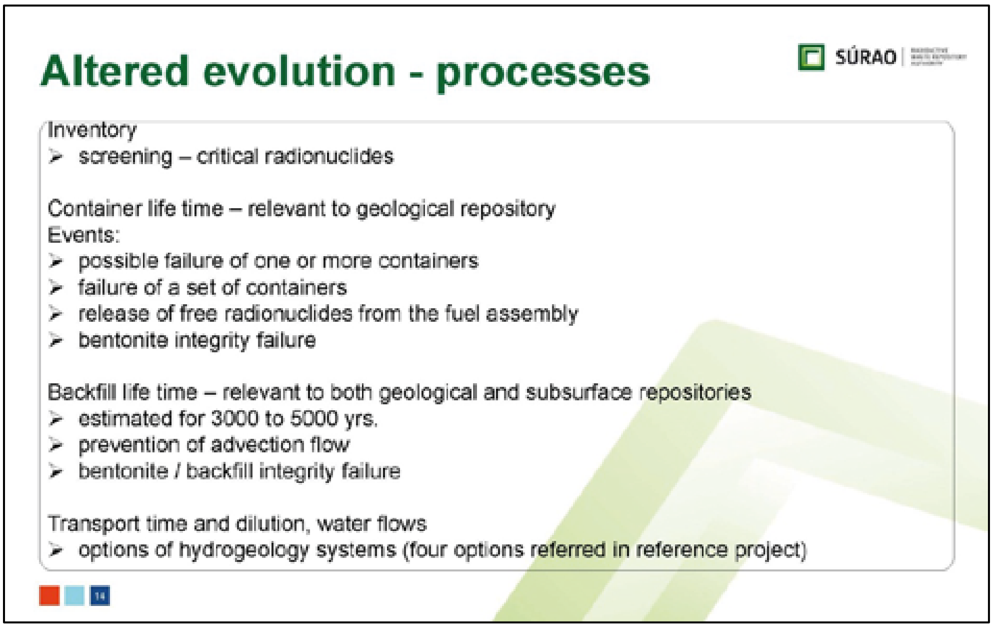
Altered evolution - processes
SÚRAO
Inventory
➢ screening – critical radionuclides
Container life time – relevant to geological repository
Events:
➢ possible failure of one or more containers
➢ failure of a set of containers
➢ release of free radionuclides from the fuel assembly
➢ bentonite integrity failure
Backfill life time – relevant to both geological and subsurface repositories
➢ estimated for 3000 to 5000 yrs.
➢ prevention of advection flow
➢ bentonite / backfill integrity failure
Transport time and dilution, water flows
➢ options of hydrogeology systems (four options referred in reference project)
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Modelling

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Standardization of models

- ✓ approval by regulatory body – checking of verification and validation processes, parallel calculations
- ✓ sensitivity analysis
- ✓ uncertainty analysis

Robust model – GoldSim (standardized tool)

- ➢ principal output: dose
- ➢ assessment of subsystems: near field, far field and biosphere

Special models to validate robust results and to support GoldSim inputs

- ➢ calculation of inventory
- ➢ near field – performance of components (saturation process, corrosion, distribution of container failures)
- ➢ heat flow and transport
- ➢ hydyrogeological flow and transport

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Sensitivity analysis

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Leading process is to assess the weight of criteria / indicators in following issues:

- ➢ safety
- ➢ project
- ➢ geological
- ➢ geotechnical
- ➢ stability of the system

Not yet included, but used in practice:

- ➢ the ratio of radionuclides with potential to instant release (equivalent to leachability in subsurface repositories)
- ➢ source term (Bq/m^3, Bq/yr.) on the interface repository – host structure
- ➢ source term dependence on near field geometry
- ➢ dilution in far field
- ➢ groundwater transport time
- ➢ concentration of radionuclides in environmental components

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Scenarios application - Bratrství

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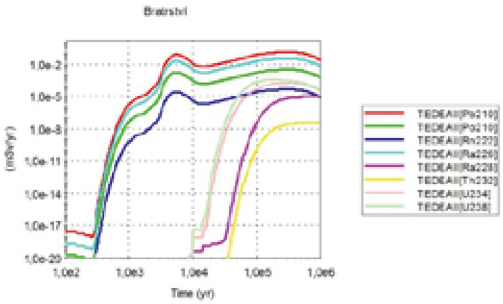

- diffusive transport till 300 yrs.
- full saturation in 300 yrs. and start of advective flow
- loss of backfill isolation function – 3000 yrs.
- ingrowth of daughter radionuclides since 10 000 yrs.
- maximum dose 500 000 yrs.

Application

- optimization of spending repository volume
- plan of closure

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Scenarios application - Richard

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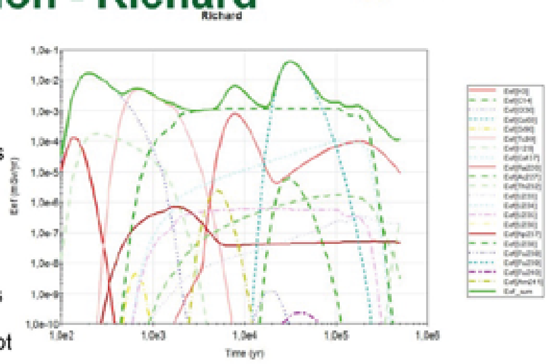

- ✓ co-disposal with natural radionuclides
- ✓ considered co-disposal with waste from decommissioning
- ✓ reconstruction of repository – preparation of new volumes
- ✓ geometrical changes in near field – better described: real geometry leads to lower doses
- ✓ processes listed in previous case - not substantial
- ✓ presence of movable radionuclides is still decisive
- ✓ maximum dose is related to a special radionuclide within the followed period

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Scenarios application – geological repository

Actually used as a support of geological repository siting process

- siting criteria / indicators have been formally developed
- till now, the support of safety assessment not applied – site specific data are missing
- categories: safety, project, geological, geotechnical, stability of the system

Goals for near future:

- actualization of the reference project for potential sites – normal evolution and alternative scenarios
- formulation of long term safety related scenarios
- quantification of criteria, where possible, esp. regarding host structure and stability of components
- application of criteria in siting process
- Inventory related research and calculation, esp. Releasable fraction
- description, limitation, and specification of near field geometry
- choice of two candidate sites in 2025

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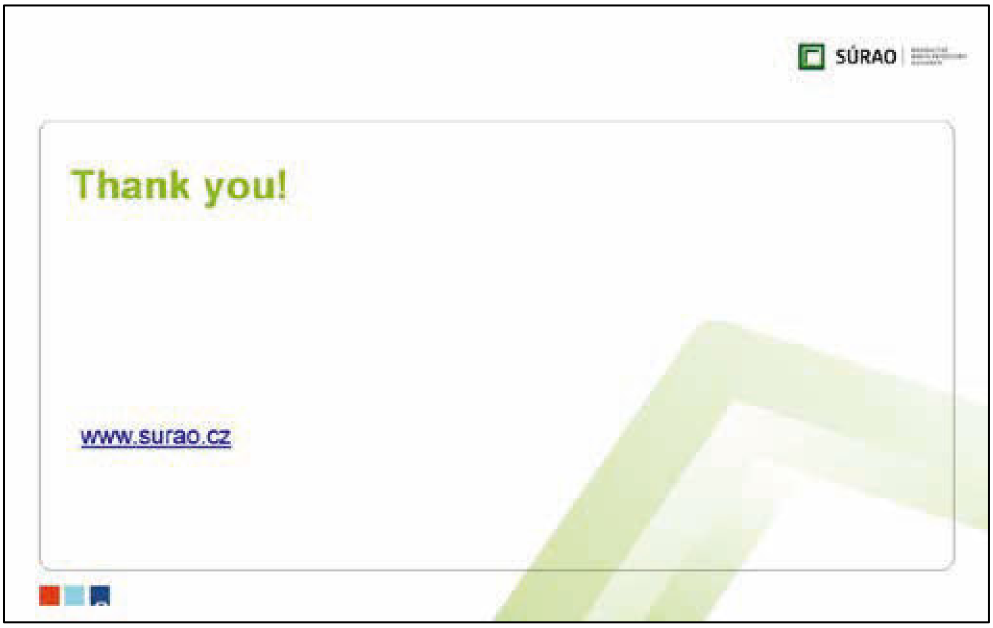
Support of R&D

Assured usually by subcontractors

- MESA
- RED-IMPACT
- EBS
- DOPAS
- PAMINA
- SPIN
- BIOCLIM

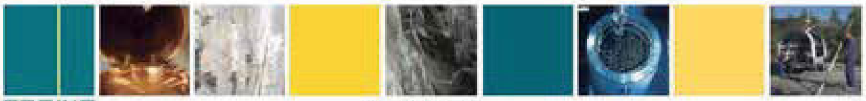
Providing background, not yet applicable for geological repository.

20


SÚRAO
Thank you!
www.surao.cz

Posiva's scenario development methodology (with an example)

Nuria Marcos
nuria.marcos@sroy.fi



POSIVA NEA 02.06.2015 1

Scenarios – Disposal system (1)

- The climatic evolution gives the key boundary conditions for the disposal system evolution along with the initial state of the disposal system components.
- The disposal system evolution comprises both the evolution of the repository system and the surface system.
- Even if the definition of base, variants and disturbance scenarios applies to the total disposal system, the detailed description of the evolution of the repository system and the surface system can be decoupled because:
  - only a few FEPs act in both the repository system and the surface environment (e.g. crustal uplift affects surface hydrology and groundwater evolution), and
  - the detailed evolution of the surface system is constrained, according to STUK's YVL guide D.5 paragraph 306 to the "*assessment period, during which the radiation exposure of humans can be assessed with sufficient reliability, and which shall extend at a minimum over several millennia (GD 736/2008)*", whereas
  - the nuclide specific constrains for the radioactive releases to the environment (STUK's YVL guide D.5 paragraph 312) apply for limiting the radiation exposures arising beyond the assessment period mentioned above (YVL guide D.5, paragraph 311).

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Scenarios – Disposal system (2)

- Moreover, exactly the same methodology cannot be applied for the repository and surface environment since **safety functions** can be assigned to the repository system components, but not to the surface environment.

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Scenarios - Repository system (1)

- Posiva's methodology for the scenario formulation concerning the repository system follows a top-down approach in first identifying the safety functions, complementing it with the use of single FEPs or combination of FEPs to check that the scenarios are comprehensive. It is also based on the regulatory framework and can be summarised as follows:

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Scenarios – Repository system (2)

1. The regulatory framework; it is prescriptive in terminology and definitions.
2. The safety functions for each of the repository system components are defined (***Design Basis*** report).
3. FEPs that could adversely affect one or more safety functions at a given time, position/s, condition/s are identified and taken into account (i.e. <u>FEPs are linked to the evolution of the system in time and space</u>).

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Scenarios – Repository system (3)

- Lines of evolution are defined that describe in a timeline the coupled evolution of the repository system components ultimately leading to radionuclide releases.
- Each line of evolution is then classified under the corresponding scenario types using STUK's scenario terminology (base, variant, disturbance) taking into account the relevance (and/or likelihood) of the FEPs implied in each of the lines (i.e. how the FEPs may affect the safety functions)

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Scenarios – Repository system (4)

- From each scenario a set of calculation cases is defined to assess the potential radiological impact. The calculation cases take into account variations in the models and parameter values that account for uncertainties in the assumptions, and data used.
- If sufficient data are available, the deterministic cases are complemented by probabilistic sensitivity analyses.
- As stated previously the FEPs that may affect the safety functions of the repository system components are taken into account in formulating the lines of evolution for each scenario. Climate evolution is the overarching FEPs affecting the evolution of the entire disposal system.

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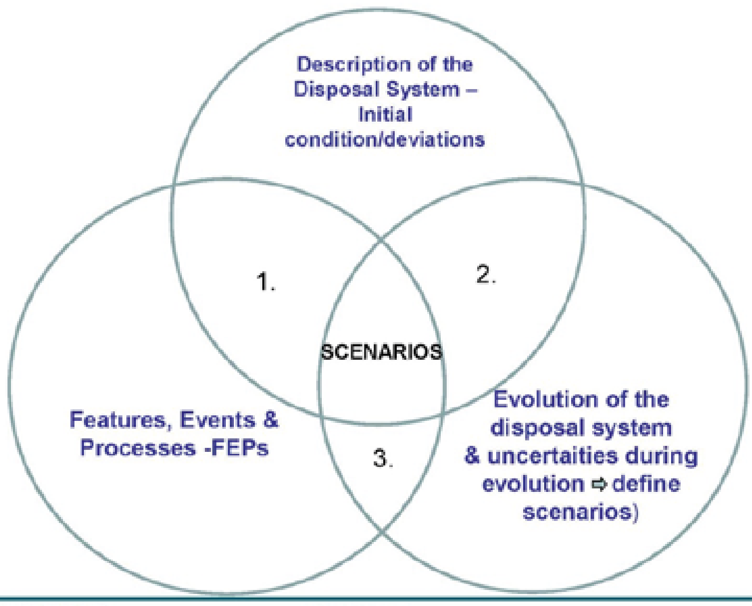

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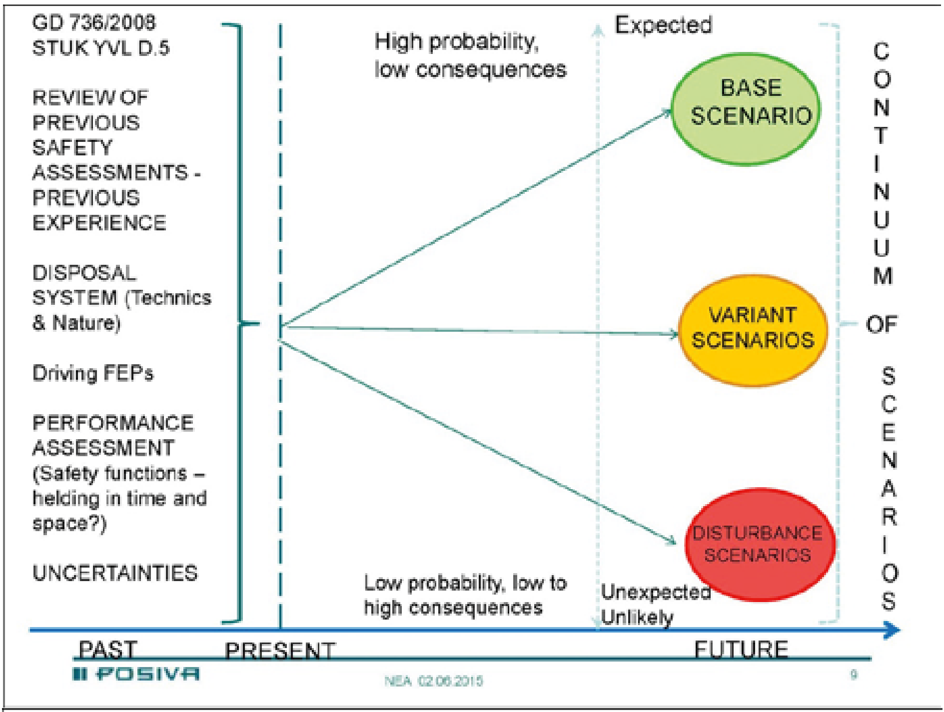

- An example (1)

1. Taking into account the regulatory framework:
   - Variant scenarios: "*The influence of declined performance of a single safety function or, in case of coupling between safety functions, the combined effects of declined performance of more than one safety functions shall be analysed by means of variant scenarios*".
2. Safety functions
   - Canister – containment
   - Buffer – retardation
3. FEPs adversely affecting the safety functions of canister and buffer
   - Canister – the feature of having an initial penetrating defect, any type of corrosion leading to failure
   - Buffer – deviations in manufacturing and emplacement piping/erosion, montmorillonite transformation, alteration of accessory minerals

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- An example (2)

- Line(s) of evolution leading to radionuclide releases
  - The canister has lost its safety function of containment due to 1) an initial penetrating defect, 2) corrosion enlarging the defect within a certain time span
  - Adverse groundwater composition(s) affects the safety funtion of the buffer by changing its properties – thickness of the buffer changes
- A variant scenario is defined and calculation cases defined to account for uncertainties in groundwater composition that, at any time, may give rise to uncertainties in porewater composition, sorption, diffusion and solubility values.

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CLIMATE EVOLUTION

GROUNDWATER FLOW AND COMPOSITION

An example - VARIANT SCENARIO 1

Component Safety function	Canister	Buffer	Backfill	Closure	Geospher e
Containtment	**Lost** – initial penetrating defect – enlarging in time	-	-	-	-
Retention	"small hole"	Sorption Diffusion Aquecus solubility and speciation Montmorillonite transformation "Piping & erosion"	Sorption Diffusion Aqueous solubility and speciation	-	Sorption Diffusion and Matrix Diffusion Aqueous solubility and speciation

Uncertainties: porewater composition; buffer thickness; flow and flow paths; groundwater composition, rate and extent of defect enlargement

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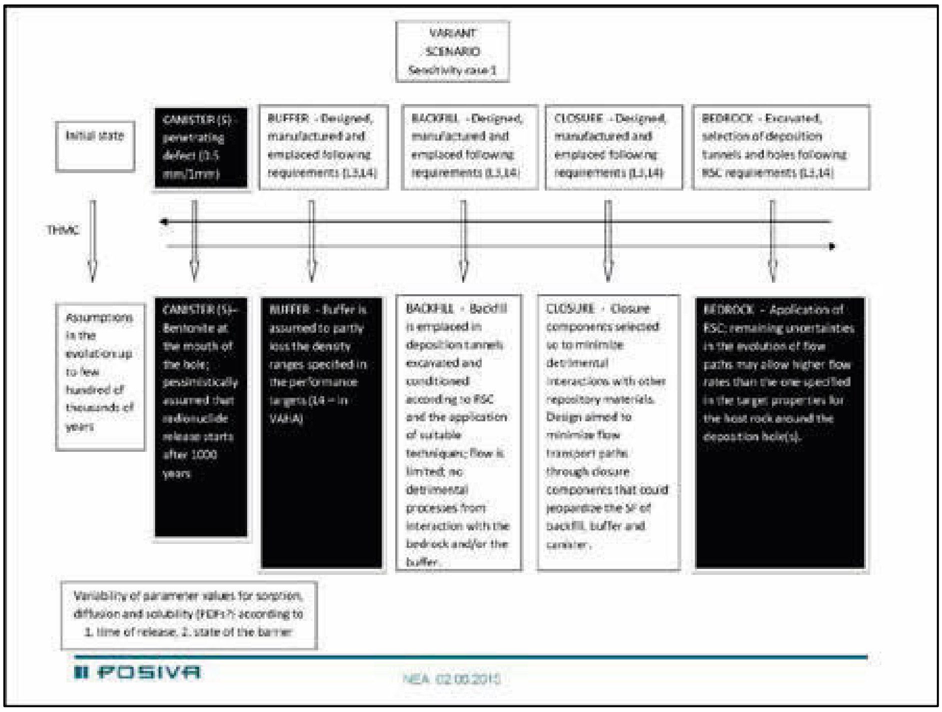

The way forward

- As required in the regulator's (STUK) feedback to the safety case for the construction licence application (CLA) a completely systematic methodology for the formulation of scenarios, including those that lead to radionuclide release as well as those that do not, will be developed, applied and documented in support of the operational licence application.
- The essential elements of the methodology will be the same as for the CLA, but transparency and traceability in its application will be enhanced.

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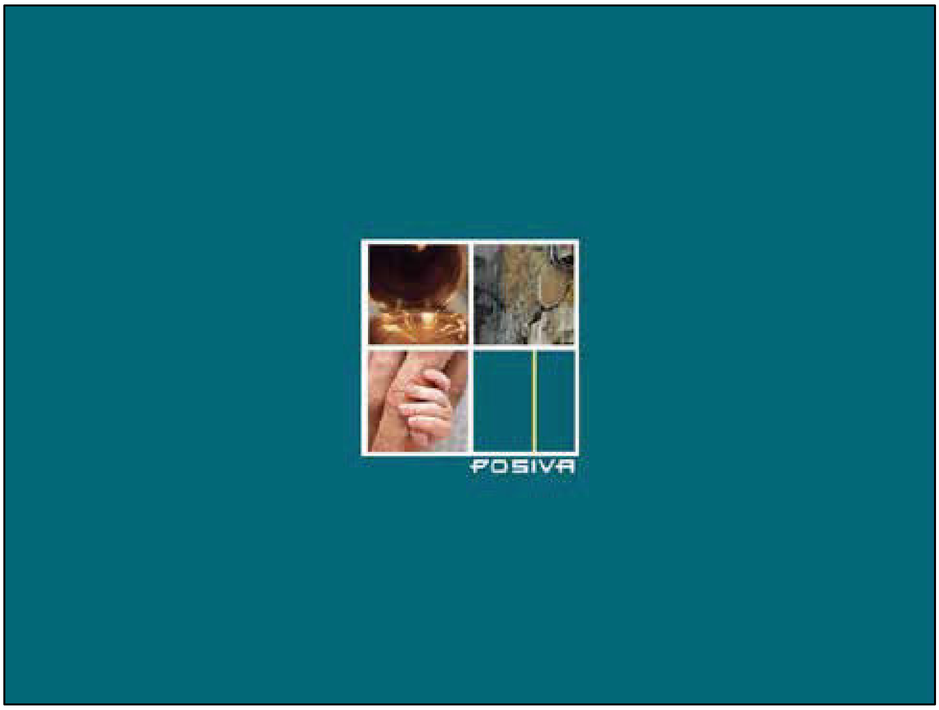

POSIVA

ANDRA
French national radioactive waste management agency

Andra's Scenarios Development Methodology and Application for Cigeo Post-Closure Safety

L. GRIFFAULT, S. VOINIS, M. BURGIO, D. COELHO,
J.de MEREDIEU, and S.SY

AEN/OECD Scenario Workshop, June 1-3, 2015, Paris, France

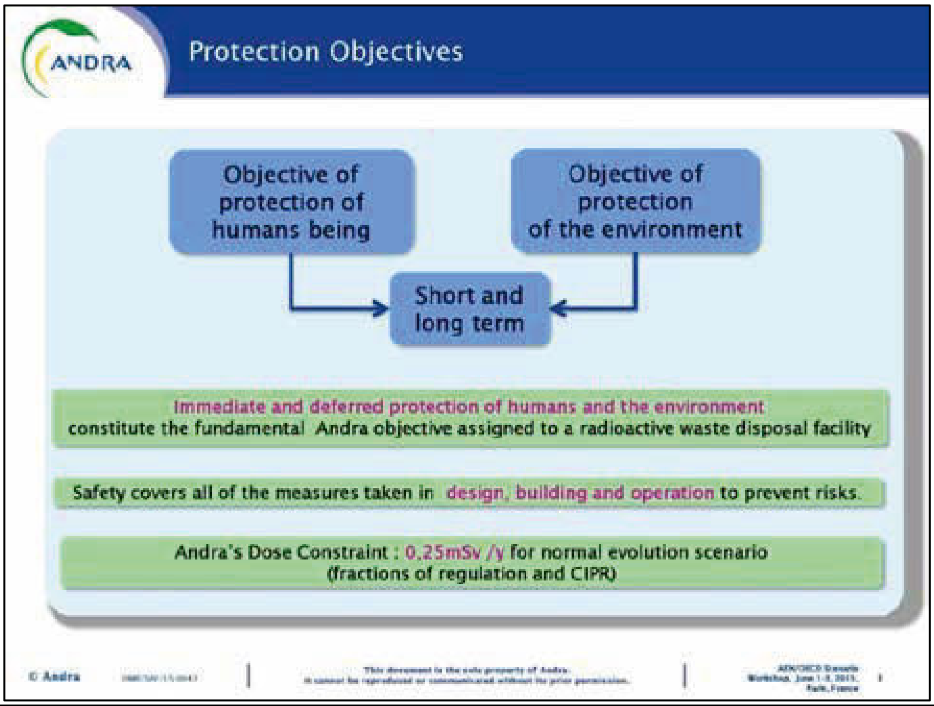
Cigéo and the National Context

Cigéo

- Since 2011 the project entered an industrial design development and has become the Industrial Center for Geological Disposal

National Context

- A Dossier studying concept designs has been transmitted to the Nuclear Safety Authority in 2012
- A Dossier of Safety Options will be submitted in 2015
- Application for the authorization of the repository due in 2017


ANDRA
Protection Objectives
Objective of protection of humans being
Objective of protection of the environment
Short and long term
Immediate and deferred protection of humans and the environment
constitute the fundamental Andra objective assigned to a radioactive waste disposal facility
Safety covers all of the measures taken in design, building and operation to prevent risks.
Andra's Dose Constraint : 0.25mSv /y for normal evolution scenario
(fractions of regulation and CIPR)
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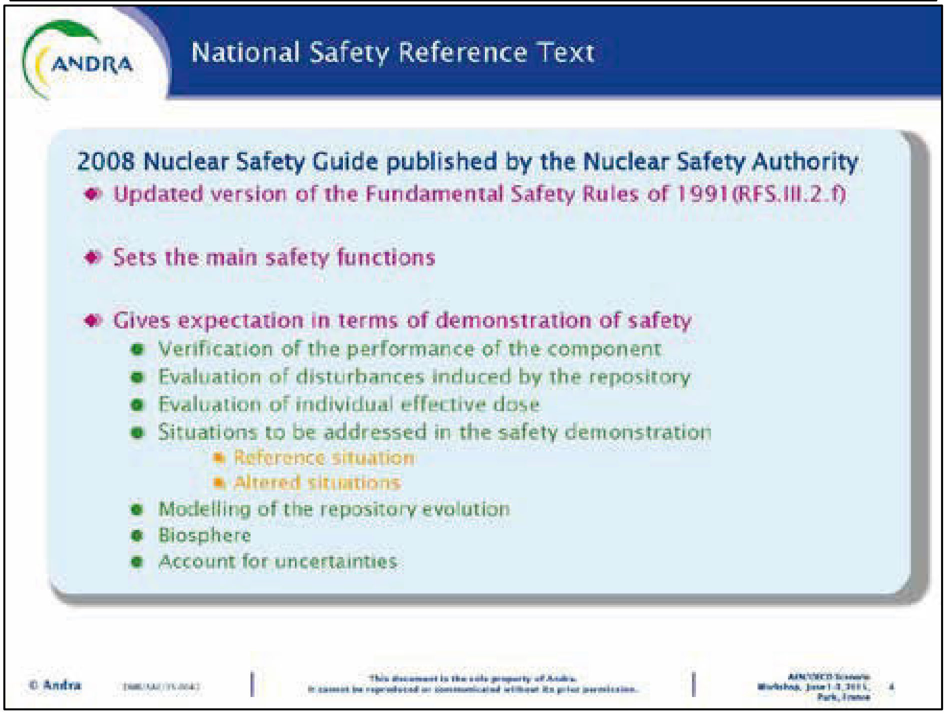
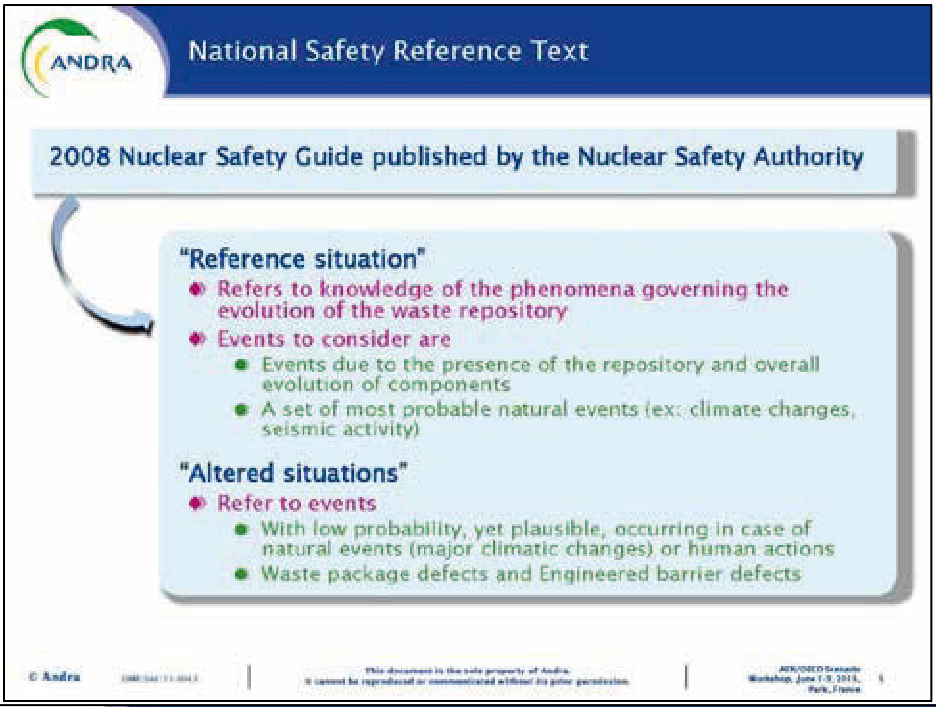

ANDRA
National Safety Reference Text
2008 Nuclear Safety Guide published by the Nuclear Safety Authority
Updated version of the Fundamental Safety Rules of 1991(RFS.III.2.f)
Sets the main safety functions
Gives expectation in terms of demonstration of safety
Verification of the performance of the component
Evaluation of disturbances induced by the repository
Evaluation of individual effective dose
Situations to be addressed in the safety demonstration
Reference situation
Altered situations
Modelling of the repository evolution
Biosphere
Account for uncertainties
© Andra


ANDRA
National Safety Reference Text
2008 Nuclear Safety Guide published by the Nuclear Safety Authority
"Reference situation"
Refers to knowledge of the phenomena governing the evolution of the waste repository
Events to consider are
Events due to the presence of the repository and overall evolution of components
A set of most probable natural events (ex: climate changes, seismic activity)
"Altered situations"
Refer to events
With low probability, yet plausible, occurring in case of natural events (major climatic changes) or human actions
Waste package defects and Engineered barrier defects
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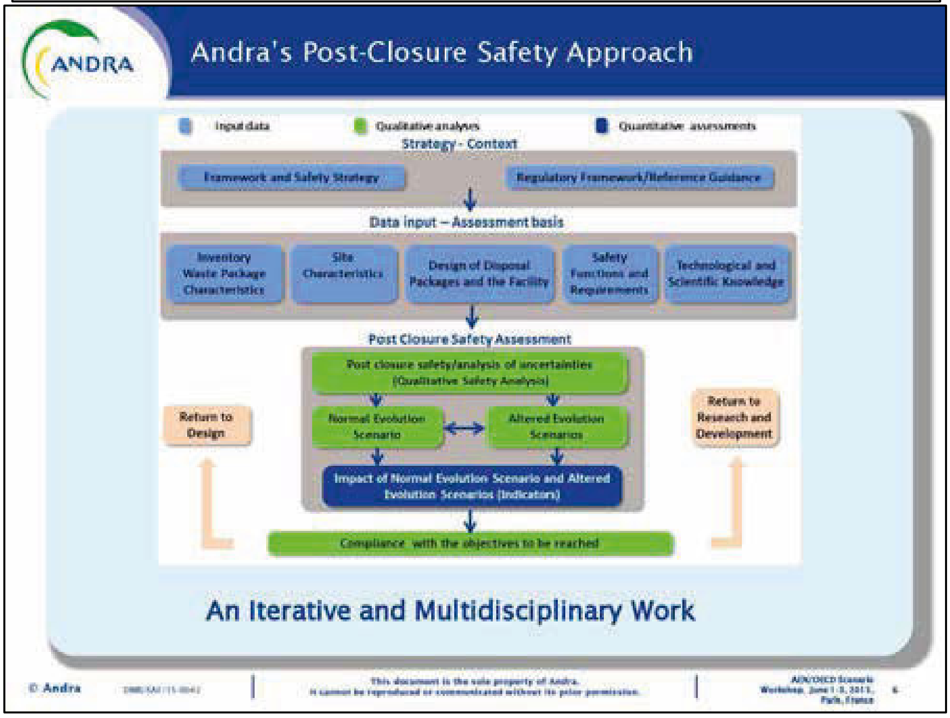
ANDRA
Andra's Post-Closure Safety Approach
Input data
Qualitative analyses
Quantitative assessments
Strategy - Context
Framework and Safety Strategy
Regulatory Framework/Reference Guidance
Data input – Assessment basis
Inventory Waste Package Characteristics
Site Characteristics
Design of Disposal Packages and the Facility
Safety Functions and Requirements
Technological and Scientific Knowledge
Post Closure Safety Assessment
Post closure safety/analysis of uncertainties (Qualitative Safety Analysis)
Normal Evolution Scenario
Altered Evolution Scenarios
Impact of Normal Evolution Scenario and Altered Evolution Scenarios (Indicators)
Return to Design
Return to Research and Development
Compliance with the objectives to be reached
An Iterative and Multidisciplinary Work
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Andra's Post-Closure Safety Approach

Post-closure Safety Approach Includes both

- A Qualitative Approach for Systematic Analysis of the Associated Uncertainties
- A Quantitative Approach for Evaluation of the overall Level of Safety and Performance of the Disposal System

Development of scenarios constitutes the fundamental basis for the quantitative assessment as well as the choice of data and models to assess the scenarios

Three Types of Scenarios

- Normal Evolution Scenario
- Altered Evolution Scenario
- What-if scenarios

7

General Objectives of Scenarios

Normal Evolution Scenario

- To confirm the performance achieved
- Compliance with safety objectives to be reached, protection objectives defined by the Nuclear Safety Authority
- That the disposal safety functions (as wanted by the designer) are verified/realized using appropriate indicators
  - Overall activity leaving component (waste packages, the underground structures and the host rock)
  - Concentration distributions of dissolved materials
- Refer to (NSA 2008)
  - Events due to the presence of the repository and overall evolution of components
  - A set of most probable natural events (ex: climate changes, seismic activity)

8

ANDRA

General Objectives of Scenarios

Altered Evolution Scenarios

- To evaluate the Repository Robustness in case of malfunction or failure of one component
- Refer to (NSA)
  - Natural Events with low probability, yet plausible
  - Human actions
  - Malfunctioning/Failure of Engineered components
    - Waste Package
    - Seals
    - ....

What-if scenarios

- To further evaluate the overall Repository Robustness
  - May be used to explore the repository behavior assuming the degradation of several safety functions
- Refer to
  - One or cumulated independent events with very low probability that severely impair several functions

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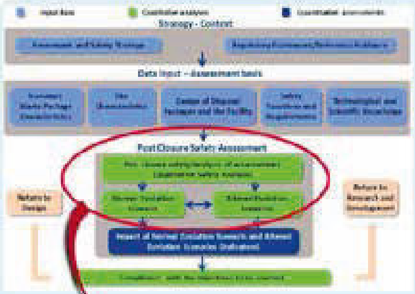
Post-Closure Safety : some Key Elements



Post-Closure Safety analysis relies upon a series of key elements

- The Post-Closure Safety Functions and Requirements
- The Architecture Design and Technical Solutions
- The Scientific Understanding of the Repository System and its Evolution (including Potential Internal Interactions)
- The Handling of Uncertainties and the Development of Scenarios
- Simulation and Quantitative Assessments

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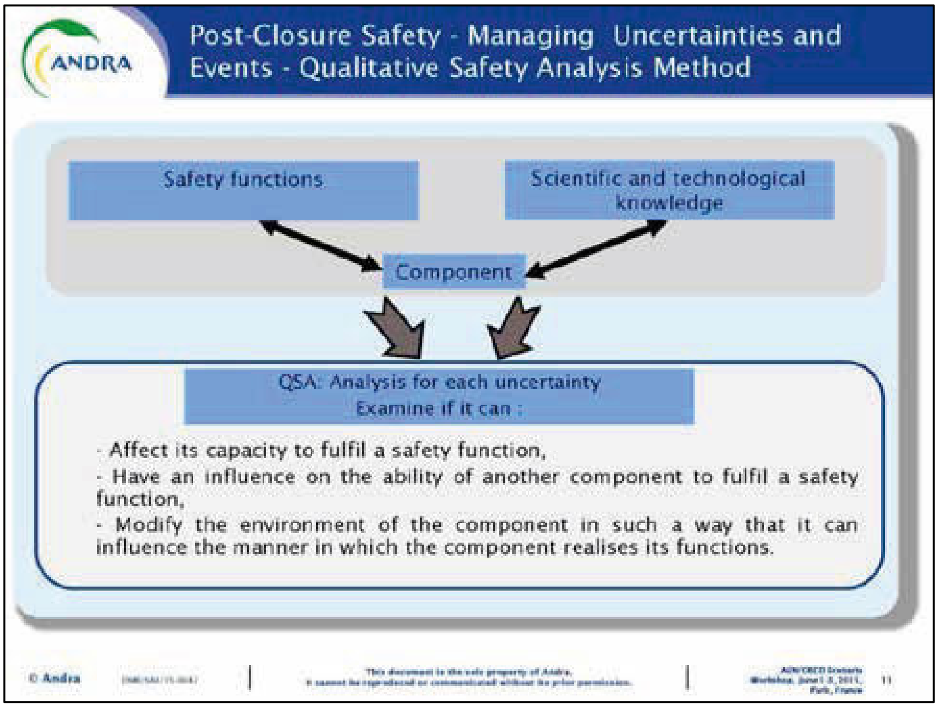
ANDRA
Post-Closure Safety - Managing Uncertainties and Events - Qualitative Safety Analysis Method
Safety functions
Scientific and technological knowledge
Component
QSA: Analysis for each uncertainty
Examine if it can :
- Affect its capacity to fulfil a safety function,
- Have an influence on the ability of another component to fulfil a safety function,
- Modify the environment of the component in such a way that it can influence the manner in which the component realises its functions.
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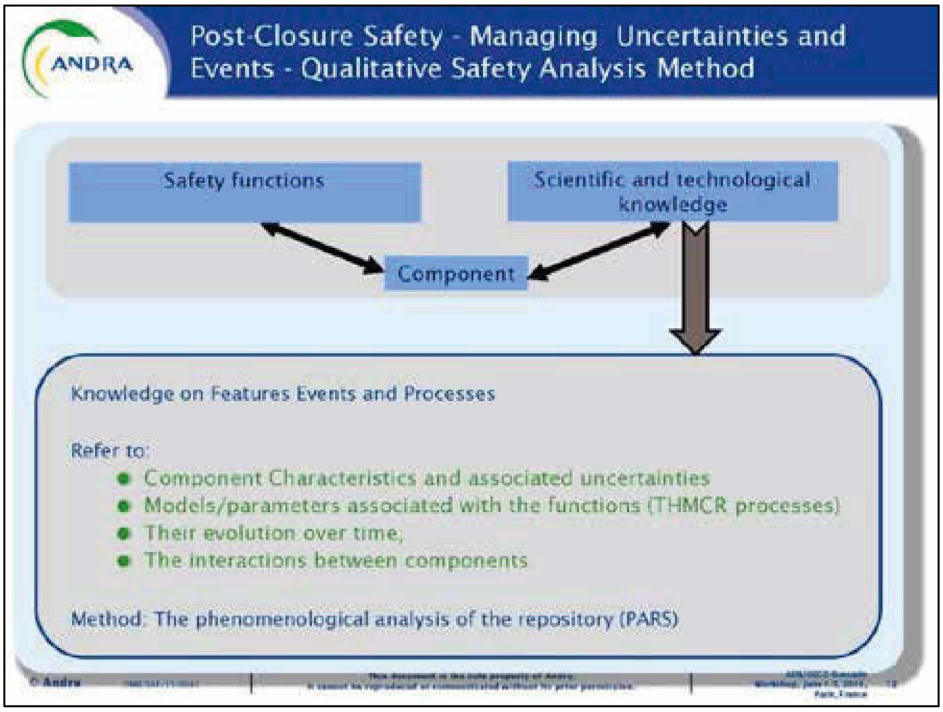
ANDRA
Post-Closure Safety - Managing Uncertainties and Events - Qualitative Safety Analysis Method
Safety functions
Scientific and technological knowledge
Component
Knowledge on Features Events and Processes
Refer to:
Component Characteristics and associated uncertainties
Models/parameters associated with the functions (THMCR processes)
Their evolution over time,
The interactions between components
Method: The phenomenological analysis of the repository (PARS)
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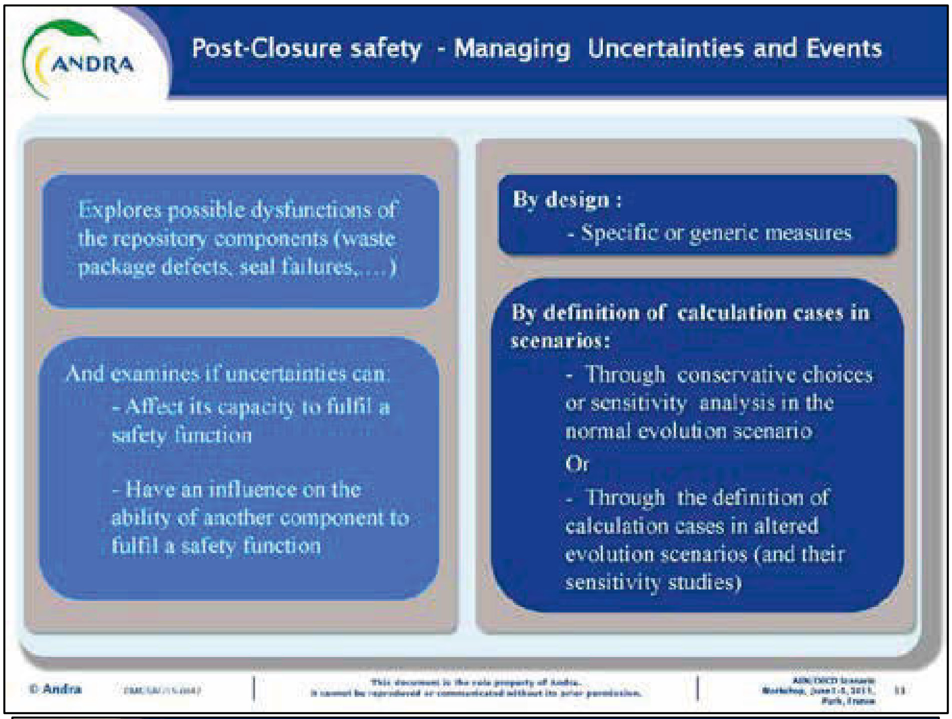
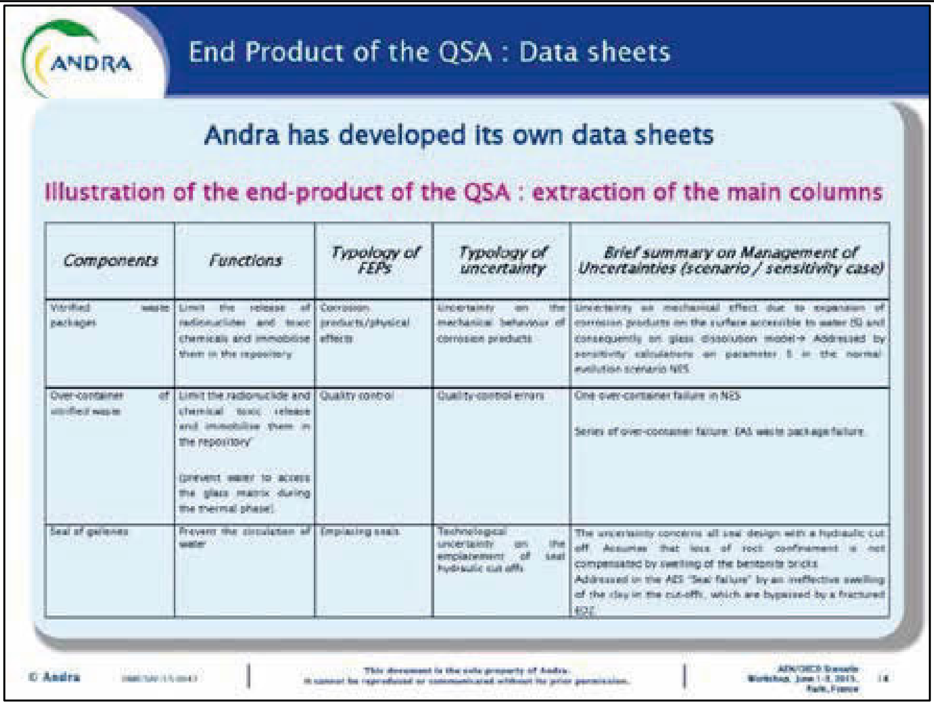
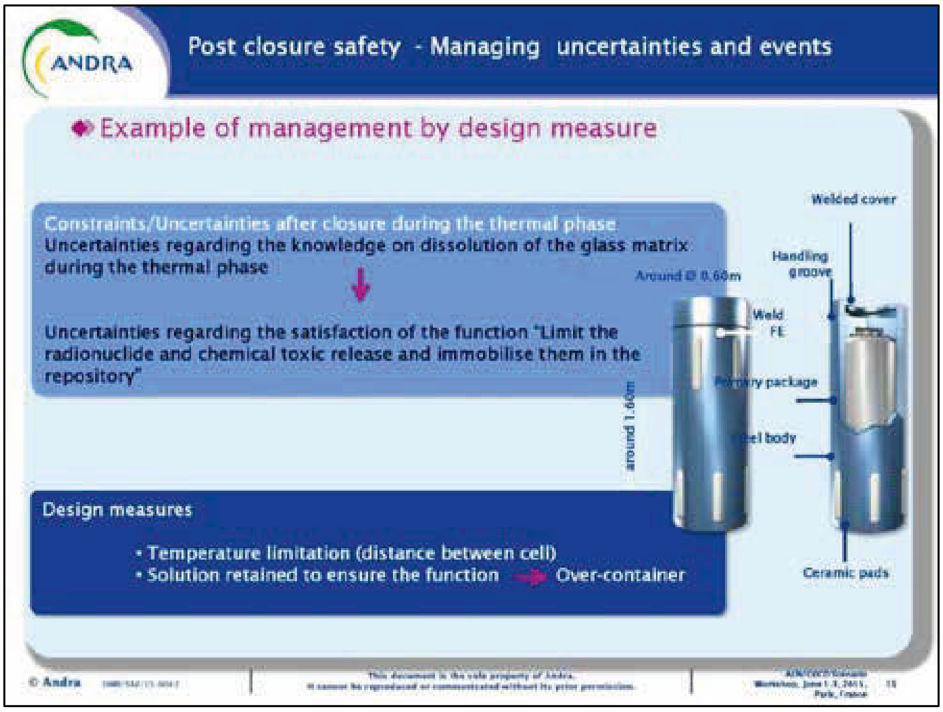




Components	Functions	Typology of FEPs	Typology of uncertainty	Brief summary on Management of Uncertainties (scenario / sensitivity case)
Vitrified waste packages	Limit the release of radionuclides and toxic chemicals and immobilise them in the repository	Corrosion products/physical effects	Uncertainty on the mechanical behaviour of corrosion products	Uncertainty on mechanical effect due to expansion of corrosion products on the surface accessible to water (S) and consequently on glass dissolution model→ Addressed by sensitivity calculations on parameter S in the normal evolution scenario NES
Over-container of vitrified waste	Limit the radionuclide and chemical toxic release and immobilise them in the repository' (prevent water to access the glass matrix during the thermal phase)	Quality control	Quality-control errors	One over-container failure in NES Series of over-container failure: EAS waste package failure
Seal of galleries	Prevent the circulation of water	Emplacing seals	Technological uncertainty on the emplacement of seal hydraulic cut offs	The uncertainty concerns all seal design with a hydraulic cut off. Assumes that loss of rock confinement is not compensated by swelling of the bentonite bricks Addressed in the AES "Seal failure" by an ineffective swelling of the clay in the cut-offs, which are bypassed by a fractured EDZ



ANDRA
Post closure safety - Managing uncertainties and events
Example of management by design measure
Constraints/Uncertainties after closure during the thermal phase
Uncertainties regarding the knowledge on dissolution of the glass matrix during the thermal phase
Uncertainties regarding the satisfaction of the function "Limit the radionuclide and chemical toxic release and immobilise them in the repository"
Design measures
• Temperature limitation (distance between cell)
• Solution retained to ensure the function Over-container
Around Ø 0.60m
around 1.60m
Welded cover
Handling groove
Weld FE
Primary package
Steel body
Ceramic pads
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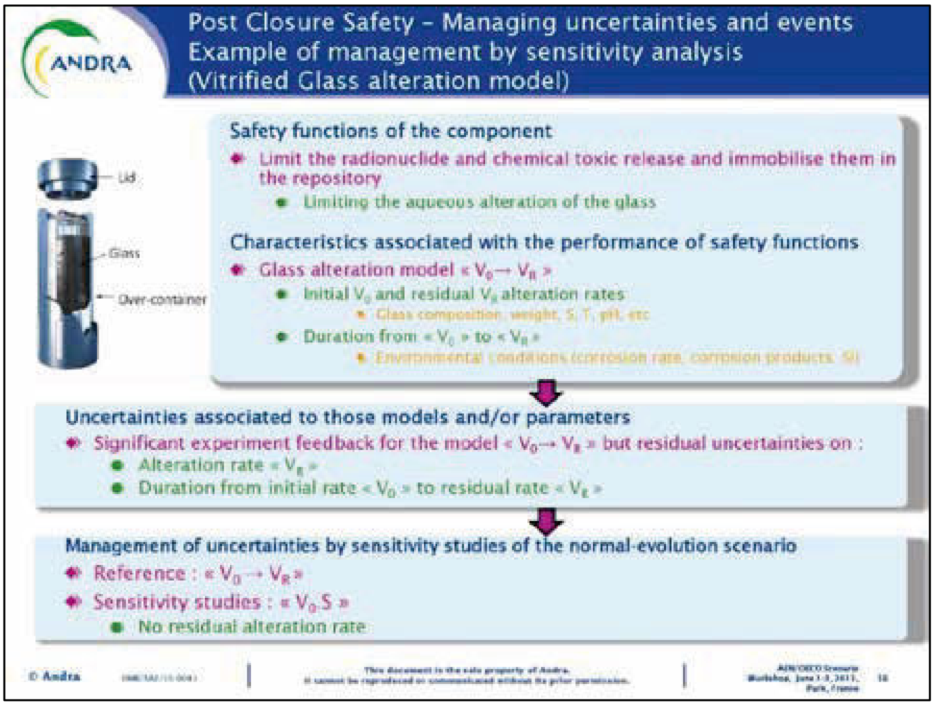

ANDRA
Post Closure Safety – Managing uncertainties and events
Example of management by sensitivity analysis
(Vitrified Glass alteration model)
Lid
Glass
Over-container
Safety functions of the component
Limit the radionuclide and chemical toxic release and immobilise them in the repository
Limiting the aqueous alteration of the glass
Characteristics associated with the performance of safety functions
Glass alteration model « $V_0 \rightarrow V_R$ »
Initial V_0 and residual V_R alteration rates
Glass composition, weight, S, T, pH, etc
Duration from « V_0 » to « V_R »
Environmental conditions (corrosion rate, corrosion products, Si)
Uncertainties associated to those models and/or parameters
Significant experiment feedback for the model « $V_0 \rightarrow V_R$ » but residual uncertainties on :
Alteration rate « V_R »
Duration from initial rate « V_0 » to residual rate « V_R »
Management of uncertainties by sensitivity studies of the normal-evolution scenario
Reference : « $V_0 \rightarrow V_R$ »
Sensitivity studies : « V_0.S »
No residual alteration rate
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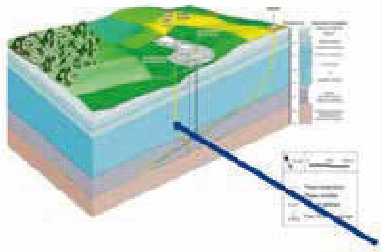
Post Closure Safety – Managing uncertainties and events



- Safety functions of the component
  - Delaying and attenuating the migration of radionuclides
- Characteristics associated with the performance of safety functions
  - Favourable characteristics of the Callovo-Oxfordian (permeability, diffusion, retention properties, solubility)
- External events
  - *Inadvertent human Intrusion due to a loss of the memory of the repository*

Management of uncertainties inadvertent human intrusion:

+ *Influence of the uncertainty on duration of the memory*

On the long term → Addressed by AES Borehole at a reasonable date (after 500years as required by NSA)

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In 2005: Three Scenarios Affecting the Safety Functions

- "Seal-failure" scenario
  - Failure of shaft or galleries seals, or of all seals.
  - Sensitivity studies at the containment parameters of the EDZ, seals, etc.

- "Package-failure" scenario
  - Failure of all or part of over-containers for vitrified waste.
  - Sensitivity study to test the influence of the hydraulic transient.

- "Borehole" scenario
  - Different locations, one or two boreholes.
  - Sensitivity studies to the characteristics of the EDZ (K), of packages, etc.

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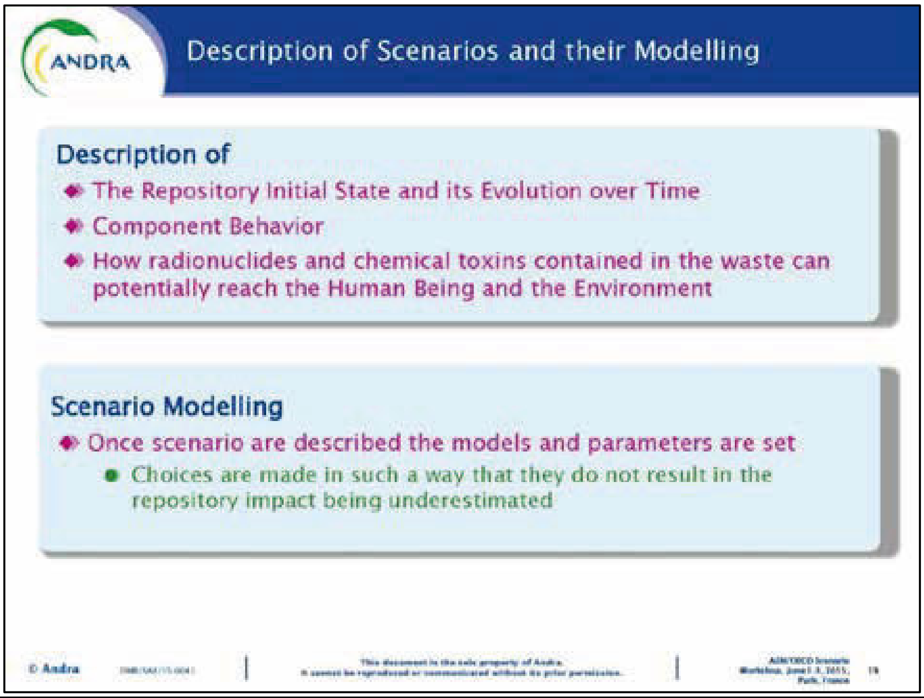
ANDRA
Description of Scenarios and their Modelling
Description of
The Repository Initial State and its Evolution over Time
Component Behavior
How radionuclides and chemical toxins contained in the waste can potentially reach the Human Being and the Environment
Scenario Modelling
Once scenario are described the models and parameters are set
Choices are made in such a way that they do not result in the repository impact being underestimated
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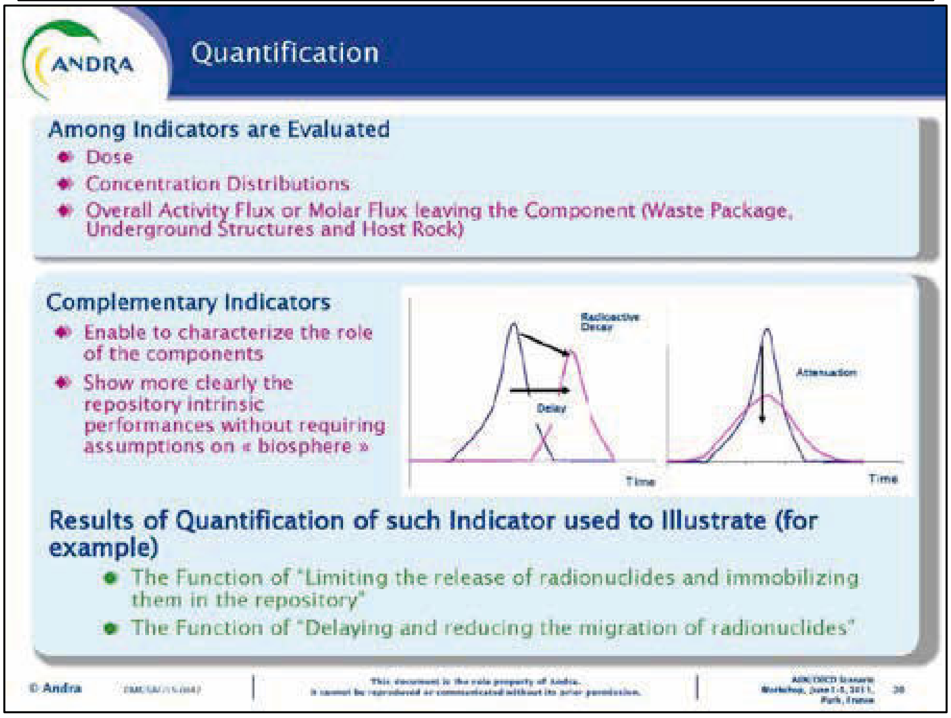
ANDRA
Quantification
Among Indicators are Evaluated
Dose
Concentration Distributions
Overall Activity Flux or Molar Flux leaving the Component (Waste Package, Underground Structures and Host Rock)
Complementary Indicators
Enable to characterize the role of the components
Show more clearly the repository intrinsic performances without requiring assumptions on « biosphere »
Radioactive Decay
Delay
Time
Attenuation
Time
Results of Quantification of such Indicator used to Illustrate (for example)
The Function of "Limiting the release of radionuclides and immobilizing them in the repository"
The Function of "Delaying and reducing the migration of radionuclides"
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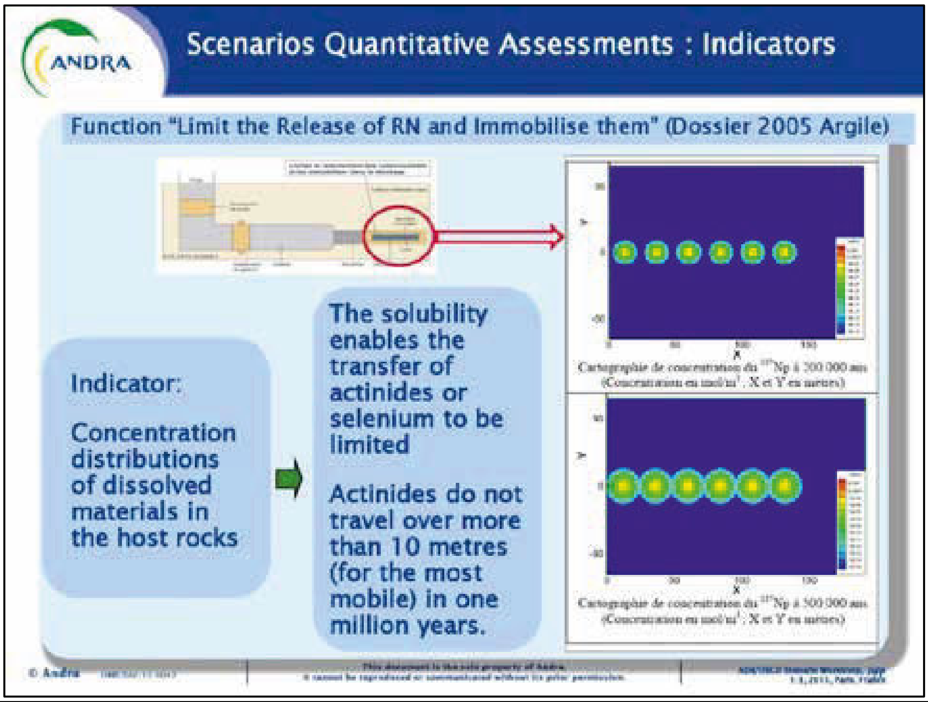
ANDRA
Scenarios Quantitative Assessments : Indicators
Function "Limit the Release of RN and Immobilise them" (Dossier 2005 Argile)
Indicator:
Concentration distributions of dissolved materials in the host rocks
The solubility enables the transfer of actinides or selenium to be limited
Actinides do not travel over more than 10 metres (for the most mobile) in one million years.
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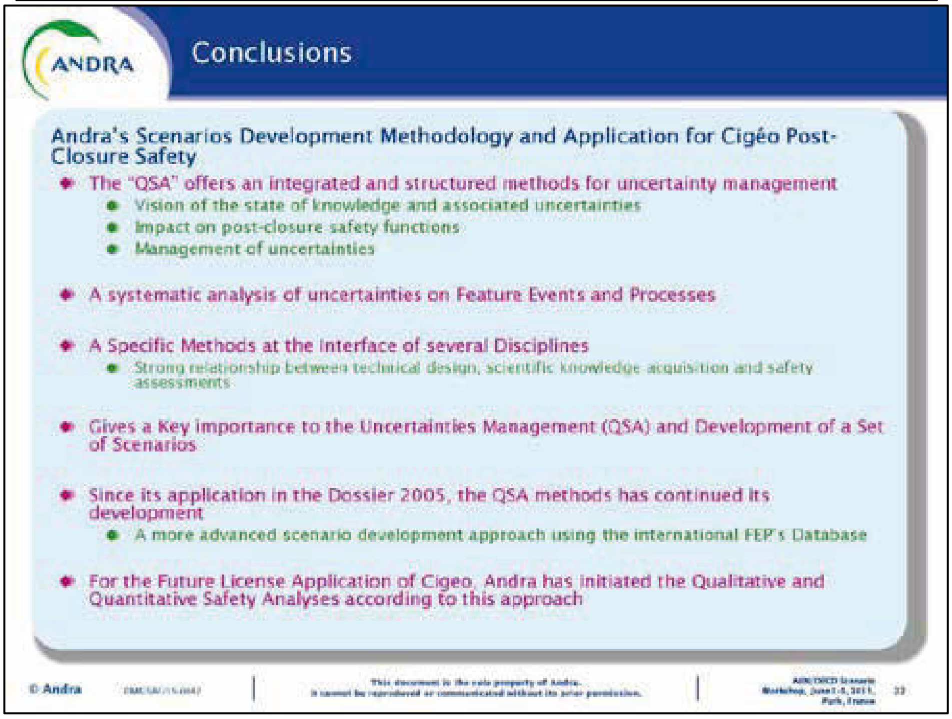
ANDRA
Conclusions
Andra's Scenarios Development Methodology and Application for Cigéo Post-Closure Safety
The "QSA" offers an integrated and structured methods for uncertainty management
Vision of the state of knowledge and associated uncertainties
Impact on post-closure safety functions
Management of uncertainties
A systematic analysis of uncertainties on Feature Events and Processes
A Specific Methods at the Interface of several Disciplines
Strong relationship between technical design, scientific knowledge acquisition and safety assessments
Gives a Key importance to the Uncertainties Management (QSA) and Development of a Set of Scenarios
Since its application in the Dossier 2005, the QSA methods has continued its development
A more advanced scenario development approach using the international FEP's Database
For the Future License Application of Cigeo, Andra has initiated the Qualitative and Quantitative Safety Analyses according to this approach
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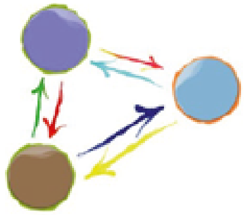
GRS

Scenario Development: The German Strategy



Arbeitskreis „Szenarienentwicklung"
(Working Group Scenario Development)

NEA IGSC Scenario Development Workshop, 1-3 June 2015, Paris | Scenario Development: Germany

GRS

German Working Group Scenario Development

- Current cast of the Working Group:
  - DBE Technology GmbH
  - Federal Institute for Geosciences and Natural Resources (BGR)
  - Federal Office for Radiation Protection (BfS)
  - Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB)
  - Gesellschaft für Anlagen- und Reaktorsicherheit gGmbH (GRS)
  - Institute for Nuclear Waste Disposal (INE)
  - Landesamt für Bergbau, Energie und Geologie (LBEG)
  - Technical University Clausthal (TUC)
- Visit: http://www.grs.de/en/content/working-group-scenario-development

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GRS

History of Development and Application

- Approach developed in R&D projects for HLW
  - Salt (ISIBEL, 2006 - 2010)
  - Clay (AnSichT, since 2012)
- First full application for the preliminary Safety Analysis for the salt dome Gorleben (2010 -2013) → appropriate approach
- Application for the Morsleben repository for LLW/ILW (since 2013)
- NEA FEP catalogue / database

Supported by:

Federal Ministry of Economics and Energy

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

Bundesamt für Strahlenschutz (Federal Ministry for Radiation Protection)

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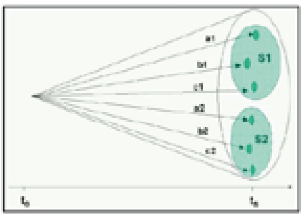
GRS

Objectives of Scenario Development in PA/SA

- Primary objective for Safety Assessment / Safety Case:

Handling of scenario uncertainties
  - comprehensiveness
  - consistency
  - reproducibility, traceability
  - transparency



  - probability (regulatory requirement)
- Secondary objectives (requirements)
  - Site selection process: Host rock independent methodology?
  - Performance Assessment: Transfer scenarios to „safety models" (framework for numerical models for safety demonstration)

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Regulatory Requirements (BMU 2010)

- The comprehensive identification and analysis of safety-relevant scenarios and their allocation to probability categories pursuant to chapter 6:
  - 6.2 For the post-closure phase, evidence must be provided that for a **probable development** through the release of radionuclides from the emplaced radioactive waste, an additional effective dose in the range of only **10^{-5} Sv/a** can occur for individuals
  - 6.3 For a **less probable development** in the post-closure phase, evidence must be provided that the additional effective dose caused by the release of radionuclides from the emplaced radioactive waste does not exceed **10^{-4} Sv/a** for the individuals affected.
  - 6.4 For an **improbable development**, reasonable risks or reasonable radiation exposure have not been quantified.

Download of the English version of the German Safety Requirements:
http://www.bmub.bund.de/fileadmin/bmu-import/files/english/pdf/application/pdf/sicherheitsanforderungen_endlagerung_en_bf.pdf

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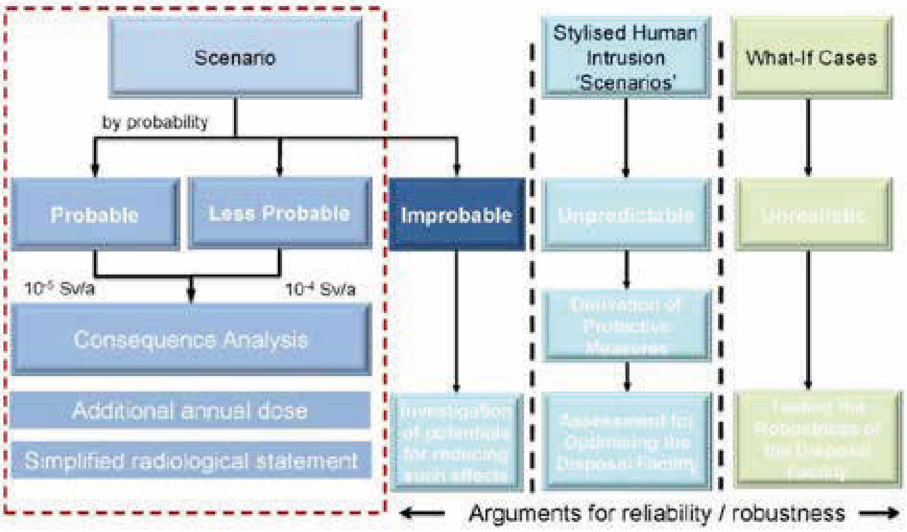
Terminology / Classification / Definition



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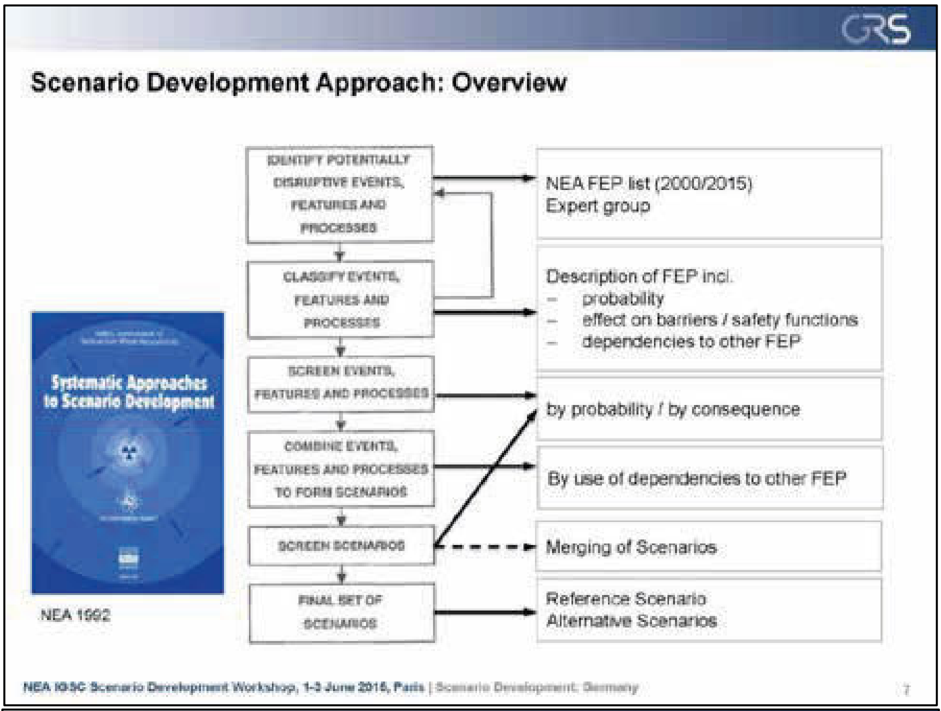
GRS
Scenario Development Approach: Overview
IDENTIFY POTENTIALLY DISRUPTIVE EVENTS, FEATURES AND PROCESSES
CLASSIFY EVENTS, FEATURES AND PROCESSES
SCREEN EVENTS, FEATURES AND PROCESSES
COMBINE EVENTS, FEATURES AND PROCESSES TO FORM SCENARIOS
SCREEN SCENARIOS
FINAL SET OF SCENARIOS
NEA FEP list (2000/2015)
Expert group
Description of FEP incl.
– probability
– effect on barriers / safety functions
– dependencies to other FEP
by probability / by consequence
By use of dependencies to other FEP
Merging of Scenarios
Reference Scenario
Alternative Scenarios
Systematic Approaches to Scenario Development
NEA 1992
NEA IGSC Scenario Development Workshop, 1-3 June 2015, Paris | Scenario Development: Germany
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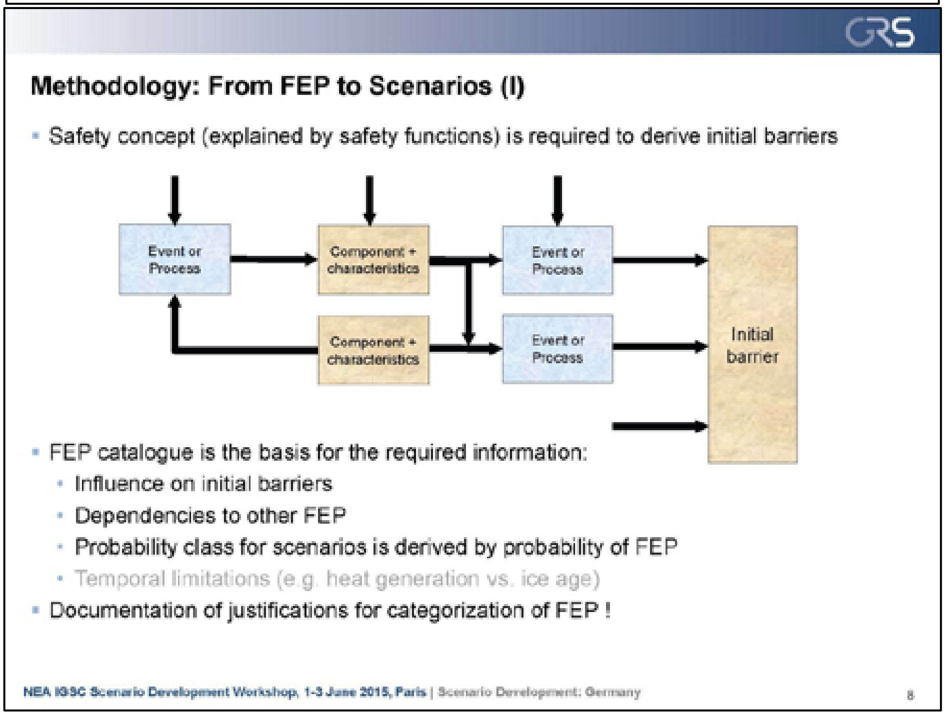
GRS
Methodology: From FEP to Scenarios (I)
Safety concept (explained by safety functions) is required to derive initial barriers
Event or Process
Component + characteristics
Event or Process
Component + characteristics
Event or Process
Initial barrier
FEP catalogue is the basis for the required information:
Influence on initial barriers
Dependencies to other FEP
Probability class for scenarios is derived by probability of FEP
Temporal limitations (e.g. heat generation vs. ice age)
Documentation of justifications for categorization of FEP !
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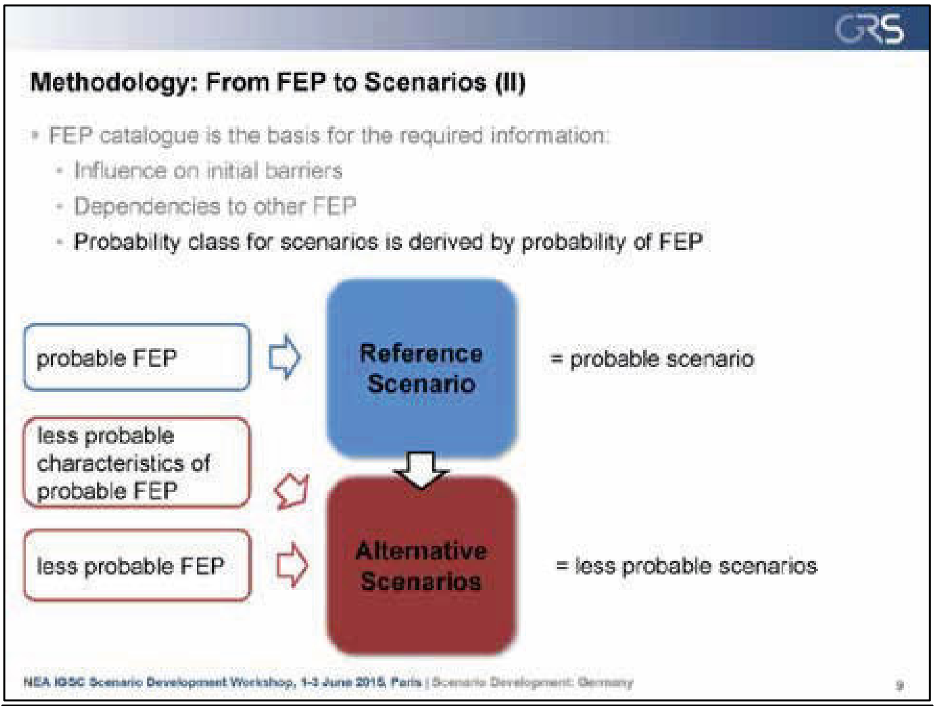
GRS
Methodology: From FEP to Scenarios (II)
FEP catalogue is the basis for the required information:
Influence on initial barriers
Dependencies to other FEP
Probability class for scenarios is derived by probability of FEP
probable FEP
less probable characteristics of probable FEP
less probable FEP
Reference Scenario
Alternative Scenarios
= probable scenario
= less probable scenarios
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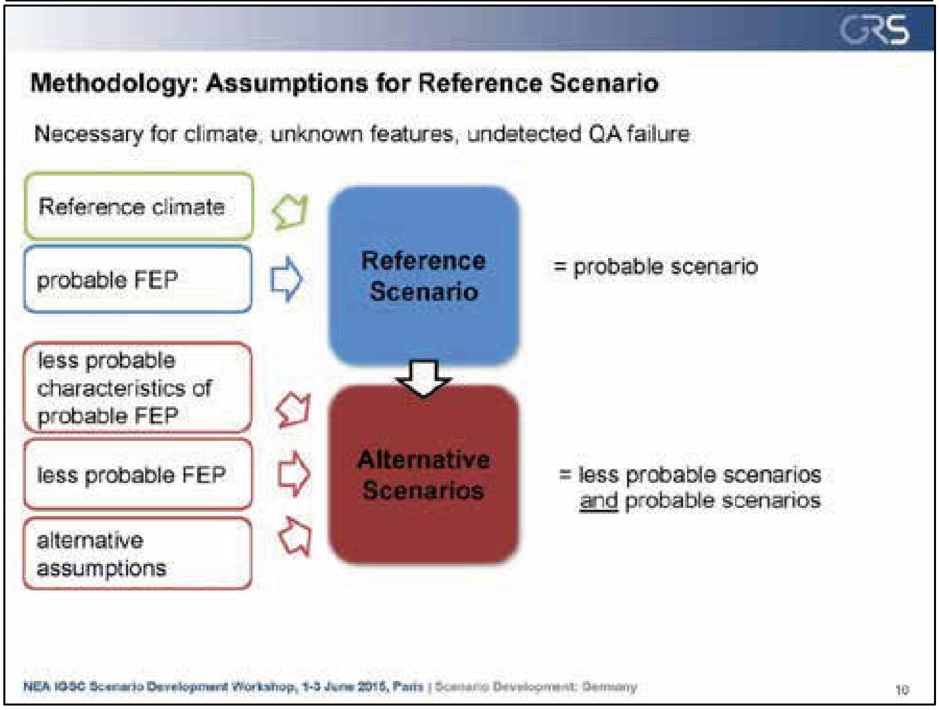
GRS
Methodology: Assumptions for Reference Scenario
Necessary for climate, unknown features, undetected QA failure
Reference climate
probable FEP
less probable characteristics of probable FEP
less probable FEP
alternative assumptions
Reference Scenario
Alternative Scenarios
= probable scenario
= less probable scenarios and probable scenarios
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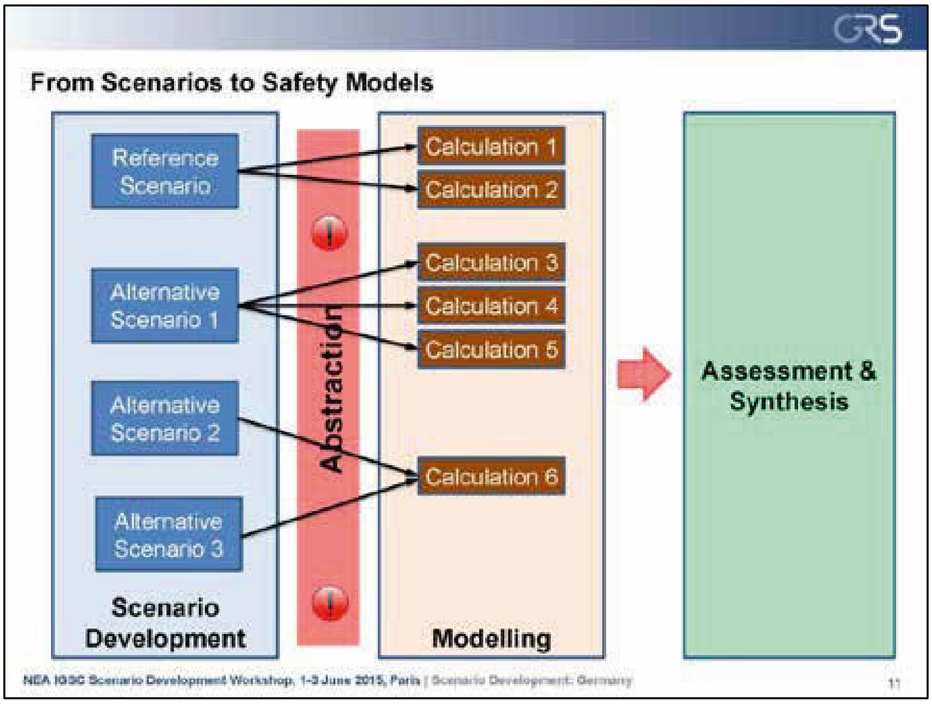

Indicators according to Safety Requirements

- Safety indicator "additional effective dose" → see slide 4
- A **simplified long-term radiological statement** without modeling the dispersion of substances in the overburden and adjoining rock is permissible if the radioactive substances released from the containment-providing rock zone lead to a **maximum of 0.1 person-millisieverts per year for probable developments** and a **maximum of 1 person-millisievert for less probable developments**.
- These person-millisieverts shall be calculated using a recognised generic exposure model for analyses of long-term safety, for which it should be assumed that:
  - The reference group in question contains 10 persons that obtain their entire annual water requirement for nutritional purposes (including drinking water, animal watering, crop irrigation) from a well, and
  - This well water contains all the radionuclides that have escaped from the isolating rock zone in the year in case. The dilution of well water to a mineral content which would permit it to be used as drinking water should be taken into account.

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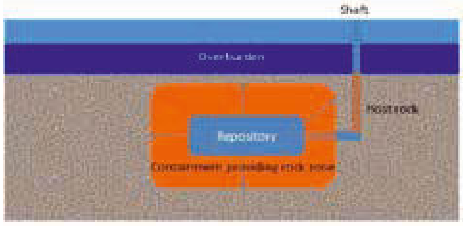
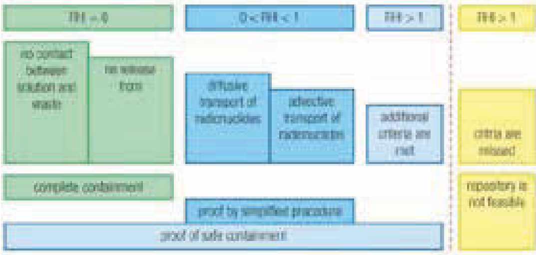
GRS

Containment-providing Rock Zone and Radiological Hazard Index



Radiological Hazard Index (RHI) =

$$\frac{RN\ (Bq/a)\ /\ W\ (m^3/a)\ *\ DCF}{\text{Reference Value}}$$



Source: Preliminary Safety Analysis Gorleben Salt Dome

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GRS

Summary

- Scenario development constitutes the fundamental basis for the quantitative assessment
- Principals / objectives of scenario development in Germany follow international discussions and recommendations (NEA 1992, NEA 2000, IAEA SSG-23 etc.)
  - Reference Scenario vs. Alternative Scenarios
  - SSG-23: 'For the relevant features, events and processes, a thorough examination of interactions between them and their combination in suitable scenarios is performed. The process used for development of scenarios should be fully documented and justified.'
- A systematic and formalized approach is considered important to reach transparency and reproducibility (stakeholder engagement)
- Expert judgement is key input to categorization of FEP → Scenario development (Documentation of justifications!)
- Transfer of scenarios to safety models requires a high degree of abstraction and a strong collaboration of scenario developers and modelers

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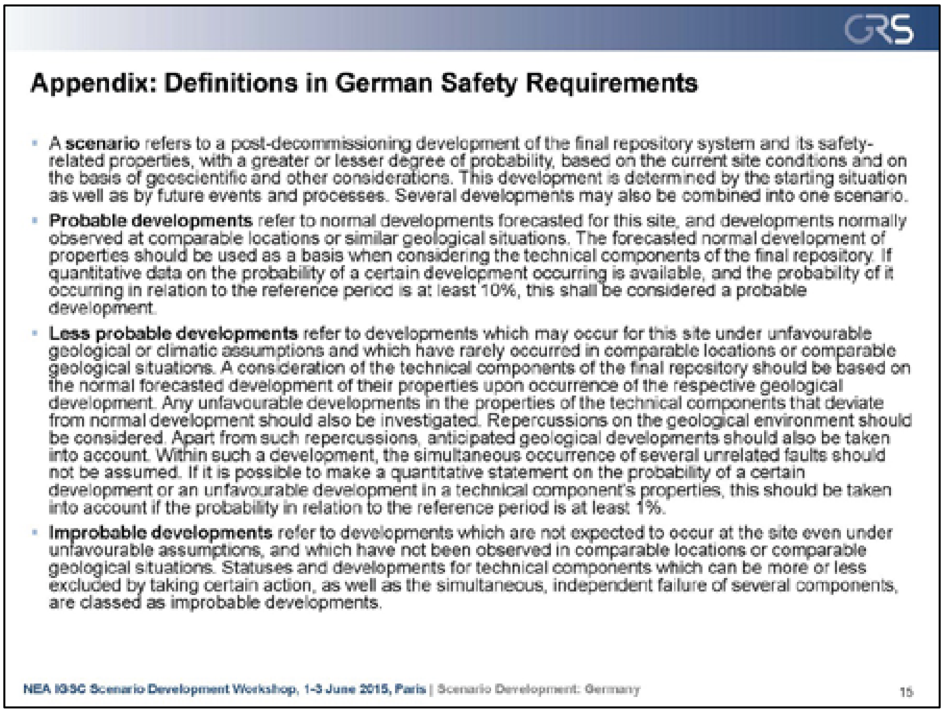
GRS
Appendix: Definitions in German Safety Requirements
A scenario refers to a post-decommissioning development of the final repository system and its safety-related properties, with a greater or lesser degree of probability, based on the current site conditions and on the basis of geoscientific and other considerations. This development is determined by the starting situation as well as by future events and processes. Several developments may also be combined into one scenario.
Probable developments refer to normal developments forecasted for this site, and developments normally observed at comparable locations or similar geological situations. The forecasted normal development of properties should be used as a basis when considering the technical components of the final repository. If quantitative data on the probability of a certain development occurring is available, and the probability of it occurring in relation to the reference period is at least 10%, this shall be considered a probable development.
Less probable developments refer to developments which may occur for this site under unfavourable geological or climatic assumptions and which have rarely occurred in comparable locations or comparable geological situations. A consideration of the technical components of the final repository should be based on the normal forecasted development of their properties upon occurrence of the respective geological development. Any unfavourable developments in the properties of the technical components that deviate from normal development should also be investigated. Repercussions on the geological environment should be considered. Apart from such repercussions, anticipated geological developments should also be taken into account. Within such a development, the simultaneous occurrence of several unrelated faults should not be assumed. If it is possible to make a quantitative statement on the probability of a certain development or an unfavourable development in a technical component's properties, this should be taken into account if the probability in relation to the reference period is at least 1%.
Improbable developments refer to developments which are not expected to occur at the site even under unfavourable assumptions, and which have not been observed in comparable locations or comparable geological situations. Statuses and developments for technical components which can be more or less excluded by taking certain action, as well as the simultaneous, independent failure of several components, are classed as improbable developments.
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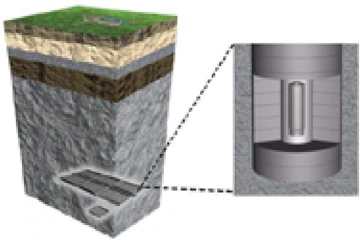
Scenario development for the risk-informed safety assessment of the geological disposal

A.Makiuchi, K. Ishida, S. Kurosawa, M. Inagaki, K. Ishiguro and H. Umeki
Nuclear Waste Management Organization of Japan (NUMO)

T. Ebashi, K. Wakasugi, H. Makino and M. Shibata
Japan Atomic Energy Agency (JAEA)

Background of geological disposal program

- A reference concept for HLW disposal



Robust EBS in stable geological environment: excluding large impact of natural events and processes, e.g. volcanic and fault activities

  - Similar concept applied for SNF direct disposal for R&D by JAEA

- Volunteering approach to siting
  - … No volunteer so far
- Safety regulation not yet specified

P.1

Safety Assessment and Safety Case

- To properly assess and compare volunteers, a move is required away from past very conservative safety assessment modelling towards models and databases that are as realistic as possible
- SA has to be set in the context of a safety case that includes both operational and post-closure phases
- Scenario analysis has to capture state-of-the-art knowledge from a wide range of technical disciplines
- Based on past experience, exponentially expanding knowledge base needs to be managed using advanced KM tools accessed within a user-friendly communication platform

NUMO JAEA P.2

Risk-informed approach for safety assessment: application

- Guidelines for scenario development for the sub-surface disposal of LLW by Nuclear Safety Commission, 2010, to be reconsidered by Nuclear Regulation Authority, the present regulator
  - "likely scenario" : 10 μSv/y
  - "less-likely scenario" : 300 μSv/y
  - "very unlikely scenario" : 10-100 mSv/event
  - "human intrusion scenario" :
    - ✓ 1-10 mSv/y to those around the site
    - ✓ 20-100 mSv to intruder
- Knowledge base on geological hazards is particularly suited to a risk-informed approach: combining description of impact with probability in particular time frames
- Next step is expansion of scenarios for each of these classes and application when sites come forward

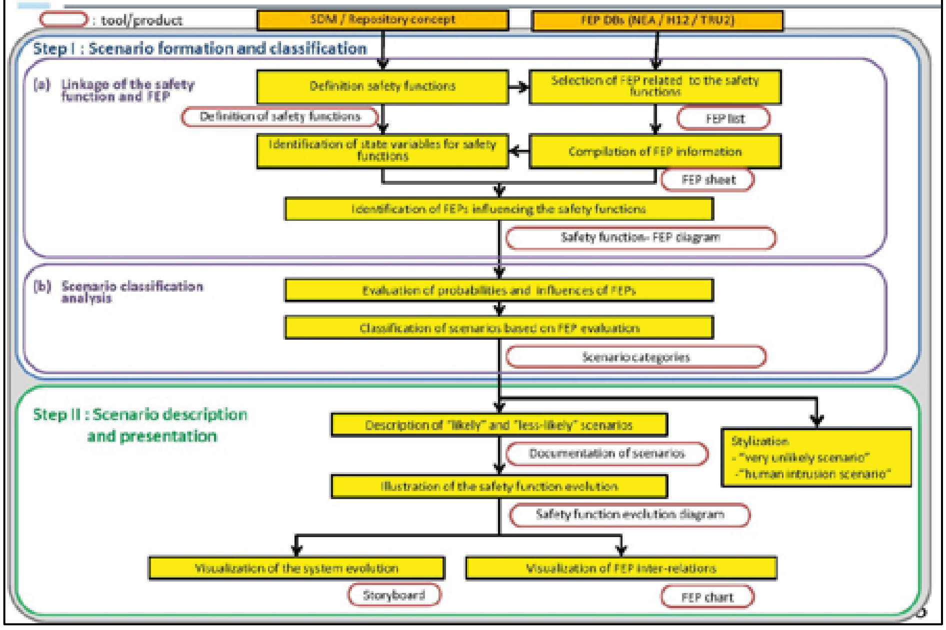
NUMO JAEA P.3

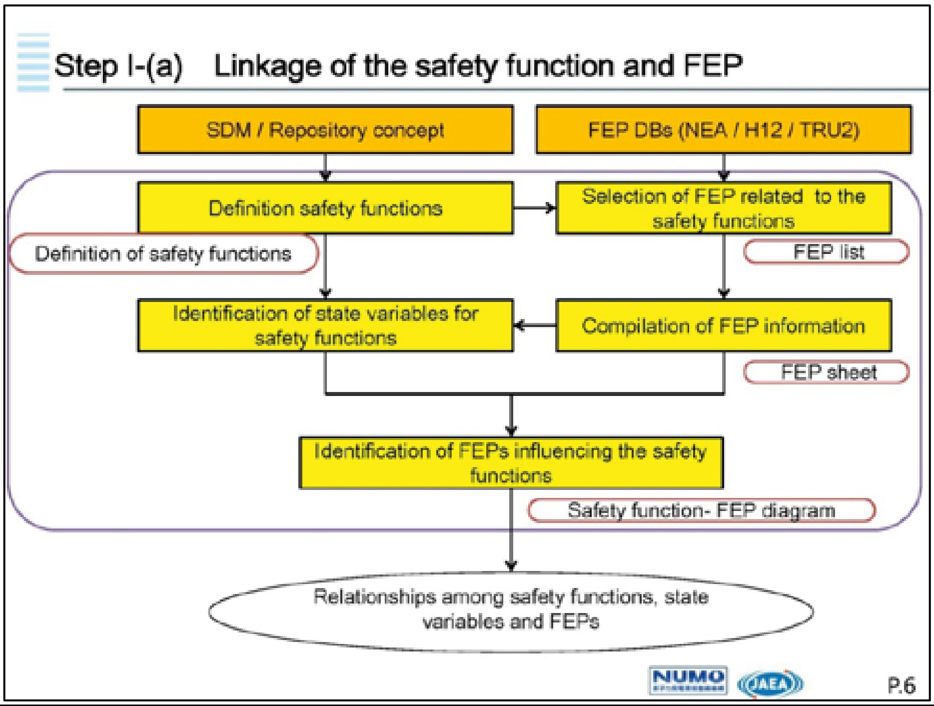
A holistic scenario development method

- Develop a general procedure with supporting toolkits to meet basic requirements: *comprehensiveness, completeness, sufficiency, traceability, and transparency (esp. expert judgment)*
- Combined approach: *a more traditional, bottom-up, FEP-based approach* + *a top-down method based on safety functions*
- Appropriate to risk-informed safety assessment
  - allowing develop "likely scenario" as realistic as possible, representing best current understanding of relevant FEPs in terms of extent and rate of impact on RNs containment and eventual release and transport
  - linked to representation of potential site as 4D SDM, which integrate understanding of the current characteristics of sites and how these evolve with time
  - need also to assess very unlikely, and human intrusion scenarios, applying stylized approach where appropriate

NUMO JAEA P.4

Overall procedure for scenario development





Step I-(a) Linkage of the safety function and FEP

<Definition of safety functions>

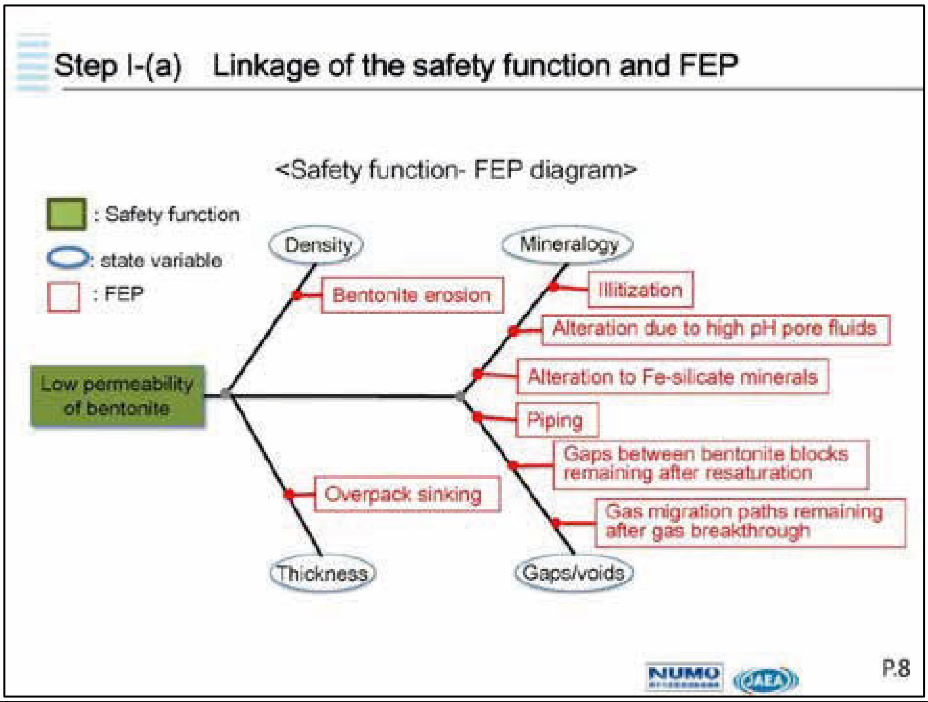
Safety Functions for reference system			System component
Isolation	Protection from long-term geological evolution		Geosphere
	Limitation of human intrusion		Geosphere
Containment	Restriction of leaching of radionuclides	Low leaching rate	Glass matrix
		Preventing contact with groundwater during the period when the heat generation rate is significant	Over-pack
	Retardation of nuclide migration	Solubility limited release of RNs	Geosphere
		Solubility limited release of RNs	EBS
		Restriction of migration by advection	Buffer
		Prevention and restriction of colloid migration	Buffer
		Retardation of nuclide migration by sorption	Buffer
		Retardation of nuclide migration by sorption	Geosphere
		Low groundwater flow	Geosphere
		Decreases of release rate by dispersion	Geosphere
		Preventing the access tunnel and rocks around the tunnel from functioning as a preferential migration path	Plug/backfill

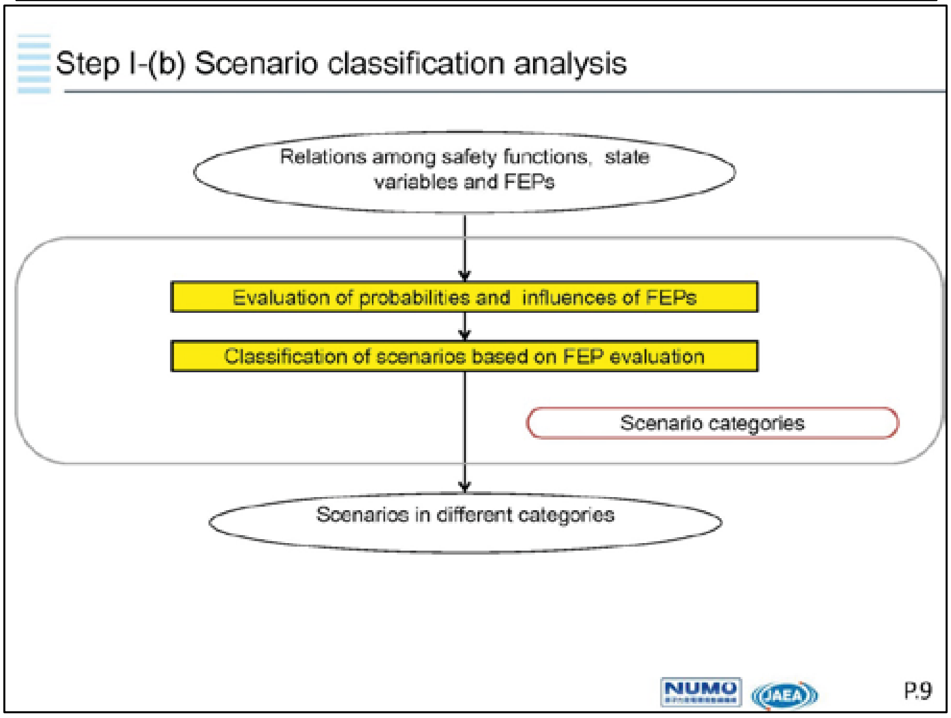
<FEP list>

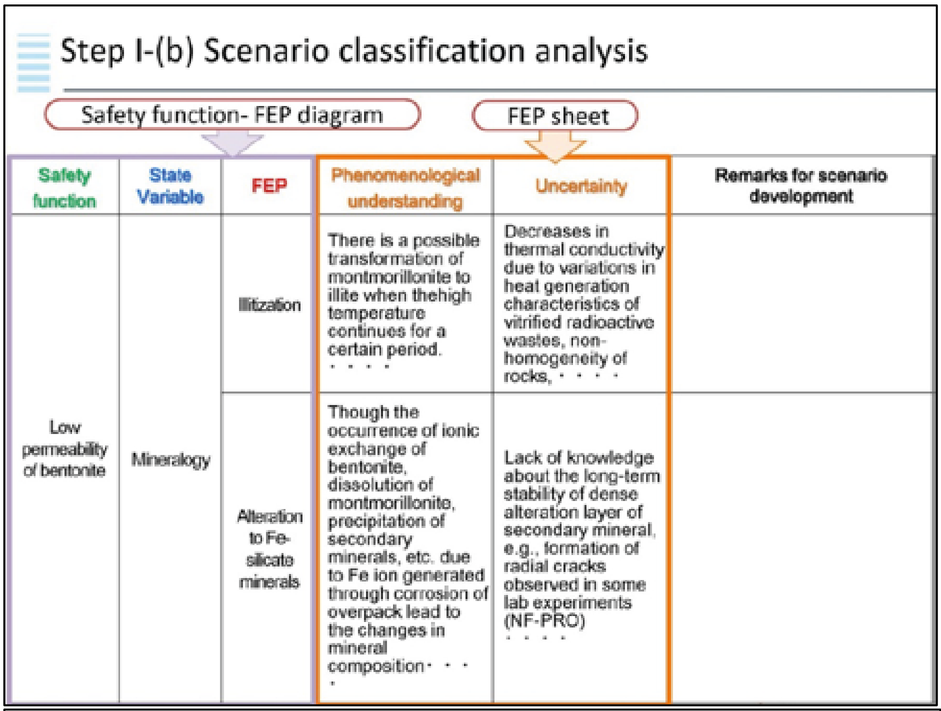
-structured by NEA FEP list
-extraction of FEPs related to reference system referring to NEA, H12 and TRU2

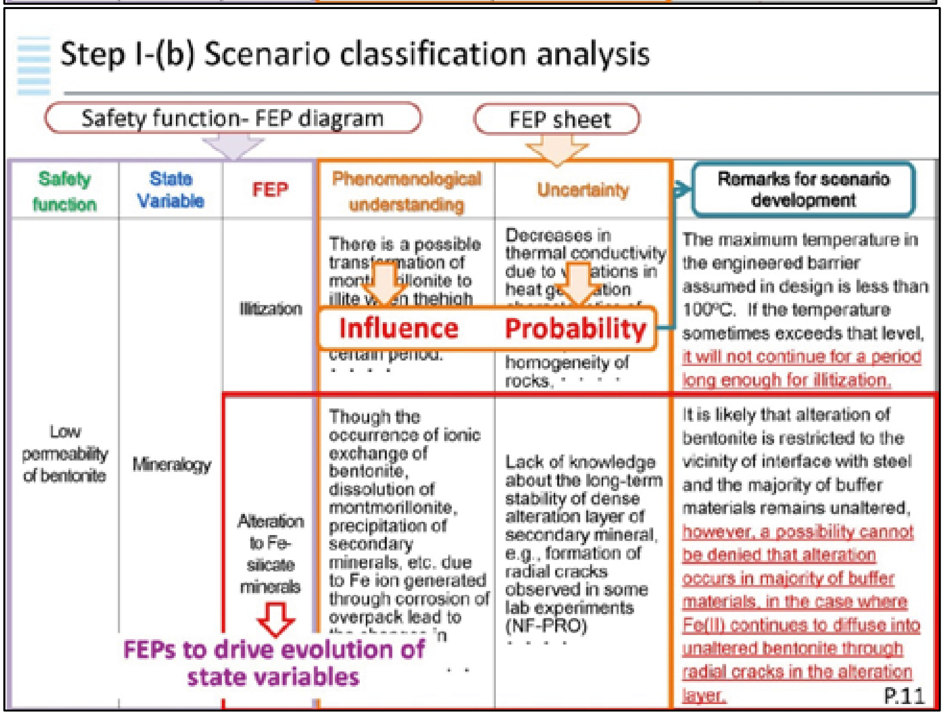
<FEP sheet>

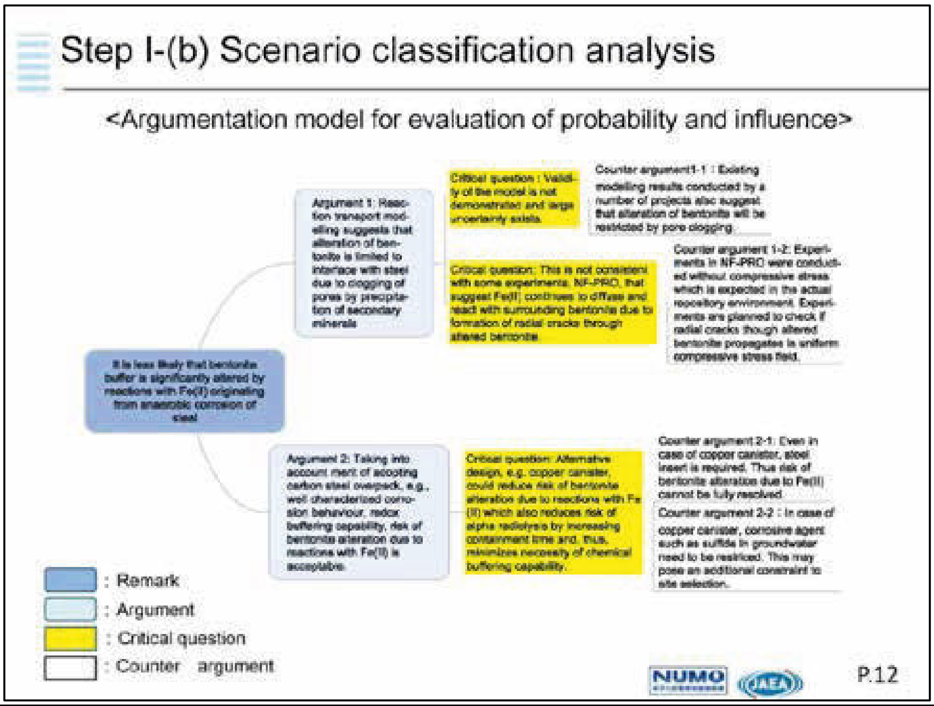
	Structure of FEP sheet
1	FEP name
2	Definition
3	Influence to state variables
4	Relevant information and knowledge
5	Natural analogues
6	Issues for further understanding
7	Examples of FEP treatment in literature else where
8	References
9	Change tracking information

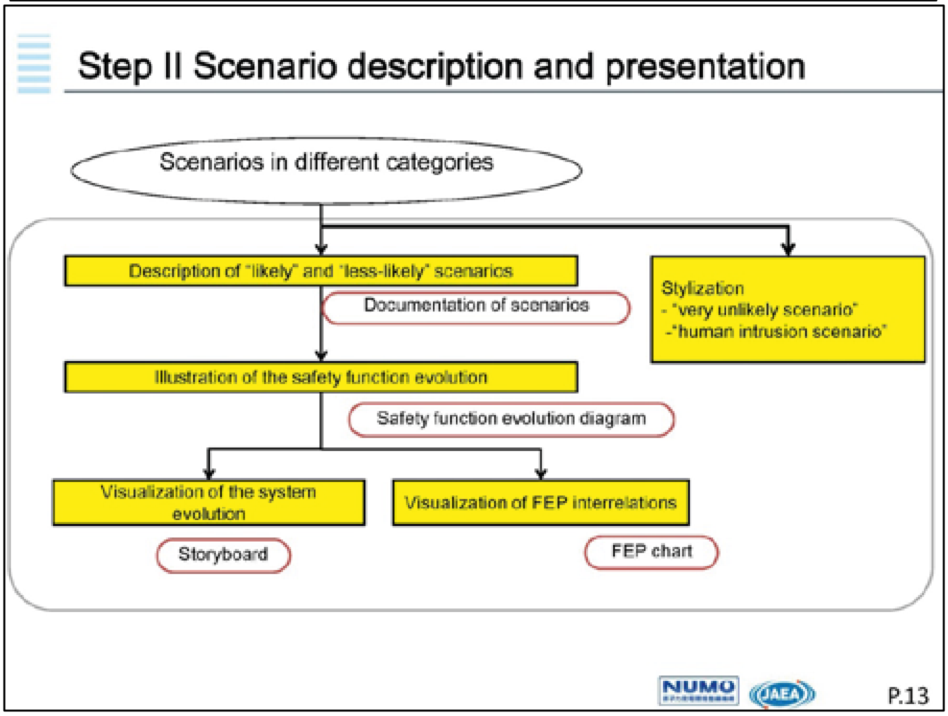

Step I-(a) Linkage of the safety function and FEP
<Safety function- FEP diagram>
: Safety function
: state variable
: FEP
Low permeability of bentonite
Density
Bentonite erosion
Overpack sinking
Thickness
Mineralogy
Illitization
Alteration due to high pH pore fluids
Alteration to Fe-silicate minerals
Piping
Gaps between bentonite blocks remaining after resaturation
Gas migration paths remaining after gas breakthrough
Gaps/voids
P.8


Step I-(b) Scenario classification analysis
Relations among safety functions, state variables and FEPs
Evaluation of probabilities and influences of FEPs
Classification of scenarios based on FEP evaluation
Scenario categories
Scenarios in different categories
P.9


Step I-(b) Scenario classification analysis
Safety function- FEP diagram
FEP sheet
Safety function
State Variable
FEP
Phenomenological understanding
Uncertainty
Remarks for scenario development
Low permeability of bentonite
Mineralogy
Illitization
There is a possible transformation of montmorillonite to illite when thehigh temperature continues for a certain period. · · · ·
Decreases in thermal conductivity due to variations in heat generation characteristics of vitrified radioactive wastes, non-homogeneity of rocks, · · · ·
Alteration to Fe-silicate minerals
Though the occurrence of ionic exchange of bentonite, dissolution of montmorillonite, precipitation of secondary minerals, etc. due to Fe ion generated through corrosion of overpack lead to the changes in mineral composition· · · ·
Lack of knowledge about the long-term stability of dense alteration layer of secondary mineral, e.g., formation of radial cracks observed in some lab experiments (NF-PRO) · · · ·


Step I-(b) Scenario classification analysis
Safety function- FEP diagram
FEP sheet
Safety function
State Variable
FEP
Phenomenological understanding
Uncertainty
Remarks for scenario development
Low permeability of bentonite
Mineralogy
Illitization
Influence
Probability
homogeneity of rocks, · · · ·
The maximum temperature in the engineered barrier assumed in design is less than 100ºC. If the temperature sometimes exceeds that level, it will not continue for a period long enough for illitization.
Alteration to Fe-silicate minerals
Though the occurrence of ionic exchange of bentonite, dissolution of montmorillonite, precipitation of secondary minerals, etc. due to Fe ion generated through corrosion of overpack lead to
Lack of knowledge about the long-term stability of dense alteration layer of secondary mineral, e.g., formation of radial cracks observed in some lab experiments (NF-PRO) · · · ·
It is likely that alteration of bentonite is restricted to the vicinity of interface with steel and the majority of buffer materials remains unaltered, however, a possibility cannot be denied that alteration occurs in majority of buffer materials, in the case where Fe(II) continues to diffuse into unaltered bentonite through radial cracks in the alteration layer.
FEPs to drive evolution of state variables
P.11


Step I-(b) Scenario classification analysis
<Argumentation model for evaluation of probability and influence>
It is less likely that bentonite buffer is significantly altered by reactions with Fe(II) originating from anaerobic corrosion of steel
Argument 1: Reaction transport modelling suggests that alteration of bentonite is limited to interface with steel due to clogging of pores by precipitation of secondary minerals
Critical question : Validity of the model is not demonstrated and large uncertainty exists.
Counter argument1-1 : Existing modelling results conducted by a number of projects also suggest that alteration of bentonite will be restricted by pore clogging.
Critical question: This is not consistent with some experiments, NF-PRO, that suggest Fe(II) continues to diffuse and react with surrounding bentonite due to formation of radial cracks through altered bentonite.
Counter argument 1-2: Experiments in NF-PRO were conducted without compressive stress which is expected in the actual repository environment. Experiments are planned to check if radial cracks though altered bentonite propagates in uniform compressive stress field.
Argument 2: Taking into account merit of adopting carbon steel overpack, e.g., well characterized corrosion behaviour, redox buffering capability, risk of bentonite alteration due to reactions with Fe(II) is acceptable.
Critical question: Alternative design, e.g. copper canister, could reduce risk of bentonite alteration due to reactions with Fe (II) which also reduces risk of alpha radiolysis by increasing containment time and, thus, minimizes necessity of chemical buffering capability.
Counter argument 2-1: Even in case of copper canister, steel insert is required. Thus risk of bentonite alteration due to Fe(II) cannot be fully resolved.
Counter argument 2-2 : In case of copper canister, corrosive agent such as sulfide in groundwater need to be restricted. This may pose an additional constraint to site selection.
: Remark
: Argument
: Critical question
: Counter argument
NUMO
JAEA
P.12


Step II Scenario description and presentation
Scenarios in different categories
Description of "likely" and "less-likely" scenarios
Documentation of scenarios
Stylization
- "very unlikely scenario"
-"human intrusion scenario"
Illustration of the safety function evolution
Safety function evolution diagram
Visualization of the system evolution
Visualization of FEP interrelations
Storyboard
FEP chart
NUMO
JAEA
P.13

Step II Scenario description and presentation

<Safety function evolution diagram>

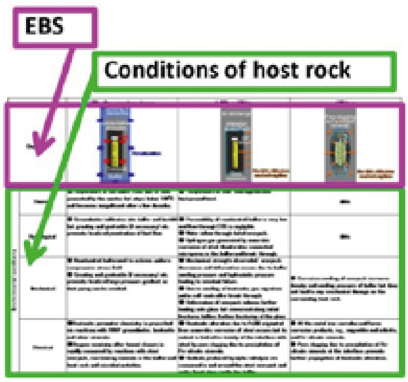
Safety Functions for reference system		Life time of function 10^3y 10^4y 10^5y 10^6y
Isolation	Protection from long-term geological evolution	Enough depth to be kept a deep underground environment
	Limiting human Intrusion	Likely less depth of utilization of using underground.
Containment	Reducing leaching of radionuclides	Slow nuclide release (Glass) Physical containment(Over pack)
	Retardation of nuclide migration	Sorption/diffsion, Low permiability (Buffer) Sorption of nuclide(Host-rock)

NUMO JAEA P.14

Step II Scenario description and presentation

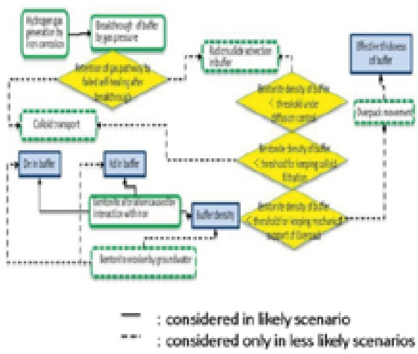
Storyboard

- Graphical representation of evolution of disposal system



FEP chart

- Inter-relations between various FEPs and relevant parameters



NUMO JAEA P.15

Summary and future plan (1)

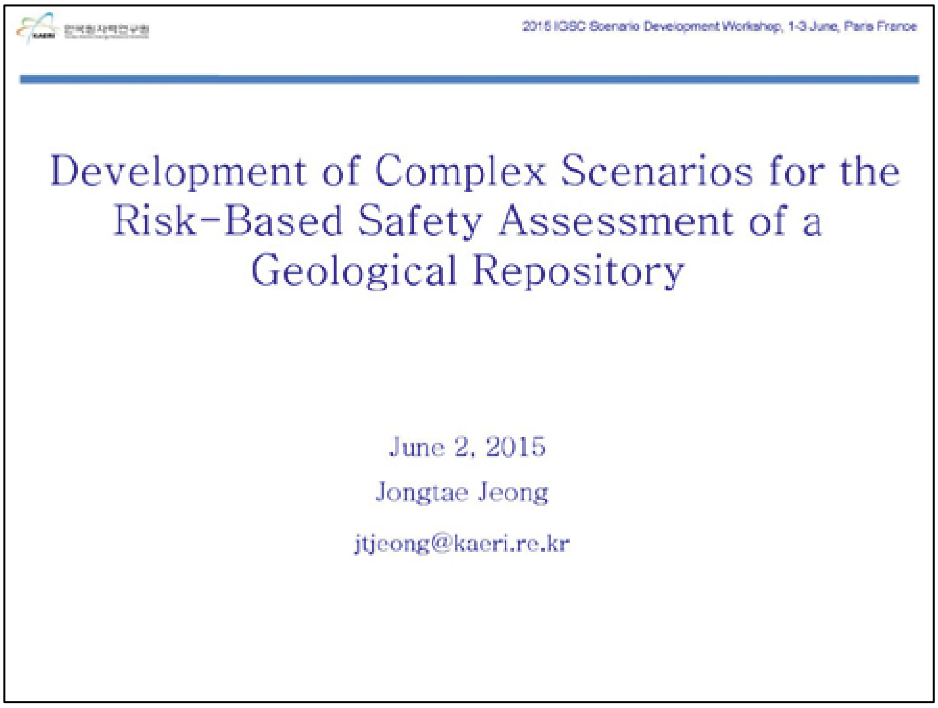
- NUMO and JAEA are jointly developing a holistic method which enables to develop scenarios for safety assessment, based on a risk-informed approach allowing clear classification of scenarios in different categories
- An overall procedure and associated toolkits have been provided to increase traceability and transparency in scenario developing process:
  - further to facilitate integration of knowledge in a structured manner among geological environment, design and SA teams;
  - to provide interface to various stakeholders

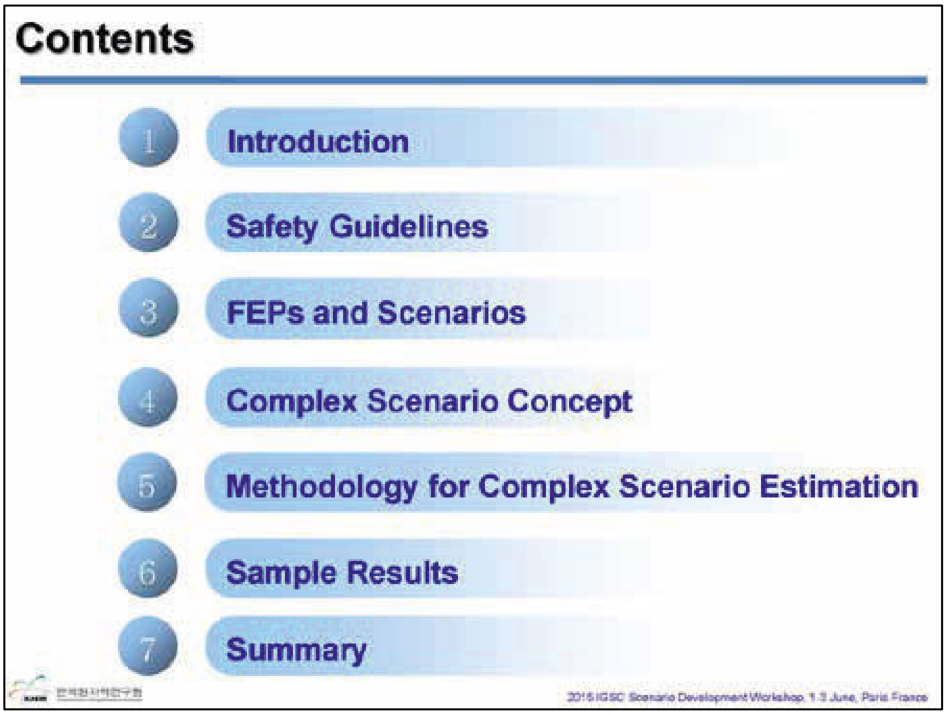
NUMO JAEA P.16

Summary and future plan (2)

- Completeness, comprehensiveness, and sufficiency in scenario development strongly depend on the purpose and context of SA and safety case as well as state-of-the-art knowledge:
  - For NUMO safety case, realistic "understanding" and development of associated "models and database" on geological environment and repository tailored to a given site are a key to judge if these aspects are satisfied
- The method is still under developing and future plan includes to examine usefulness and adequacy through the application for the safety case that are provided for HLW/TRU waste by NUMO and SNF direct disposal by JAEA, associated with peer reviews, experts workshop, etc.

NUMO JAEA P.17


2015 IGSC Scenario Development Workshop, 1-3 June, Paris France
Development of Complex Scenarios for the Risk-Based Safety Assessment of a Geological Repository
June 2, 2015
Jongtae Jeong
jtjeong@kaeri.re.kr


Contents
1 Introduction
2 Safety Guidelines
3 FEPs and Scenarios
4 Complex Scenario Concept
5 Methodology for Complex Scenario Estimation
6 Sample Results
7 Summary
2015 IGSC Scenario Development Workshop, 1-3 June, Paris France

1. Introduction

- **Two reference disposal systems in Korea:**
  - KRS: a system for the direct disposal of spent nuclear fuels
  - A-KRS: a system for the disposal of pyro-processed wastes
- **Long-term safety assessment**
  - ✓ Developed the safety assessment program using the Goldsim program.
  - ✓ To check the design feasibility of reference disposal systems.
  - ✓ Consider one reference scenario and three alternative scenarios such as well intrusion, seismic event, and early defect of waste packages.
  - ✓ The basic geological data were taken from the KURT (KAERI Underground Research Tunnel) at KAERI.
  - ✓ Checked the regulatory compliances by comparing the calculated exposure dose rates and the draft safety goals and background radiation exposure rate.
  - ✓ We suggest the development of complex scenarios to support risk-based safety assessment of a geological repository.

한국원자력연구원 2015 IGSC Scenario Development Workshop, 1-3 June, Paris France

1. Introduction

KRS: direct disposal of SF

- **Disposal Canister**
  - 50 mm copper-nodular cast iron
  - Manufacture: Roll and weld
  - Lifetime: 100,000 years
- Buffer
  - **Domestic Ca-bentonite**
  - Dry density: 1.6 g/cm^3
  - Thickness: 50 cm
  - Thermal conductivity: 1.0 W/mK

Vertical deposition: 40 m tunnel spacing	
Number of disposal tunnels	377
Length of a tunnel	251 m
Disposal Area ✓CANDU (16,000 MtHM) ✓PWR (low burnup, 20,000 MtHM)	~ 4.6 km^2 ~ 0.5 km^2 **~ 5.1 km^2**

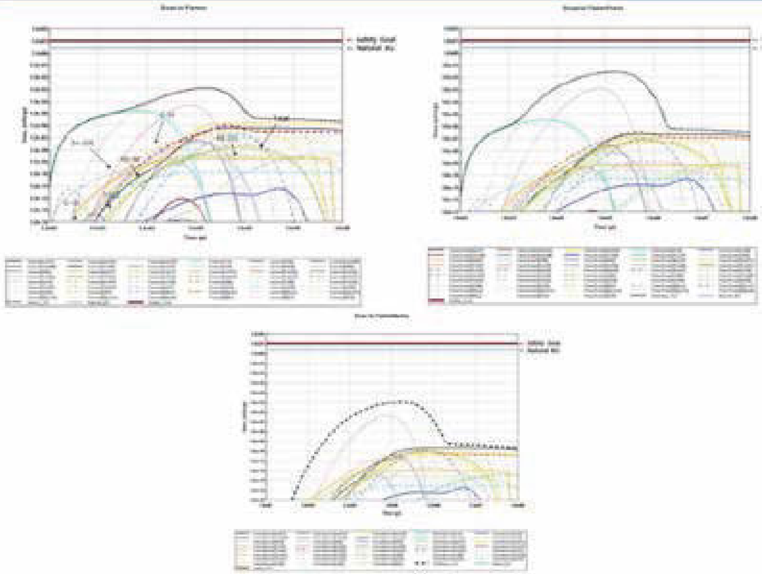
A-KRS: pyro-processed waste

- **Disposal Canister**
  - 10 mm copper-nodular cast iron
  - **Manufacture: Cold spray coating**
  - Lifetime: 1,000 years (determined by radiotoxicity)
- Buffer
  - **Domestic Ca-bentonite**
  - Dry density: 1.6 g/cm^3
  - Thickness: 36 cm
  - Thermal conductivity: 0.8 W/mK

Horizontal deposition: 25 m tunnel spacing	
Number of disposal tunnels	16
Length of a tunnel	200 m
Disposal Area	**~ 0.078 km^2**
Comparison with direct disposal (0.078 :5.1)	~1/70

한국원자력연구원 2015 IGSC Scenario Development Workshop, 1-3 June, Paris France

1. Introduction



Exposure dose rates to three exposure groups for a reference scenario

2015 IGSC Scenario Development Workshop, 1-3 June, Paris France

2. Safety Guidelines

- **Draft regulatory guidelines for HLW repository in Korea**
  - It was released in 2012 by the Nuclear Safety & Security Committee (NSSC) and now under review process.
  - Article 5 (Safety Goals)
    - ✓ The total annual risk for the representative person resulting from the radiation exposure should not exceed $1.0x10^{-6}$/yr. ($1.0x10^{-5}$/yr for LILW repository)
    - ✓ The expected radiation exposure for the representative person for each scenario should not exceed 10mSv/yr.
  - Article 6 (Safety Assessment)
    - ✓ The effective dose rates have to be assessed for the representative person and risk factor value of 0.05/Sv are to be used to convert the dose rate to the risk.
    - ✓ The scenarios have to be formed by analyzing systematically important phenomena, processes, and events which represent the characteristics of repository system and may contribute to high exposure dose rate.
    - ✓ The representative person is a representative individual that may receive high exposure dose rate among persons and follows general dietary life.
  - Article 7 (Confidence Building)

    The regulatory compliances should be supported by the multiple lines of reasoning such as the probabilistic analysis of the exposure dose and risk, uncertainty analysis, natural analogue, complementary safety indicator such as radionuclide concentration and release rates, secure of defense in depth.

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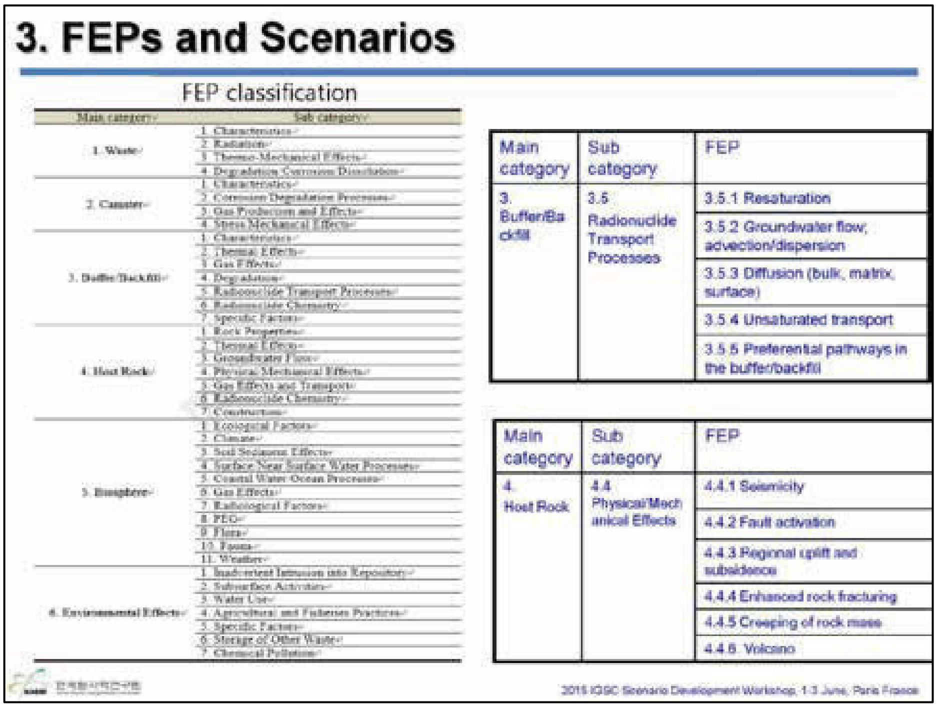
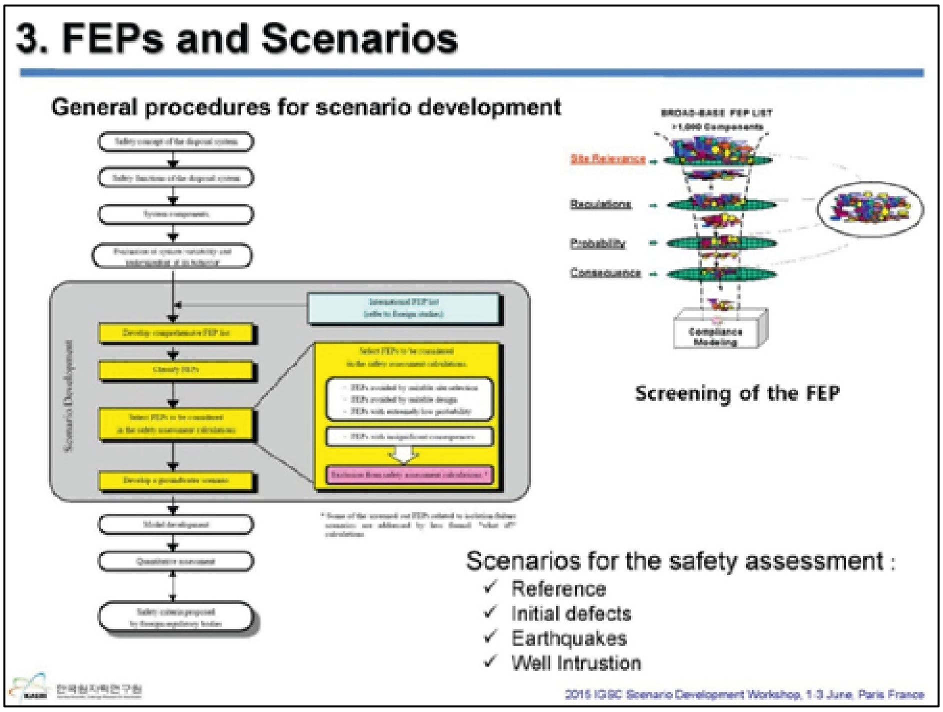


Main category	Sub category
1. Waste	1. Characteristics 2. Radiation 3. Thermo-Mechanical Effects 4. Degradation Corrosion Dissolution
2. Canister	1. Characteristics 2. Corrosion Degradation Processes 3. Gas Production and Effects 4. Stress Mechanical Effects
3. Buffer/Backfill	1. Characteristics 2. Thermal Effects 3. Gas Effects 4. Degradation 5. Radionuclide Transport Processes 6. Radionuclide Chemistry 7. Specific Factors
4. Host Rock	1. Rock Properties 2. Thermal Effects 3. Groundwater Flow 4. Physical Mechanical Effects 5. Gas Effects and Transport 6. Radionuclide Chemistry 7. Construction
5. Biosphere	1. Ecological Factors 2. Climate 3. Soil Sediment Effects 4. Surface Near Surface Water Processes 5. Coastal Water Ocean Processes 6. Gas Effects 7. Radiological Factors 8. FEO 9. Flora 10. Fauna 11. Weather
6. Environmental Effects	1. Inadvertent Intrusion into Repository 2. Subsurface Activities 3. Water Use 4. Agricultural and Fisheries Practices 5. Specific Factors 6. Storage of Other Waste 7. Chemical Pollution

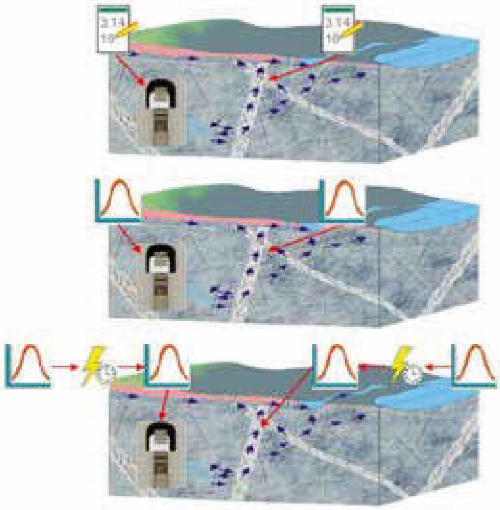
Main category	Sub category	FEP
3. Buffer/Backfill	3.5 Radionuclide Transport Processes	3.5.1 Resaturation
		3.5.2 Groundwater flow, advection/dispersion
		3.5.3 Diffusion (bulk, matrix, surface)
		3.5.4 Unsaturated transport
		3.5.5 Preferential pathways in the buffer/backfill

Main category	Sub category	FEP
4. Host Rock	4.4 Physical/Mechanical Effects	4.4.1 Seismicity
		4.4.2 Fault activation
		4.4.3 Regional uplift and subsidence
		4.4.4 Enhanced rock fracturing
		4.4.5 Creeping of rock mass
		4.4.6 Volcano



4. Complex Scenario Concept

- Single exposure scenario
  - Deterministic assessment
    - ✓ Input data for each scenario are pre-determined
  - Probabilistic assessment
    - ✓ Input data for each scenario are determined with relevant probabilistic distribution function
- Complex scenario
  - Combination of reference scenario and alternative scenarios considering their occurrence probabilities and their impacts on the repository system



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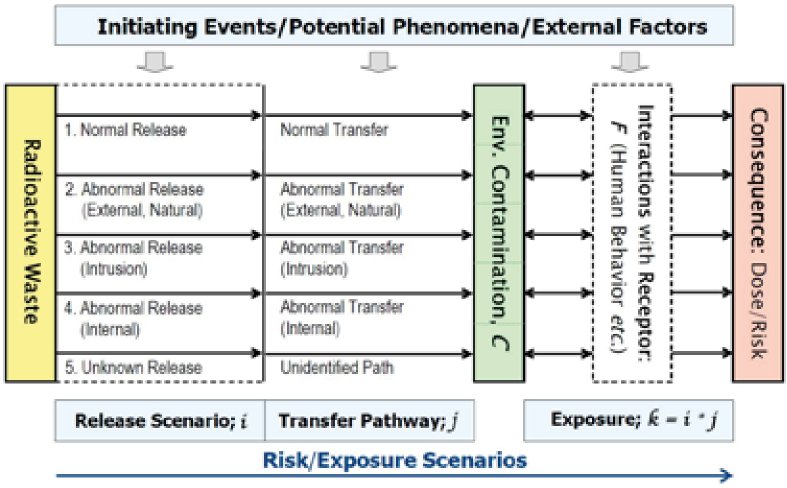
4. Complex Scenario Concept



< Seo et al. 2010. An integrated approach to risk-based post-closure safety evaluation of complex radiation exposure situations in radioactive waste disposal >

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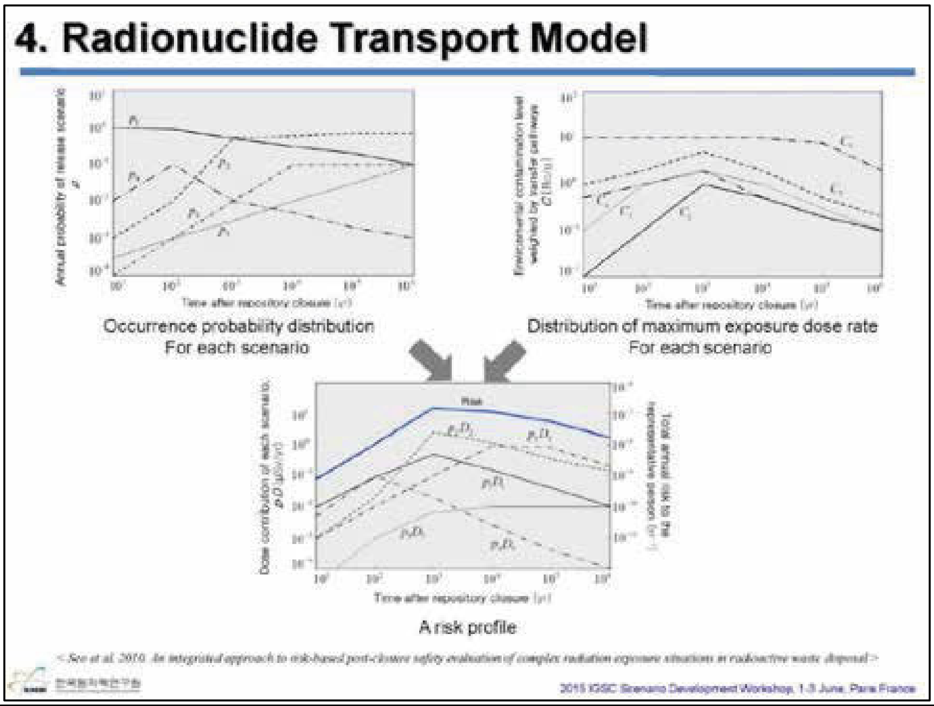
4. Radionuclide Transport Model
Occurrence probability distribution
For each scenario
Distribution of maximum exposure dose rate
For each scenario
A risk profile
< Seo et al. 2010. An integrated approach to risk-based post-closure safety evaluation of complex radiation exposure situations in radioactive waste disposal >
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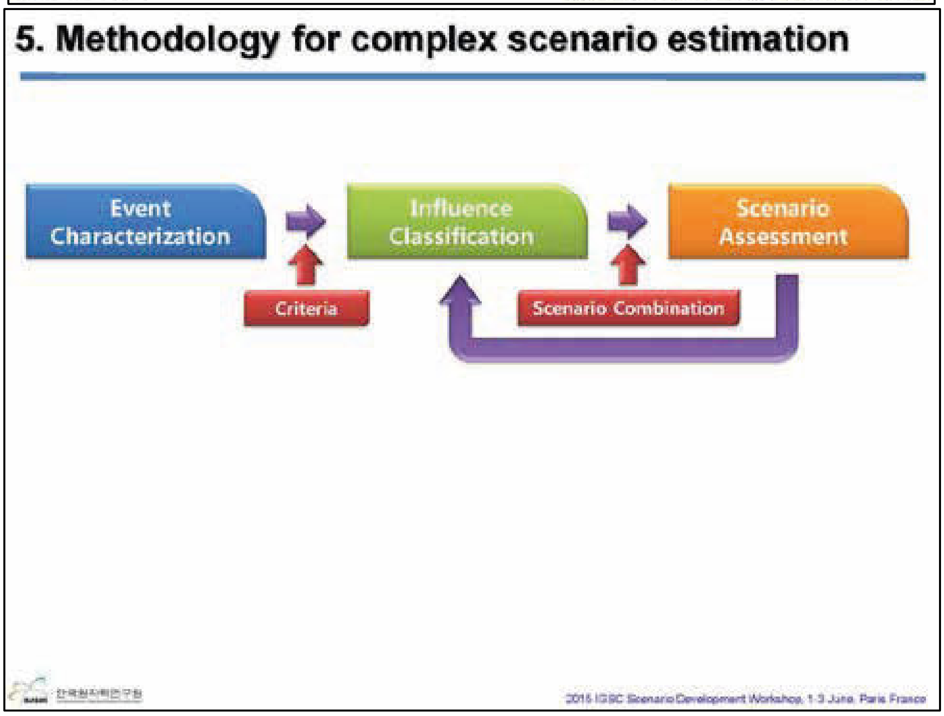
5. Methodology for complex scenario estimation
Event Characterization
Influence Classification
Scenario Assessment
Criteria
Scenario Combination
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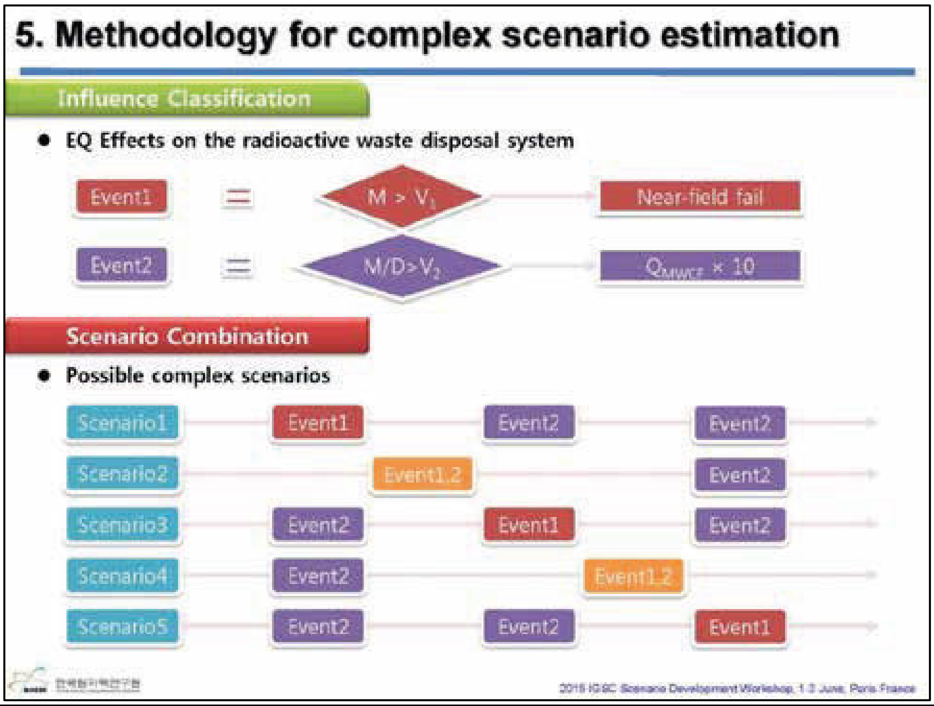
5. Methodology for complex scenario estimation
Influence Classification
EQ Effects on the radioactive waste disposal system
Event1
=
M > V1
Near-field fail
Event2
=
M/D>V2
QMWCF × 10
Scenario Combination
Possible complex scenarios
Scenario1
Event1
Event2
Event2
Scenario2
Event1,2
Event2
Scenario3
Event2
Event1
Event2
Scenario4
Event2
Event1,2
Scenario5
Event2
Event2
Event1
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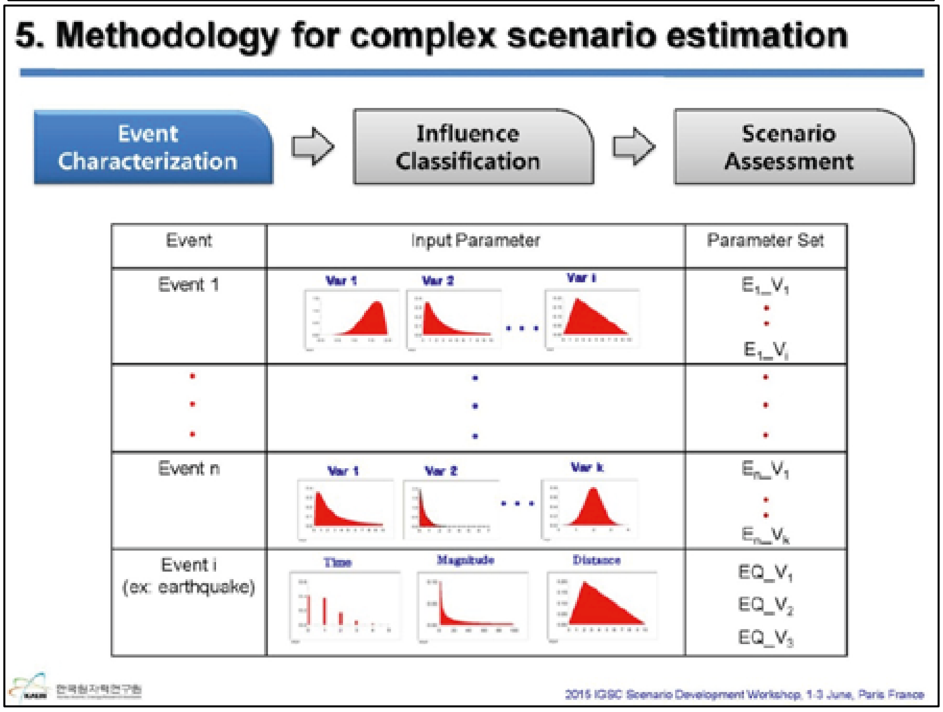
5. Methodology for complex scenario estimation
Event Characterization
Influence Classification
Scenario Assessment
Event
Input Parameter
Parameter Set
Event 1
Var 1
Var 2
Var i
E1_V1
E1_Vi
Event n
Var 1
Var 2
Var k
En_V1
En_Vk
Event i (ex: earthquake)
Time
Magnitude
Distance
EQ_V1
EQ_V2
EQ_V3
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5. Methodology for complex scenario estimation

Monte Carlo Sampling				Influence Classification				Scenario Combination				
				Release		Pathway		Scenario (Combination)				
								i1*j1	i1*j2	i2*j1	i2*j2	SUM
random	C1	random	C2	i1	i2	j1	j2	0.230	0.600	0.040	0.130	1.000
0.419	6.4	0.827	15.7	1	0	1	0	1	0	0	0	
0.814	7.5	0.881	17.3	1	0	1	0	1	0	0	0	
0.302	6.2	0.340	6.8	1	0	0	1	0	1	0	0	
0.406	6.4	0.512	9.4	1	0	0	1	0	1	0	0	
0.068	5.6	0.747	13.8	1	0	1	0	1	0	0	0	
0.850	7.6	0.782	14.6	0	1	0	1	0	0	0	1	
0.415	6.4	0.831	15.8	1	0	1	0	1	0	0	0	
0.278	6.1	0.770	14.3	1	0	1	0	1	0	0	0	
0.207	5.9	0.918	18.6	1	0	1	0	1	0	0	0	
0.835	7.5	0.496	9.1	0	1	0	1	0	0	0	1	

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5. Methodology for complex scenario estimation

Scenario Assessment

Verification of occurrence probability for each scenario

Simulation (10^2 times)	Pseudo-Theory (10^5 times)
0.07	0.041
0.25	0.184
0.02	0.033
0.15	0.141
0.51	0.601

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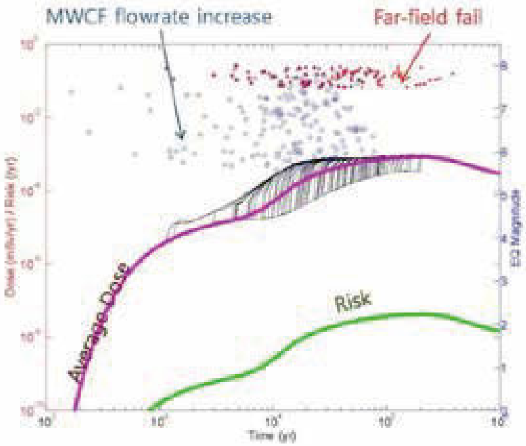
6. Sample Results

Scenario Assessment



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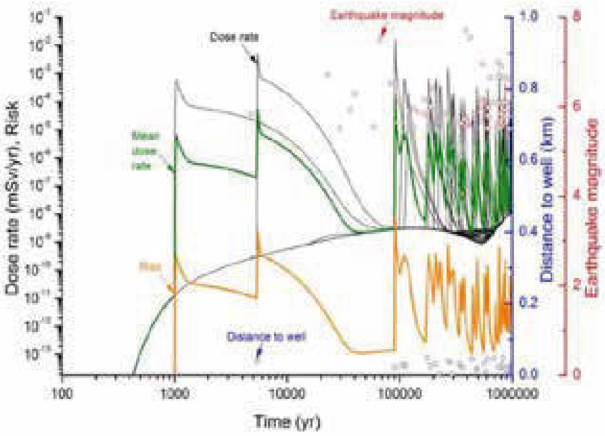
6. Sample Results

Scenario Assessment



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7. Summary

- We checked the design feasibility of reference geological repository systems by estimating peak exposure dose rate and comparing safety goals for one reference scenario and three alternative scenarios using the TSPA program developed by using Goldsim program.
- We suggested the methodology for developing complex scenarios because the primary safety goal in Korea is expressed as risk.
- The suggested methodology has following merits:
  - Can estimate risk by considering occurrence probability and exposure dose rate simultaneously
  - Can be used to risk-based long-term safety assessment of a geological repository
  - Can develop various risk profiles which can be used to support the development of safety case to get public acceptance
  - Convenient to automate the assessment process
- The characterizations of alternative scenarios such as occurrence probability and their impacts on a repository system must be preliminarily determined for the successful risk-based safety assessment with this method.
- We performed the characterization and prediction of earthquake and well intrusion by analyzing earthquake and well development data in Korea.

11th ASTOR Experts Meeting, Gyeongju, Korea, 2015

Scenarios in the safety assessment SR-Site; Methodology and application

Allan Hedin, SKB

Outline

- The safety assessment SR-Site
- Scenario methodology in SR-Site
- Response to questions to presenters

2015-06-02 Scenario methodology SR-Site 2

Background

- On March 16, 2011, SKB applied for licences to construct and operate
  - a facility for encapsulation of spent nuclear fuel in the municipality of Oskarshamn
  - a KBS-3 repository for final disposal of spent nuclear fuel at the Forsmark site in the municipality of Östhammar
- The safety assessment **SR-Site** is a key component in the safety case for the final repository

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2015-06-02 Scenario methodology SR-Site 3

The safety assessment SR-Site (1/2)

- The safety assessment SR-Site forms an essential part of SKB's license application for a final repository for spent nuclear fuel
  - KBS-3 repository concept
  - The Forsmark site
  - All spent nuclear fuel forecasted to arise in Sweden's nuclear energy program; basically 12,000 tons of BWR and PWR SF, corresponding to 6,000 canisters
- Methodology and reporting structure of SR-Site based on those of the SR-Can assessment published in 2006.
  - Comments from comprehensive regulator's review of SR-Can taken into account.
  - **Essentially the same scenario methodology in SR-Can and SR-Site**

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2015-06-02 Scenario methodology SR-Site 4

The safety assessment SR-Site (2/2)

- Objectives
  - Role of SR-Site report in licence application:
    - To demonstrate that a KBS-3 repository at the Forsmark site is safe in the long term.
  - The task of the safety assessment project SR-Site has been to investigate whether a safe repository can be built at Forsmark.
  - The main purposes of the SR-Site project were
    - To assess the safety, as defined in applicable Swedish regulations, of the proposed KBS-3 repository at Forsmark;
    - To provide feedback to design development, to SKB's R&D programme, to detailed site investigations and to future safety assessment projects.

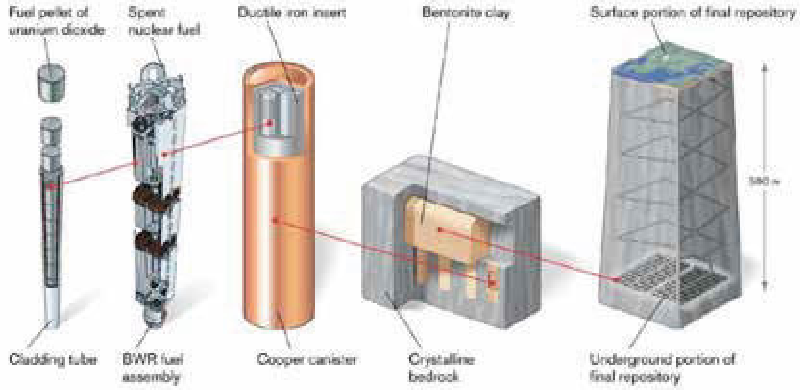
2015-06-02 Scenario methodology SR-Site 5

Reviewing

- SKB's licence application, including SR-Site under review by SSM; will also be tried by Land and environmental court.
- SR-Site reviewed by NEA International Review Team (IRT) in 2011-12
  - The IRT found "that SKB generally gives a convincing illustration and technical basis both for the feasibility of the future repository, according to the KBS-3 design, and for its radiological long-term safety"

2015-06-02 Scenario methodology SR-Site 6

The KBS-3 concept



Primary safety function: Complete containment

⇒ the safety assessment is primarily focussed on containment

Secondary safety function: Retardation

2015-06-02 Scenario methodology SR-Site 7

Scenario methodology in SR-Site

- Safety functions
- Reference evolution
- Scenario selection
- Analysis of containment function for the selected scenarios
- Quantification of dose and risk for the selected scenarios

2015-06-02 Scenario methodology SR-Site 8

Safety functions, Safety Function Indicators and Safety Function Indicator Criteria

- Overall, main safety functions: Containment and retardation
- Defining additional safety functions for canister, buffer, deposition tunnel backfill and geosphere to facilitate detailed evaluation of safety related properties of repository components over time
- Using quantitative indicators to demonstrate extent to which a safety function is upheld and, when possible, criteria for when a function is lost
- Example
  - Safety function: The canister should withstand isostatic loads
  - Indicator: Isostatic load on canister
  - Criterion: Isostatic load < 45 MPa isostatic "design load"
- Breaching of a safety function indicator criterion does not mean that the repository is unsafe, but rather that more elaborate analyses and data are needed in order to evaluate safety.
- Safety function indicator criteria are not the same as design criteria.
  - Function indicator criteria should be fulfilled throughout the assessment period – design criteria relate to the initial state of the repository.

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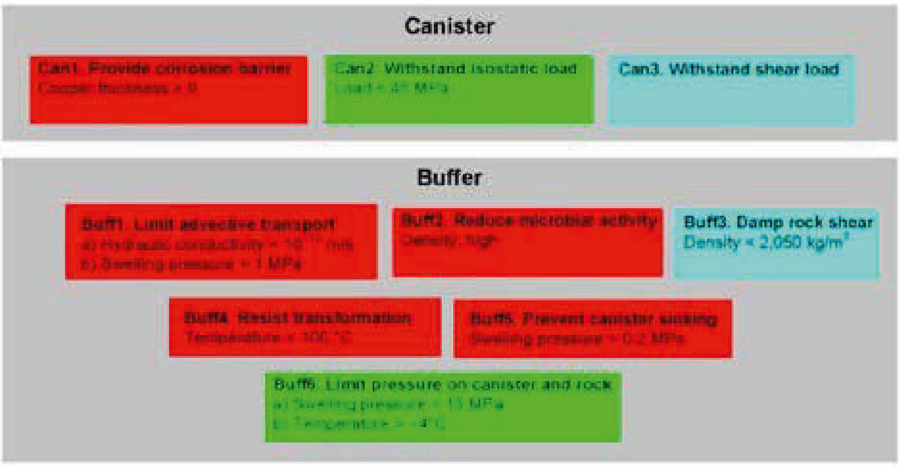
2015-06-02 Scenario methodology SR-Site 9

Safety functions related to containment; canister and buffer



2015-06-02 Scenario methodology SR-Site 10

Safety functions related to containment; deposition tunnel backfill and geosphere

Deposition tunnel backfill

BF1. Counteract buffer expansion
Density: high

Geosphere

R1. Provide chemically favourable conditions
a) Reducing conditions: Eh limited
b) Salinity: TDS limited
c) Ionic strength: $\Sigma q[M^{q+}] > 4$ mM charge equiv.
d) Concentrations of HS^-, H_2, CH_4, organic C, K^+ and Fe; limited
e) pH: pH < 11
f) Avoid chloride corrosion: pH > 4 or $[Cl^-] < 2M$

R2. Provide favourable hydrologic and transport conditions
a) Transport resistance in fractures, F: high
b) Equivalent flow rate in buffer/rock interface, Q_{eq}: low

R3. Provide mechanically stable conditions
a) GW pressure: limited
b) Shear movements at deposition holes < 0.05 m
c) Shear velocity at deposition holes < 1 m/s

R4. Provide favourable thermal conditions
a) Temperature > −4 °C (avoid buffer freezing)
b) Temperature > 0°C (validity of can shear analysis)

Safety functions: Use in SR-Site

- The safety functions are used
  - for focusing, at an early stage, on critical issues to be studied in the safety assessment,
  - for structuring the evaluation of safety in a comprehensive reference evolution, and,
  - **for the derivation of scenarios in the assessment**
    - **How could safety functions possibly be breached?**

SKB

Analysis of a reference evolution

- A reasonable development of the repository system is analysed in different time frames
  - Excavation/operation
  - First temperate period after closure
  - First full glacial cycle after closure
    - Assuming repetition of the long-term external conditions during the last 120,000 year cycle
  - Additional repetitions to cover 10^6 yr time frame
  - Safety functions evaluated at end of each time frame
- Extensive modelling of THMC aspects of the evolution
- Inclusion of all relevant FEPs related to containment from a preceding FEP screening
- Focused on the containment function of the repository
  - No consequence calculations
- The analysis demonstrates a reasonable, but not necessarily "the most likely", evolution of the system
- Forms the basis for a Main scenario

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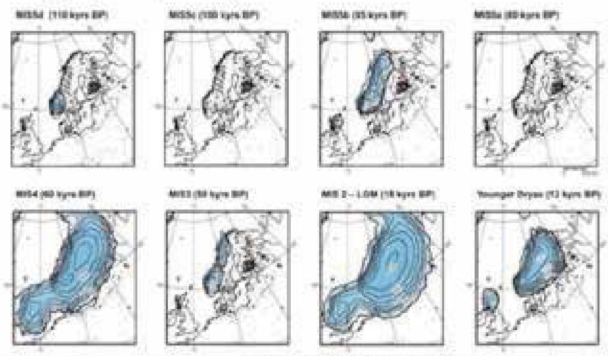
2015-06-02 Scenario methodology SR-Site 13

Reference evolution: Assumed repetition of latest 120,000 years glacial cycle

- Initial "transient" caused by excavation of host rock and construction and presence of repository. Transients can be anything from years to thousands of years
- Long-term evolution characterised by changes induced by the changing external conditions.
- Numerous analysis of (often coupled) thermal, hydraulic, mechanical and chemical phenomena done when studying the reference evolution – forms the basis for understanding repository development



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2015-06-02 Scenario methodology SR-Site 14

Selection of scenarios

- Some basic principles for selection in regulations
  - But implementer is free to develop method for selection
- Approach essentially based on safety functions
  - Main scenario = reference evolution
  - Additional scenarios assessing possibilities of failures of key safety functions:
    - Buffer transformation
    - Buffer freezing
    - Advective conditions in buffer
    - Canister failure due to shear load
    - Canister failure due to isostatic load
    - Canister failure due to corrosion
    - Combinations of the above scenarios
  - Residual scenarios
    - to illustrate barrier functions related to radionuclide transport – loss of barriers or barrier properties are postulated
    - related to future human actions, e.g.
      - Inadvertent boring through a canister from surface
      - Abandoned, incompletely sealed repository

2015-06-02 Scenario methodology SR-Site 15

Use of safety functions when selecting and analysing additional scenarios (1/2)

- Consider key safety function: How can it be lost?
- Example: The canister should withstand isostatic load
  - Define scenario "Canister failure due to isostatic load"
  - Look for all possible ways this could occur
    - Evaluate uncertainties not considered in the reference evolution/main scenario
    - Higher than reference buffer density leading to high buffer swelling pressures on canister?
    - Severe design flaws in canister insert, weakening the structure?
    - More massive ice sheets in future glaciations than assumed in reference evolution?
    - I.e. evaluate uncertainties related to all FEPs of relevance for this safety function
- Follow established template when assessing extent of failures

2015-06-02 Scenario methodology SR-Site 16

Use of safety functions when selecting and analysing additional scenarios (2/2)

- Bottom line: Could it happen?
- If yes:
  - estimate probability or assume pessimistically p=1
  - calculate consequences and include in risk summation
- If no:
  - consider as residual scenario not to be included in risk summation
  - In some cases: calculate consequences for illustrational purposes
- Not all safety functions used to generate a scenario
  - Lumping necessary since functions are connected and not fully independent

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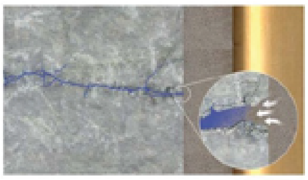
2015-06-02 Scenario methodology SR-Site 17

Two scenarios contributed to the calculated risk in SR-Site

1. The erosion/corrosion scenario
   - The buffer material is generally stable in Swedish groundwaters
   - For low ionic strength groundwaters, the buffer may erode
   - May occur after extended periods of temperate climate or for glacial conditions
   - A small fraction of deposition holes may then experience substantial erosion of the buffer, leading to enhanced canister corrosion by sulphide in the groundwater



2. The shear load scenario
   - Large earthquakes are very rare in Sweden today, but cannot be excluded in large fracture zones over a glacial cycle, particularly in the post-glacial phase
   - Such earthquakes may cause secondary shear movements in larger single fractures intersecting canister positions
   - Means are taken to avoid such positions, but there is a small likelihood of inadvertently accepting an unsuitable position

- Both scenarios yield, with pessimistic assumptions, small but non-negligible canister failure probabilities over one million years

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2015-06-02 Scenario methodology SR-Site 18

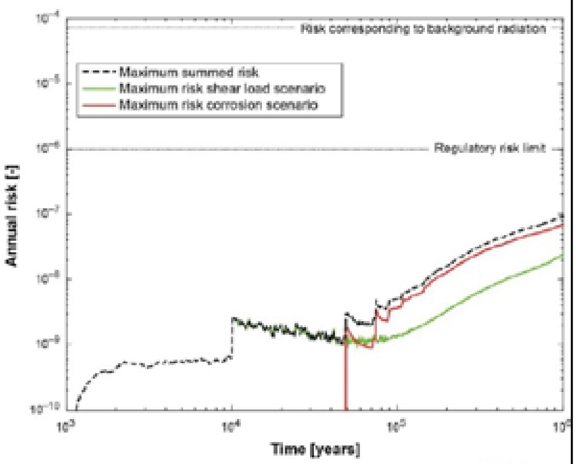
Quantification of dose and risk for the selected scenarios

- The extents of canister failures are propagated from the previous step
  - i.e. two risk contributing scenarios
- Within each scenario, a range of conditions related to retardation are explored in a number of calculation cases
  - Using methodology similar to that of exploring extent of canister failures
- Consequences also analysed for a range of “what if”-cases not included in the risk summation

2015-06-02 Scenario methodology SR-Site 19

Calculated risk for the two contributing scenarios

- **Central conclusion**
  A KBS-3 repository that fulfils long-term safety requirements can be built at the Forsmark site
  - The calculated risk for a final repository at Forsmark is below the regulatory risk criterion with a margin, even in a million year time perspective.



2015-06-02 Scenario methodology SR-Site 20

Response to questions to presenters (1/2)

✓*Objectives in PA/SA (in line with stage of the program)*

✓*Terminology/classification/definitions*

✓*Approach/methodology (in particular use of safety functions/use of FEPs, place of technology knowledge and scientific knowledge)*

- *Temporal sequences, handling of issues related to timescales*
  - Timescales as described above for reference evolution
  - Analyst also forced to address the relevance of the sequence in which different processes or events occur

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2015-06-02 Scenario methodology SR-Site 21

Response to questions to presenters (2/2)

- *From scenarios to safety models*
  - Most "models" occur in reference evolution that precedes scenario selection
  - Models for consequence calculations abstracted using "traditional" approaches
- *Evolution of scenario methods as safety cases are refined*
  - Scenario method changed essentially with the introduction of safety functions in SKB's case
  - Essentially the same scenarios as before, but much more straightforward to argue that we capture essential features and uncertainties in the system with safety function approach
- *Indicators*
  - Risk + several additional indicators, e.g. Finnish release constraints, natural fluxes, natural concentrations used in SR-Site (not really a scenario issue)
- *If experience used in other field/industry was applied in your scenario development, please describe in your ppt.*
  - Didn't use such input

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2015-06-02 Scenario methodology SR-Site 22

Summary; scenario methodology in SR-Site

- Define safety functions
- Analyse reference evolution; focus on containment potential – all containment related FEPs remaining after screening are included; i e essentially a bottom-up approach
- Select scenarios "top down" by basing the selection on key safety functions for containment
- Analyse selected scenarios "bottom up", i e revisit uncertainties not considered in the reference evolution; quantify extent of canister failures
- If canister failure mode cannot be ruled out: Quantify consequences
- Finally: Scenarios is one ingredient in the handling of uncertainties in the assessment
  - In the end the key question is: Have all uncertainties been identified and adequately addressed?

SKB

2015-06-02 Scenario methodology SR-Site 23

The SR-Site team is grateful for your attention!

- Kastriot Spahiu & Lena Zetterström Evins, fuel
- Christina Lilja, canister
- Patrik Sellin, buffer , backfill and sealing
- Ignasi Puigdomenech & Birgitta Kalinowski, geochemistry
- Raymond Munier, geology
- Jan-Olof Selroos, ground water flow and transport
- Tobias Lindborg, Ulrik Kautsky & Eva Andersson biosphere
- Jens-Ove Näslund, climate
- Fredrik Vahlund, input data, QA modeling
- Martin Löfgren (Niressa AB), input data
- Christina Greis & Maria Lindgren, radionuclide transport
- Kristina Skagius, assistant project manager, FEP data base, intrusion, QA
- Ann-Mari Nisula, administration, QA
- Johan Andersson, co-ordination EBS initial state, rock mechanics issues, BAT issues, design feedback, etc
- Allan Hedin, project manager, methodology, etc


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Geoff Freeze, Ross Kirkes, and Christi Leigh
Sandia National Laboratories
NEA IGSC Scenario Development Workshop
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ENERGY
NNSA

Overview of US Programs

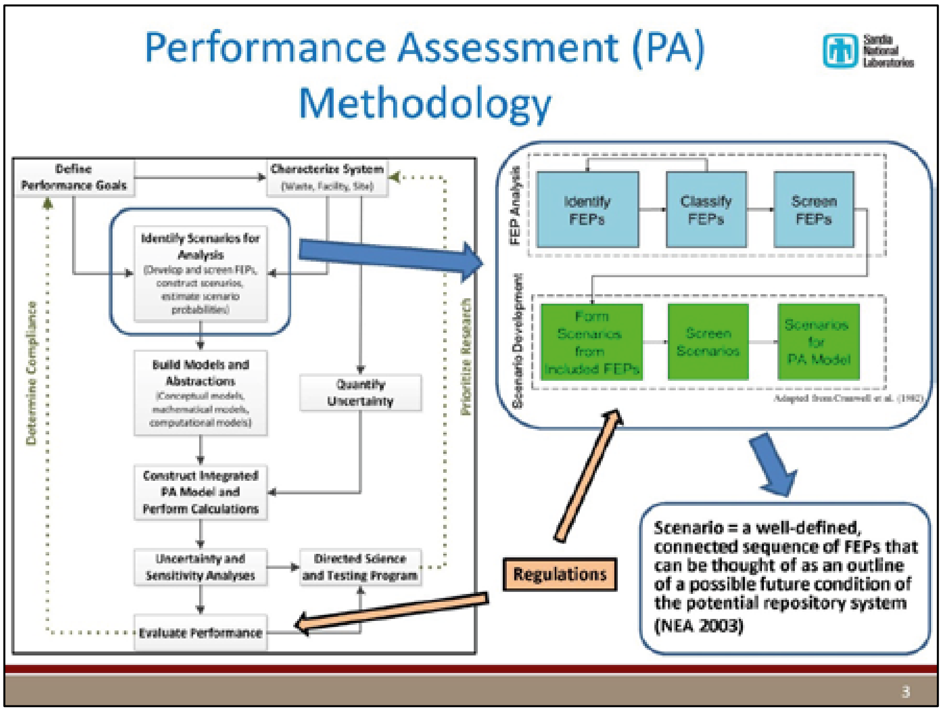
	SNF /HLW	SNF /HLW (Generic)	Transuranic (TRU)
Site	Yucca Mountain, Nevada (YM)	N/A	Waste Isolation Pilot Plant (WIPP)
Implementer	Office of Civilian Radioactive Waste Management (OCRWM)	Dept. of Energy, Office of Nuclear Energy (DOE-NE) Used Fuel Disposition Campaign (UFD)	Dept. of Energy, Office of Envir. Management (DOE-EM)
Regulator	Nuclear Regulatory Commission (NRC) 10 CFR 63 Envir. Protection Agency (EPA) 40 CFR 197	Nuclear Regulatory Commission (NRC) 10 CFR 60 ? Envir. Protection Agency (EPA) 40 CFR 191 ?	Envir. Protection Agency (EPA) 40 CFR 191, 40 CFR 194

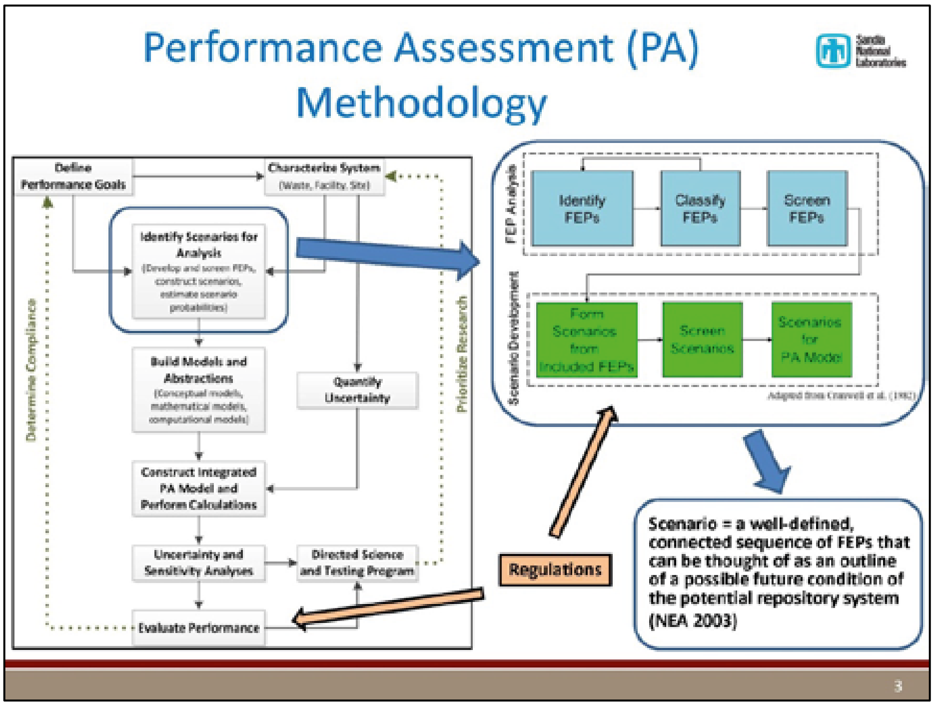
2

Overview of US Programs

	SNF /HLW	SNF /HLW (Generic)	Transuranic (TRU)
Site	Yucca Mountain, Nevada (YM)	N/A	Waste Isolation Pilot Plant (WIPP)
Implementer	Office of Civilian Radioactive Waste Management (OCRWM)	Dept. of Energy, Office of Nuclear Energy (DOE-NE) Used Fuel Disposition Campaign (UFD)	Dept. of Energy, Office of Envir. Management (DOE-EM)
Regulator	Nuclear Regulatory Commission (NRC) 10 CFR 63 Envir. Protection Agency (EPA) 40 CFR 197	Nuclear Regulatory Commission (NRC) 10 CFR 60 ? Envir. Protection Agency (EPA) 40 CFR 191 ?	Envir. Protection Agency (EPA) 40 CFR 191, 40 CFR 194

2


Performance Assessment (PA) Methodology
Define Performance Goals
Characterize System
(Waste, Facility, Site)
Identify Scenarios for Analysis
(Develop and screen FEPs, construct scenarios, estimate scenario probabilities)
Build Models and Abstractions
(Conceptual models, mathematical models, computational models)
Quantify Uncertainty
Construct Integrated PA Model and Perform Calculations
Uncertainty and Sensitivity Analyses
Directed Science and Testing Program
Evaluate Performance
Determine Compliance
Prioritize Research
FEP Analysis
Identify FEPs
Classify FEPs
Screen FEPs
Scenario Development
Form Scenarios from Included FEPs
Screen Scenarios
Scenarios for PA Model
Adapted from Cranwell et al. (1982)
Regulations
Scenario = a well-defined, connected sequence of FEPs that can be thought of as an outline of a possible future condition of the potential repository system (NEA 2003)
3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Scenarios for PA Model
Adapted from Cranwell et al. (1982)
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3

SNF/HLW Scenario Development

- Yucca Mountain (YM)
  - Repository in unsaturated tuff
  - YM FEPs
    - Required by 10 CFR 63 and 40 CFR 197
  - YM Scenario Classes / Modeling Cases
    - Scenario/event class = "all possible specific initiating events that are caused by a common natural process (e.g., the event class for seismicity includes the range of credible earthquakes)" [10 CFR 63.102(j)]
- Used Fuel Disposition Campaign (UFD)
  - Generic (non-site-specific) repositories in salt, clay, granite, deep borehole
  - Generic UFD FEPs
  - Undisturbed scenarios only
    - Disturbed scenarios are site specific

4

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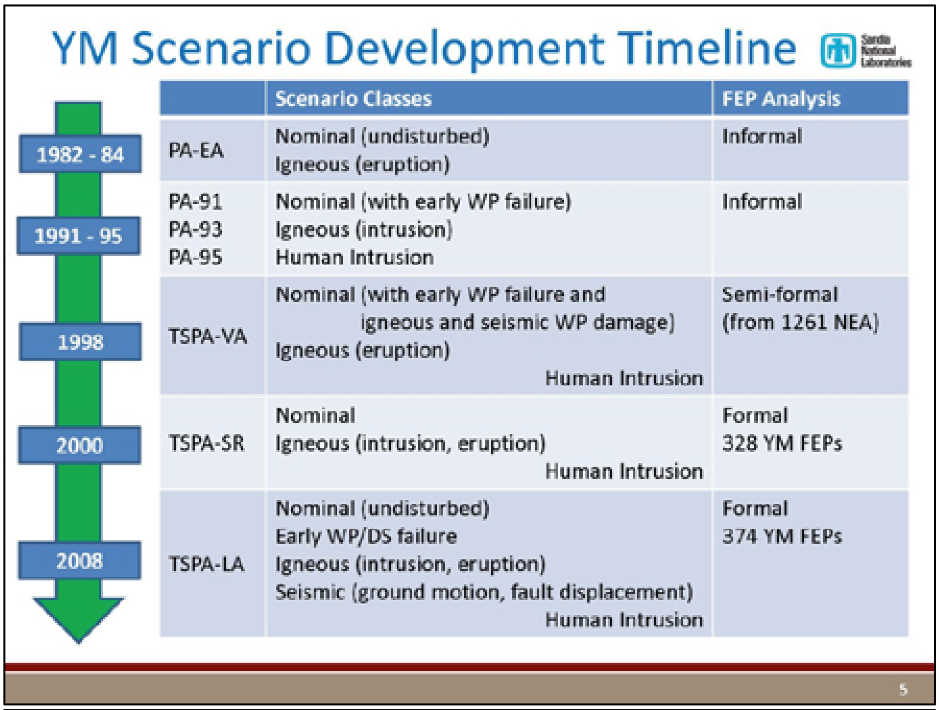
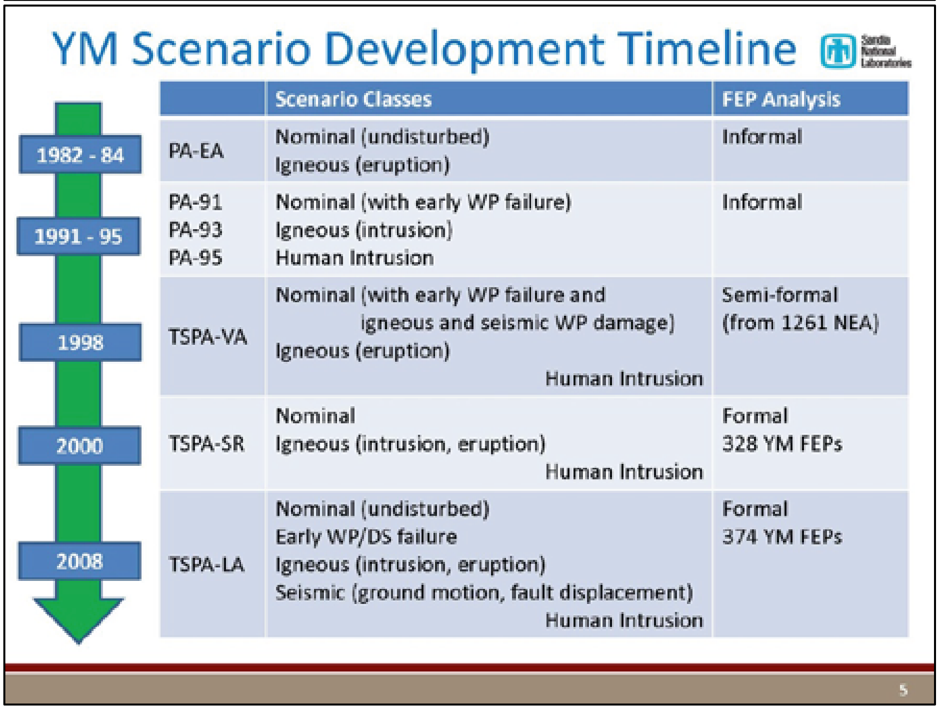
4


YM Scenario Development Timeline
Sandia National Laboratories
1982 - 84
1991 - 95
1998
2000
2008
Scenario Classes
FEP Analysis
PA-EA
Nominal (undisturbed)
Igneous (eruption)
Informal
PA-91
PA-93
PA-95
Nominal (with early WP failure)
Igneous (intrusion)
Human Intrusion
Informal
TSPA-VA
Nominal (with early WP failure and
igneous and seismic WP damage)
Igneous (eruption)
Human Intrusion
Semi-formal
(from 1261 NEA)
TSPA-SR
Nominal
Igneous (intrusion, eruption)
Human Intrusion
Formal
328 YM FEPs
TSPA-LA
Nominal (undisturbed)
Early WP/DS failure
Igneous (intrusion, eruption)
Seismic (ground motion, fault displacement)
Human Intrusion
Formal
374 YM FEPs
5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PA-EA
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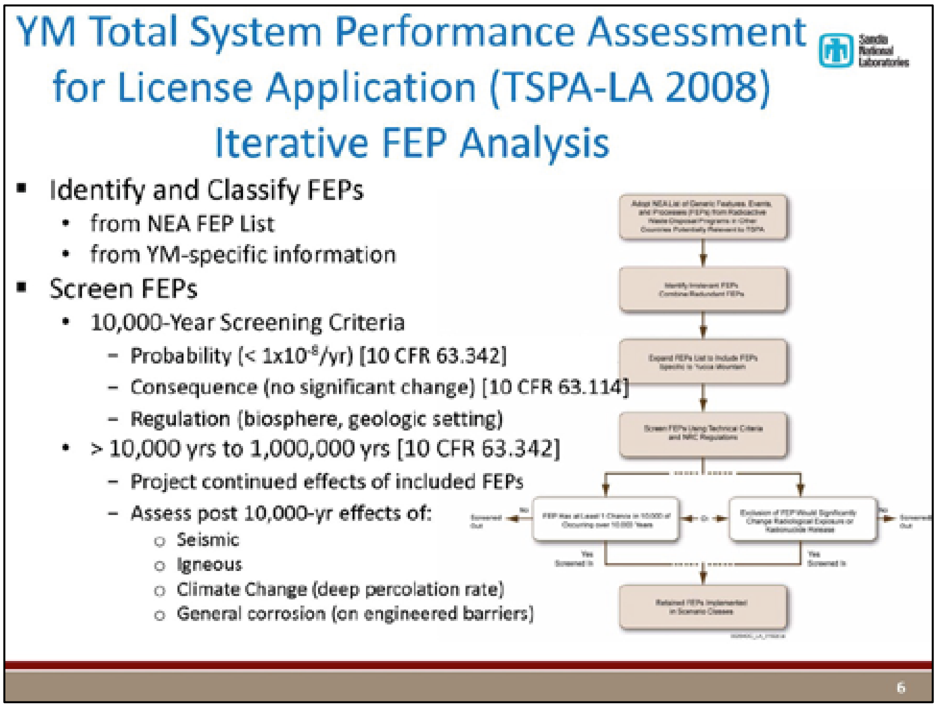
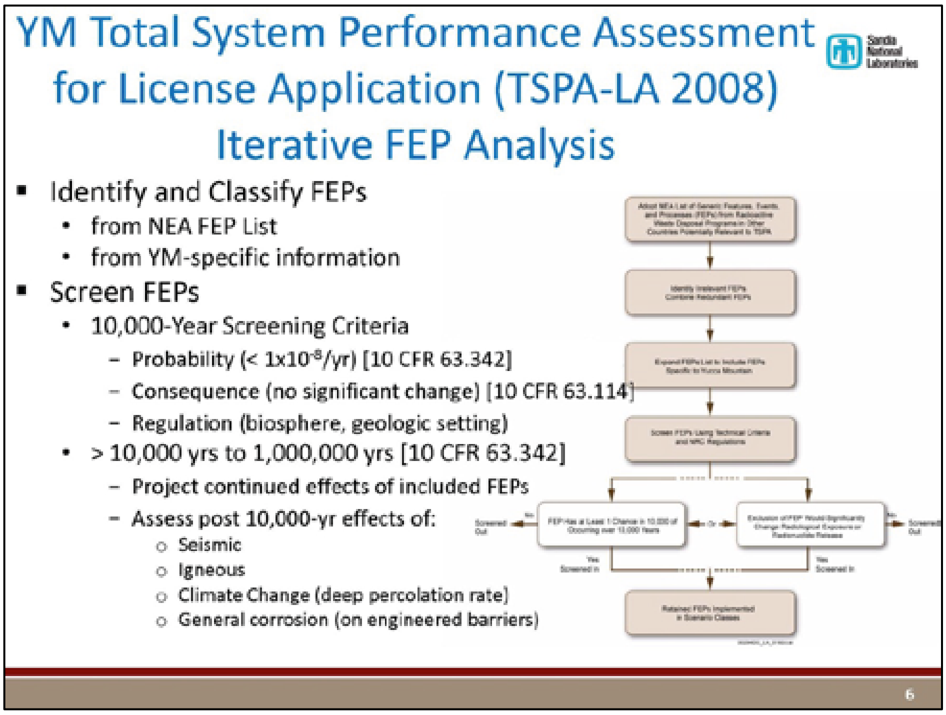

YM Total System Performance Assessment for License Application (TSPA-LA 2008) Iterative FEP Analysis
Identify and Classify FEPs
from NEA FEP List
from YM-specific information
Screen FEPs
10,000-Year Screening Criteria
Probability (< 1x10-8/yr) [10 CFR 63.342]
Consequence (no significant change) [10 CFR 63.114]
Regulation (biosphere, geologic setting)
> 10,000 yrs to 1,000,000 yrs [10 CFR 63.342]
Project continued effects of included FEPs
Assess post 10,000-yr effects of:
Seismic
Igneous
Climate Change (deep percolation rate)
General corrosion (on engineered barriers)
6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Seismic
Igneous
Climate Change (deep percolation rate)
General corrosion (on engineered barriers)
6

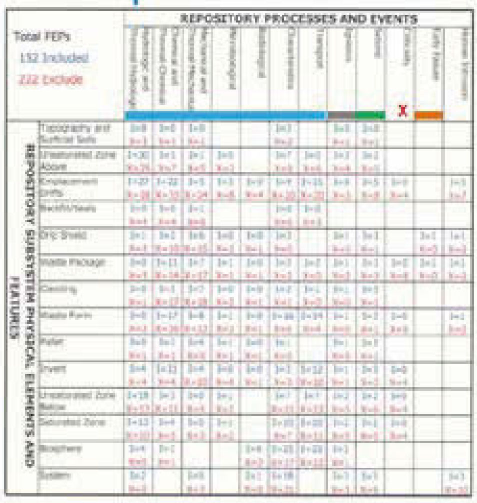
YM Total System Performance Assessment for License Application (TSPA-LA 2008) Iterative Scenario Development

- Form and Screen Scenario Classes

Included
- Nominal
- Igneous
- Seismic
- Early Failure

Included (Stylized Analysis)
- Human Intrusion
  - Specified drilling intrusion

Excluded
- Criticality



7

YM Total System Performance Assessment for License Application (TSPA-LA 2008) Iterative Scenario Development

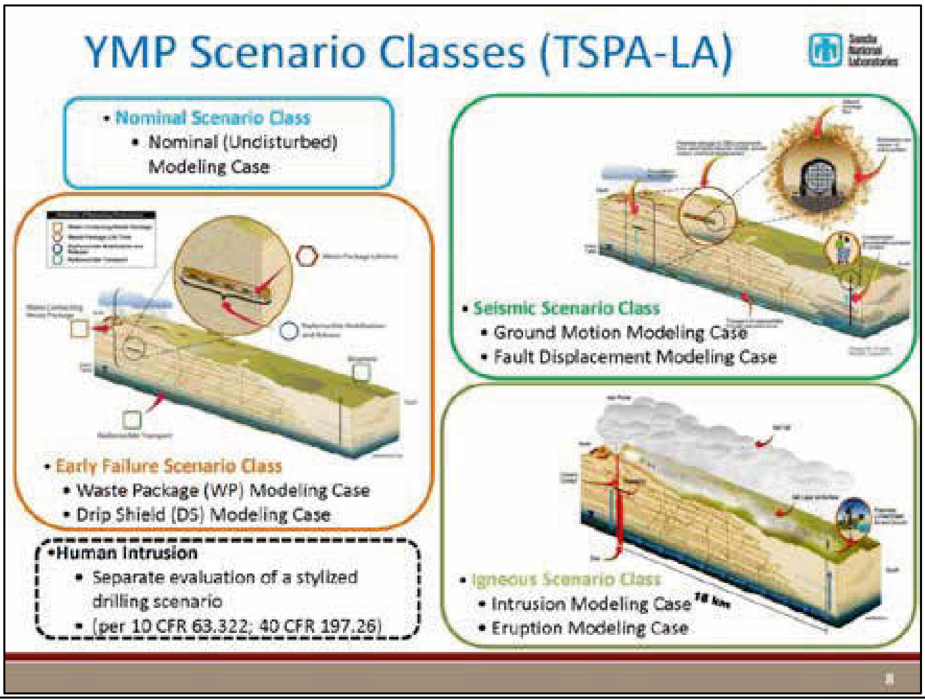
- Form and Screen Scenario Classes

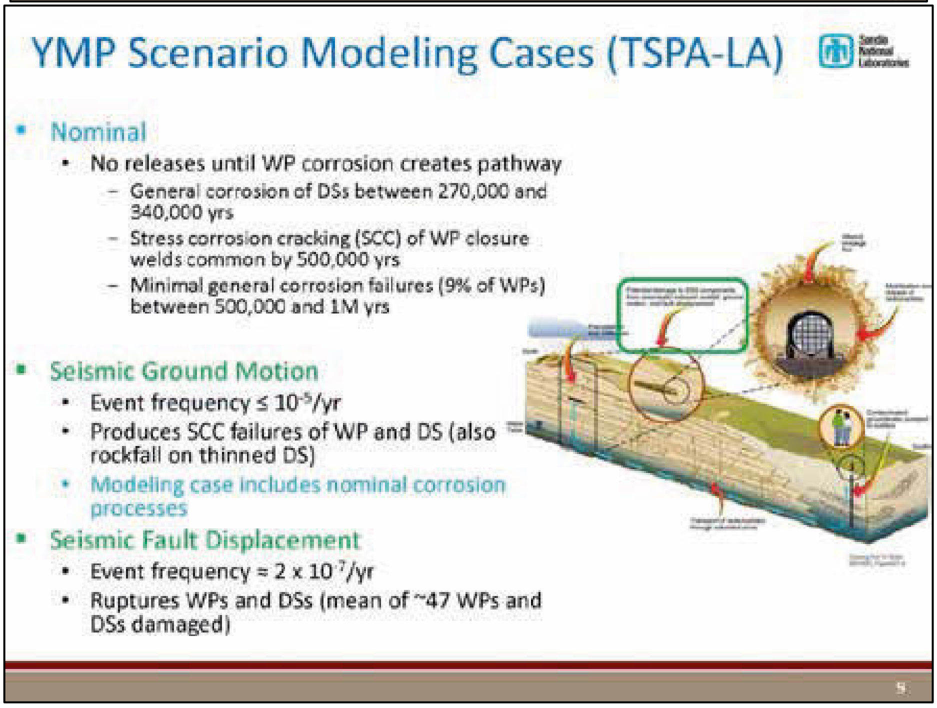
Included
- Nominal
- Igneous
- Seismic
- Early Failure

Included (Stylized Analysis)
- Human Intrusion
  - Specified drilling intrusion

Excluded
- Criticality

7

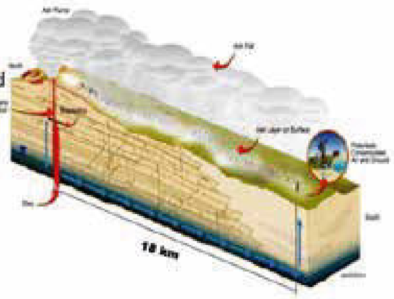

YMP Scenario Classes (TSPA-LA)
Sandia National Laboratories
• Nominal Scenario Class
• Nominal (Undisturbed) Modeling Case
• Early Failure Scenario Class
• Waste Package (WP) Modeling Case
• Drip Shield (DS) Modeling Case
•Human Intrusion
• Separate evaluation of a stylized drilling scenario
• (per 10 CFR 63.322; 40 CFR 197.26)
• Seismic Scenario Class
• Ground Motion Modeling Case
• Fault Displacement Modeling Case
• Igneous Scenario Class
• Intrusion Modeling Case
• Eruption Modeling Case
18 km
8


YMP Scenario Modeling Cases (TSPA-LA)
Sandia National Laboratories
• Nominal
• No releases until WP corrosion creates pathway
– General corrosion of DSs between 270,000 and 340,000 yrs
– Stress corrosion cracking (SCC) of WP closure welds common by 500,000 yrs
– Minimal general corrosion failures (9% of WPs) between 500,000 and 1M yrs
• Seismic Ground Motion
• Event frequency ≤ 10^{-5}/yr
• Produces SCC failures of WP and DS (also rockfall on thinned DS)
• Modeling case includes nominal corrosion processes
• Seismic Fault Displacement
• Event frequency ≈ 2 x 10^{-7}/yr
• Ruptures WPs and DSs (mean of ~47 WPs and DSs damaged)
9

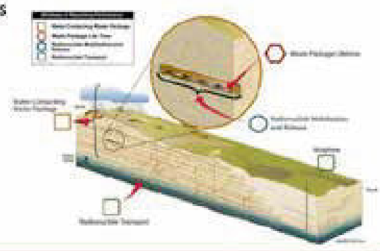
YMP Scenario Modeling Cases (TSPA-LA)

Sandia National Laboratories

- Igneous Intrusion
  - Mean event frequency = 1.7 x 10^{-8}/yr (uncertain)
  - All WPs and DSs damaged – no barrier to flow and transport
- Volcanic Eruption
  - Probability of waste intersection conditional on igneous event = 0.08
  - Mean number of WPs intersected = 3.8



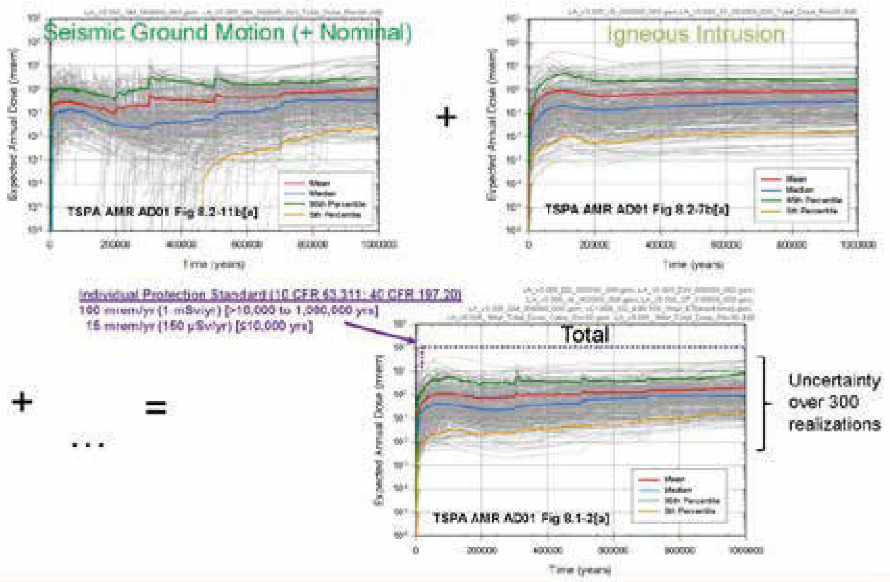
- Waste Package (WP) Early Failure
  - Probability of 1 or more early failure waste packages = 0.44
  - Expected number of early failure WPs (given early failures occur) = 2.5
- Drip Shield (DS) Early Failure
  - Probability of 1 or more early failure drip shields = 0.017
  - Expected number of early failure DSs (given early failures occur) = 1.1



10

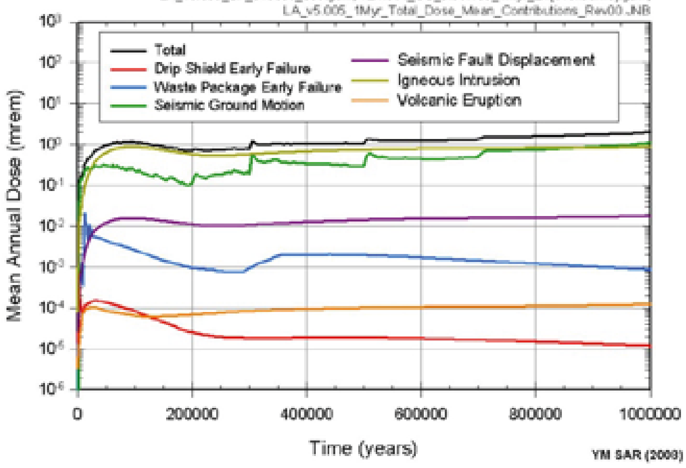
YMP Total Expected Dose (TSPA-LA)

Sandia National Laboratories



11

YMP Total Mean Dose (TSPA-LA) Contribution by Modeling Case



YM SAR (2008)

12

UFD FEP Analysis Process

- FEP Identification and Categorization
  - Started with YMP FEP list (374 FEPs) which was derived from NEA international FEP list (2000+ FEPs)
    - Considerable redundancy across the 2000+ FEPs
  - Consolidated and generalized YMP FEPs
  - Developed preliminary UFD FEP list (208 FEPs)
    - UFD FEPs categorized in accordance with NEA international FEP categories
    - Applicable to generic repositories in salt, clay, granite, (and deep borehole)

Small number of "lumped" FEPs capture all YMP and international FEPs (from several different programs and disposal concepts) at a broad level of detail

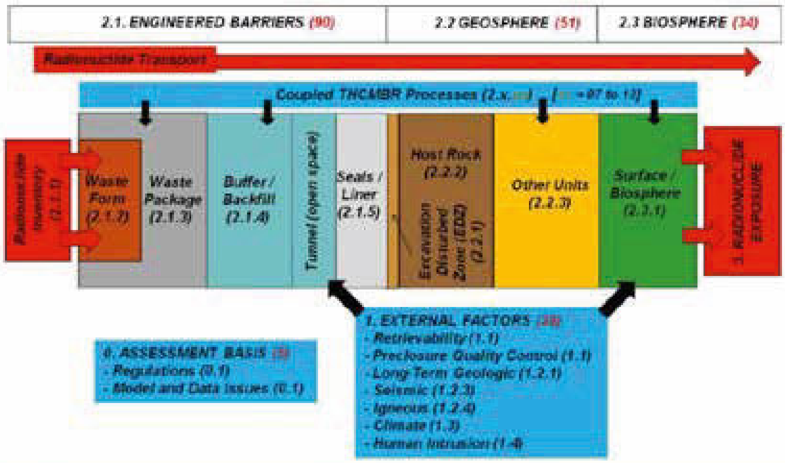
Additional detail provided by "Associated Processes"

UFD FEP Number	Phenomena	Associated Processes	Domain	Disposal Options
2.1.09.51	Advection of Dissolved Radionuclides in EBS - In Waste Form - In Waste Package - In Backfill - In Tunnel	- Flow pathways and velocity - Advective properties (porosity, tortuosity) - Dispersion - Saturation [see also Gas Phase Transport in 2.1.12.03]	EBS (TRAN)	

13

UFD FEP Analysis Process

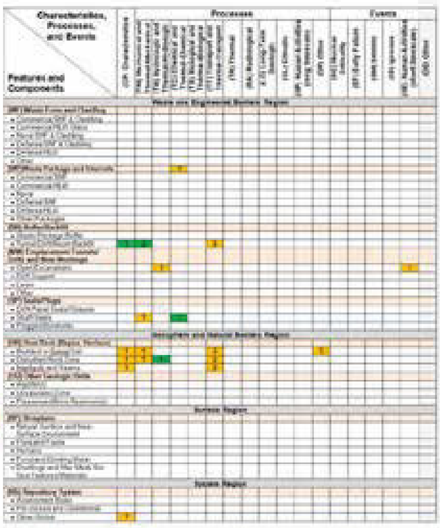
- 208 generic UFD FEPs



14

Current UFD FEP Analysis and Scenario Development

- FEP Screening and Scenario Formation
  - Preliminary FEP screening for generic repository concepts
  - Preliminary scenarios and High-Performance Computing (HPC)-based PA Models for generic repository concepts
    - Undisturbed scenarios only (disturbed scenarios are site specific)
- US/German Salt FEP Catalogue
  - Evaluating salt FEPs based on UFD, WIPP, and Gorleben FEP lists
  - Using FEP Matrix organizational structure



15

WIPP Scenario Development History

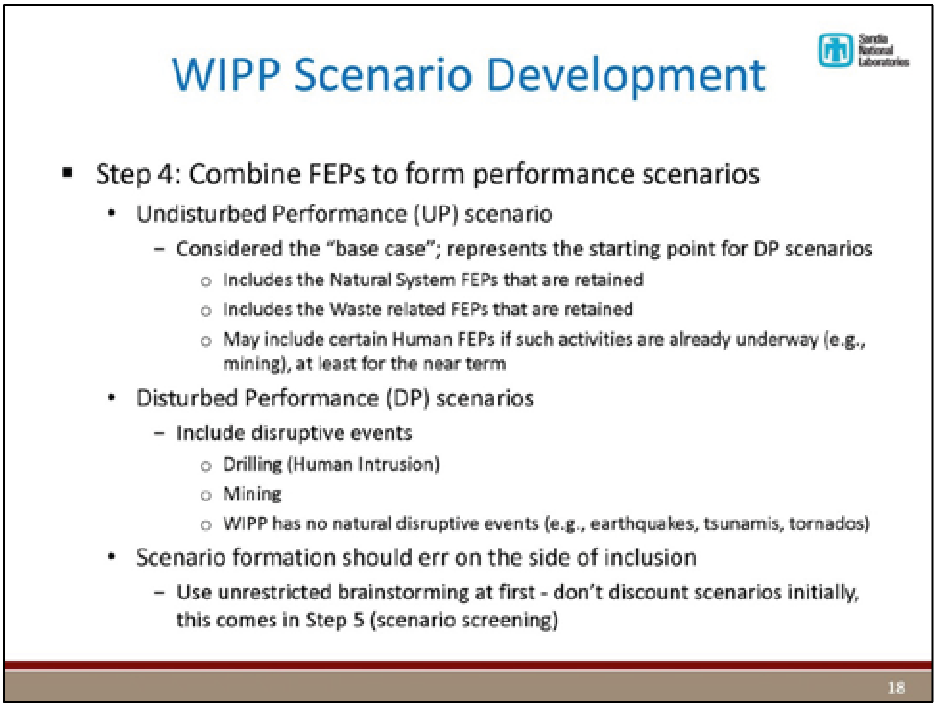
- Early scenario development process preceded regulatory guidance
- SAND80-1429 (Cranwell et al., 1982) documented a formal process for developing scenarios and the "Performance Assessment Methodology"
- Scenarios for WIPP PA "refined" from 1989 to 1996 based on input from scientific program, stakeholders, and regulator (EPA).

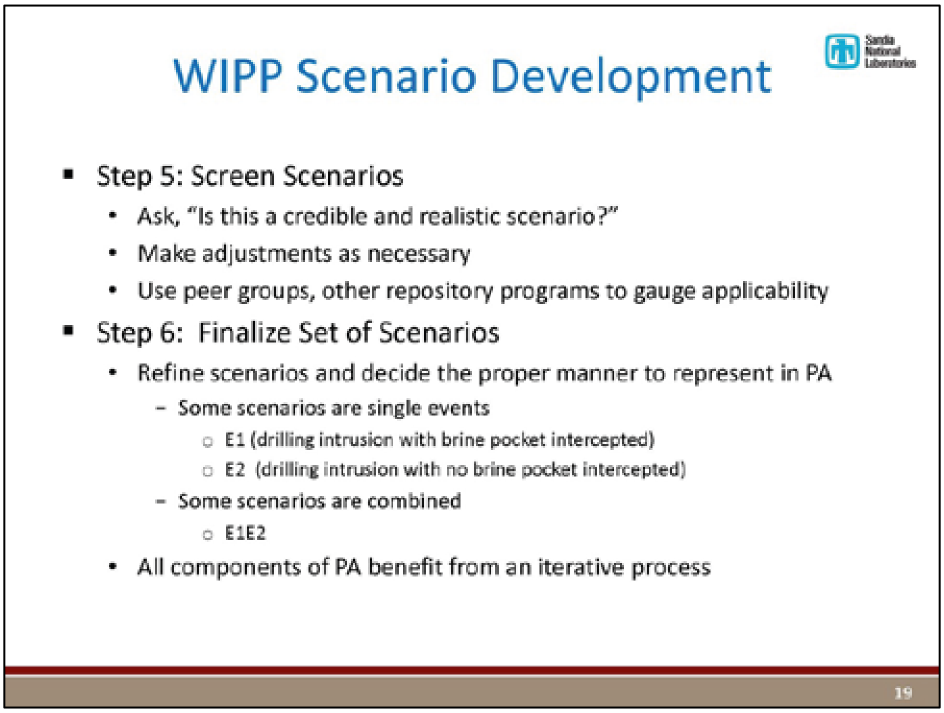
16

WIPP Scenario Development

- Step 1: Identify disruptive FEPs
  - Disruptive FEPs are defined as those FEPs that result in the creation of new pathways, or significant alteration of existing pathways, for fluid flow and, potentially, radionuclide transport within the disposal system.
- Step 2: Classify FEPs
  - Natural FEPs
  - Waste and Repository Induced FEPs
  - Human-induced FEPs
- Step 3: Screen FEPs
  - Retained FEPs are included in one or more performance scenarios
  - Excluded FEPs are screened out based on screening criteria

17


WIPP Scenario Development
Sandia National Laboratories
Step 4: Combine FEPs to form performance scenarios
Undisturbed Performance (UP) scenario
Considered the "base case"; represents the starting point for DP scenarios
Includes the Natural System FEPs that are retained
Includes the Waste related FEPs that are retained
May include certain Human FEPs if such activities are already underway (e.g., mining), at least for the near term
Disturbed Performance (DP) scenarios
Include disruptive events
Drilling (Human Intrusion)
Mining
WIPP has no natural disruptive events (e.g., earthquakes, tsunamis, tornados)
Scenario formation should err on the side of inclusion
Use unrestricted brainstorming at first - don't discount scenarios initially, this comes in Step 5 (scenario screening)
18

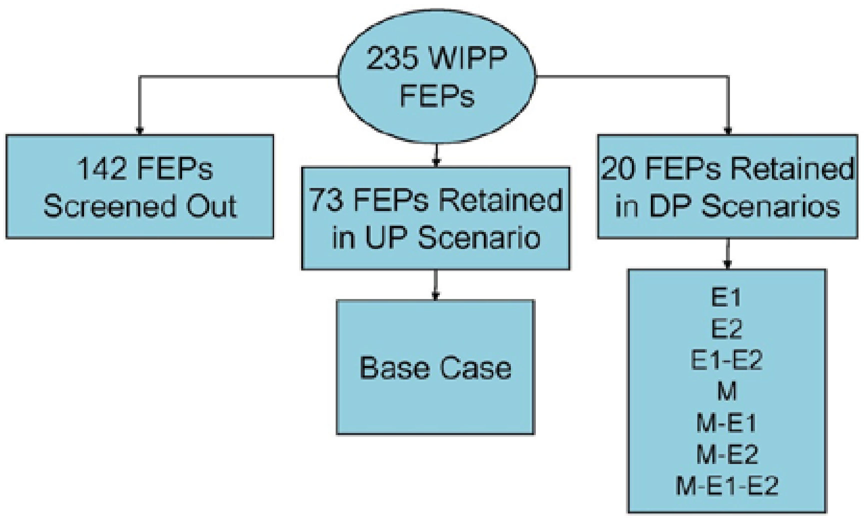

WIPP Scenario Development
Sandia National Laboratories
Step 5: Screen Scenarios
Ask, "Is this a credible and realistic scenario?"
Make adjustments as necessary
Use peer groups, other repository programs to gauge applicability
Step 6: Finalize Set of Scenarios
Refine scenarios and decide the proper manner to represent in PA
Some scenarios are single events
E1 (drilling intrusion with brine pocket intercepted)
E2 (drilling intrusion with no brine pocket intercepted)
Some scenarios are combined
E1E2
All components of PA benefit from an iterative process
19

WIPP Scenario Refinement

- Initial FEPs list development occurred before scenario development, but;
- Preliminary PAs were used to refine, and make FEPs list more appropriate and meaningful
- Evolving regulations and input from stakeholders and peers led to further refinement and development of appropriate scenarios
  - Regulatory-mandated human intrusion affected disturbed and undisturbed scenarios, specific screening criteria, etc.
  - Mining scenario not included until EPA required it with the promulgation of 40 CFR 194
  - Stakeholder concerns that a brine pocket intrusion (E1) could be followed by a non-brine pocket intrusion into the same panel thereby producing more harmful effects, hence E1E2 Scenario.

20

WIPP Scenarios



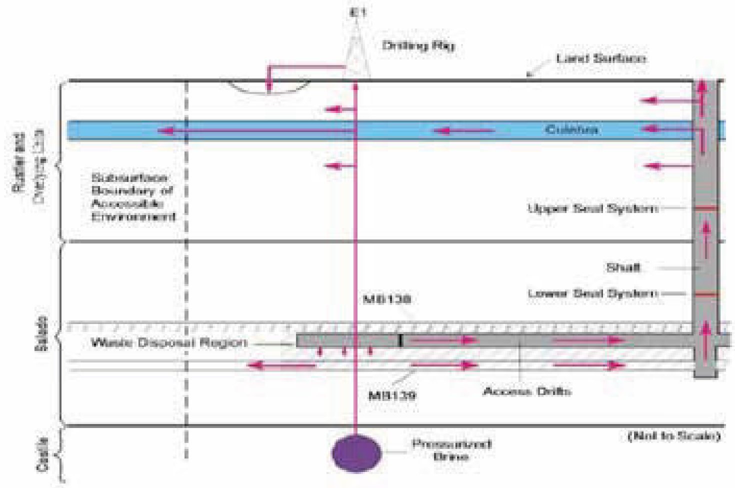
21

WIPP DP Scenarios

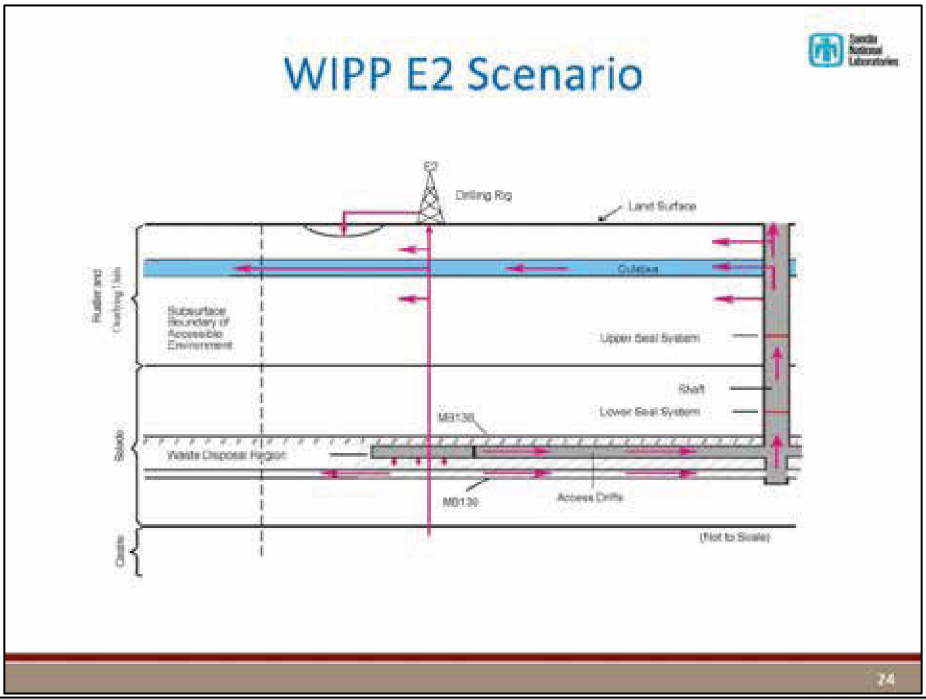
- E1 – drilling intrusion into pressurized brine pocket
- E2 – drilling intrusion that does not hit brine
- E1-E2 – drilling intrusion into the repository that was previously hit by an intrusion that intercepted a brine pocket
- M – mining
- M-E1 – mining in combination with E1
- M-E2 – mining in combination with E2
- M-E1-E2 – mining in combination with E1-E2

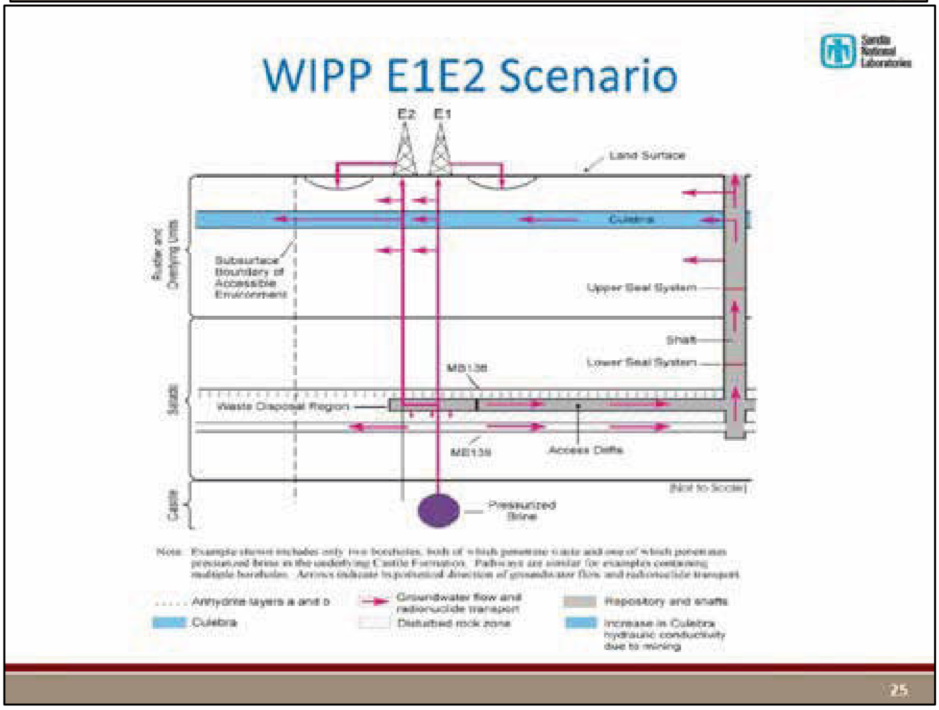
22

WIPP E1 Scenario



23


WIPP E2 Scenario
E2
Drilling Rig
Land Surface
Culebra
Subsurface Boundary of Accessible Environment
Upper Seal System
Shaft
Lower Seal System
MB138
Waste Disposal Region
MB139
Access Drifts
(Not to Scale)
24


WIPP E1E2 Scenario
E2
E1
Land Surface
Culebra
Subsurface Boundary of Accessible Environment
Upper Seal System
Shaft
Lower Seal System
MB138
Waste Disposal Region
MB139
Access Drifts
(Not to Scale)
Pressurized Brine
Anhydrite layers a and b
Groundwater flow and radionuclide transport
Repository and shafts
Culebra
Disturbed rock zone
Increase in Culebra hydraulic conductivity due to mining
25

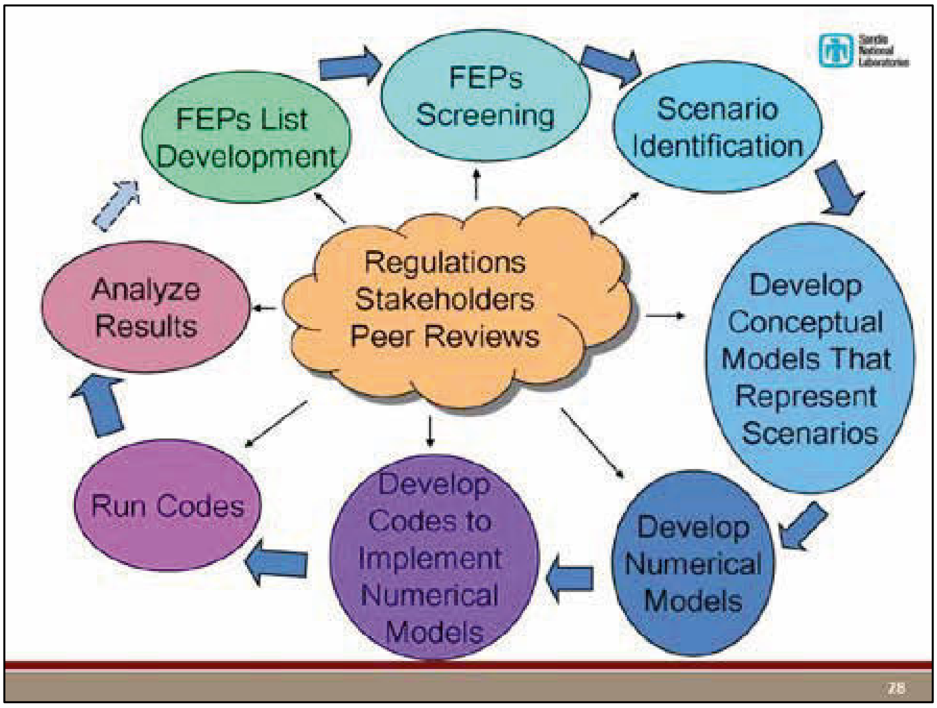
WIPP Mining Scenario

- Specified by 40 CFR 194.32 (b)
  - *Mining shall be assumed to occur with a one in 100 probability in each century of the regulatory time frame.*
- Supplemental Information, 40 CFR 194 Subpart C
  - *...DOE may use the location-specific values of hydraulic conductivity, established for the different spatial locations within the Culebra dolomite, and treat them as sampled parameters with each having a range of values varying between unchanged and increased 1,000-fold relative to the value that would exist in the absence of mining.*

26

Backup Slides

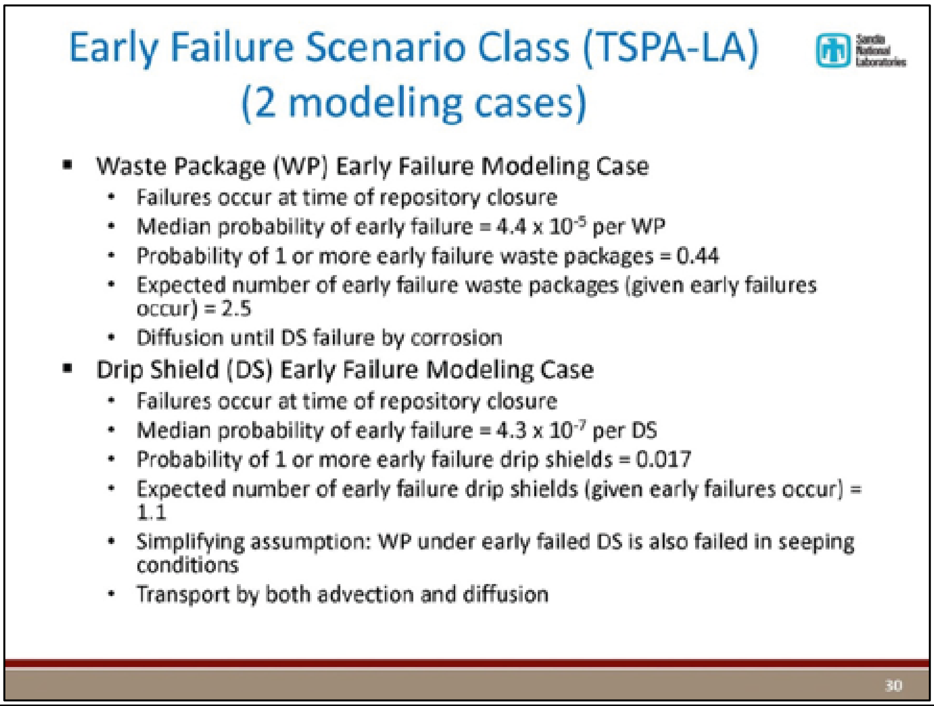
27

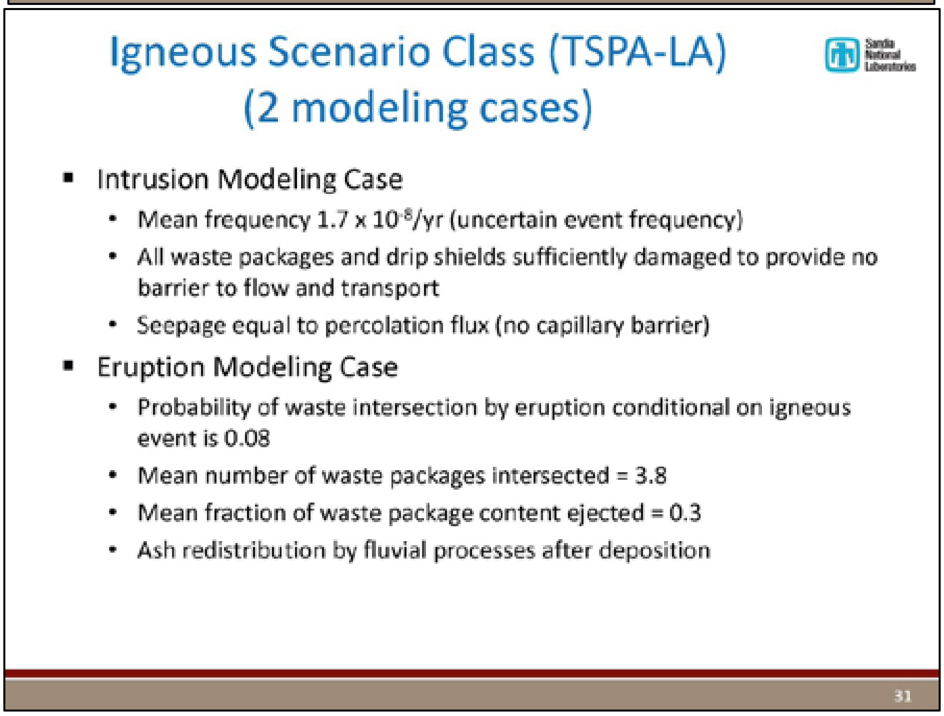


Nominal Scenario Class (TSPA-LA) (1 modeling case)

- Nominal Modeling Case
  - No releases until waste package (WP) corrosion creates pathway
  - WP failures rare before 100,000 years
  - WP failures due to stress corrosion cracking (SCC) of closure welds occur as general corrosion removes annealed layer
    - SCC common by 500,000 years
    - Releases through SCC occur by diffusion only
  - Drip shield (DS) failures due to general corrosion occur between 270,000 and 340,000 years
  - WP "patch" failures due to general corrosion rarely occur before 500,000 years
    - Mean of 9% of WPs show patch failures at 1 million years
    - Patch failures allow advective releases

29


Early Failure Scenario Class (TSPA-LA)
(2 modeling cases)
Sandia National Laboratories
Waste Package (WP) Early Failure Modeling Case
Failures occur at time of repository closure
Median probability of early failure = 4.4 x 10-5 per WP
Probability of 1 or more early failure waste packages = 0.44
Expected number of early failure waste packages (given early failures occur) = 2.5
Diffusion until DS failure by corrosion
Drip Shield (DS) Early Failure Modeling Case
Failures occur at time of repository closure
Median probability of early failure = 4.3 x 10-7 per DS
Probability of 1 or more early failure drip shields = 0.017
Expected number of early failure drip shields (given early failures occur) = 1.1
Simplifying assumption: WP under early failed DS is also failed in seeping conditions
Transport by both advection and diffusion
30

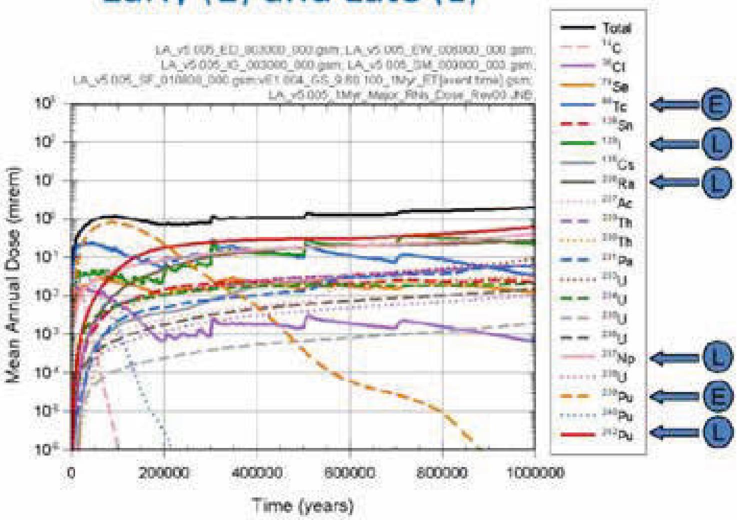

Igneous Scenario Class (TSPA-LA)
(2 modeling cases)
Sandia National Laboratories
Intrusion Modeling Case
Mean frequency 1.7 x 10-8/yr (uncertain event frequency)
All waste packages and drip shields sufficiently damaged to provide no barrier to flow and transport
Seepage equal to percolation flux (no capillary barrier)
Eruption Modeling Case
Probability of waste intersection by eruption conditional on igneous event is 0.08
Mean number of waste packages intersected = 3.8
Mean fraction of waste package content ejected = 0.3
Ash redistribution by fluvial processes after deposition
31

Seismic Scenario Class (TSPA-LA) (2 modeling cases)

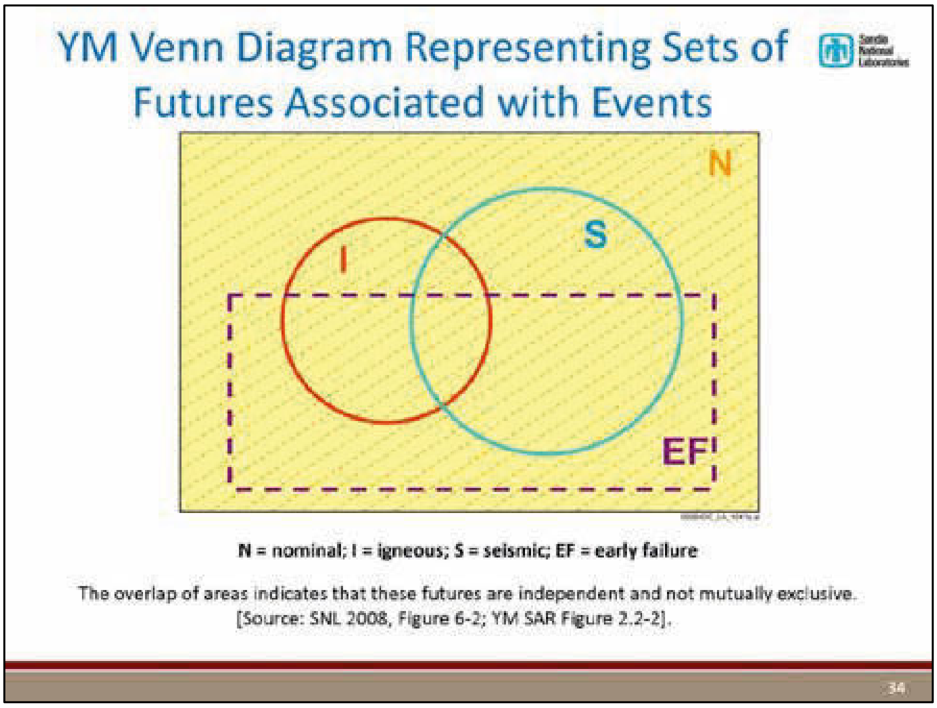
- Ground Motion (GM) Modeling Case
  - Ground motions result in SCC that allow diffusive releases
    - Frequency of events that damage codisposal (CDSP) packages: ~ 10-5 / yr
    - Frequency of events that damage transportation, aging, and disposal (TAD) packages for commercial spent nuclear fuel (CSNF): ~ 10-8 / yr
  - Cracked area accumulates with additional seismic events
  - Repeated damage may cause WP rupture (<10-8/ yr)
  - Drip shield thins by general corrosion and fails due to dynamic loading of accumulated rockfall
  - Nominal corrosion processes included for million-year analyses
    - Corrosion affects EBS response to ground motion
- Fault Displacement Modeling Case
  - Annual frequency approximately 2 x 10^{-7}/ yr
  - Fault displacements rupture waste packages and drip shields, allowing advection and diffusion
    - Size of rupture uncertain, 0 to cross-sectional area of WP
  - Mean of ~ 47 waste packages and drip shields damaged

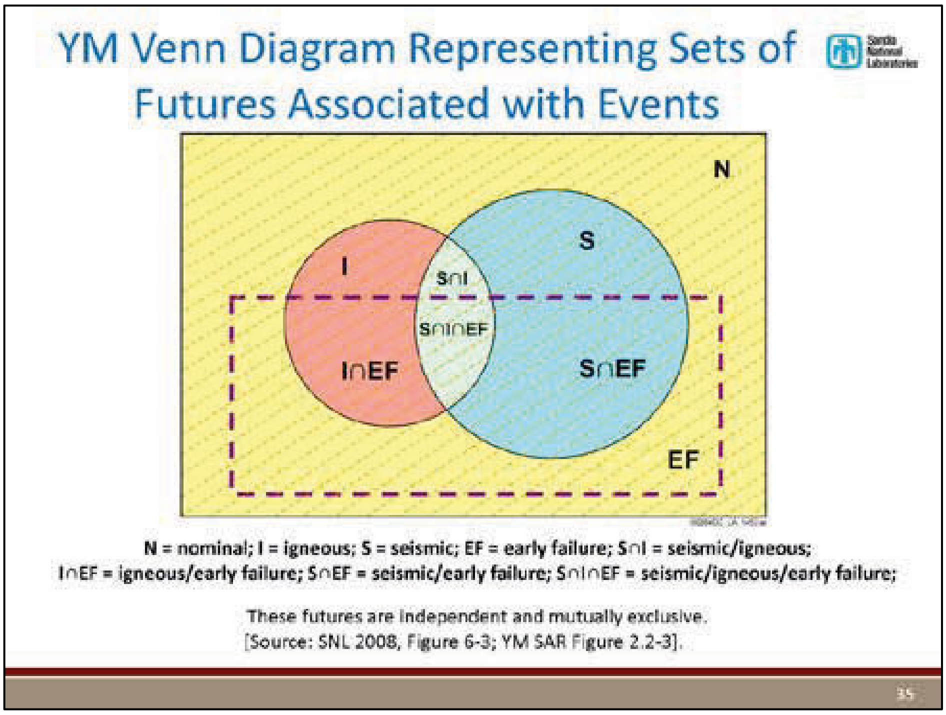
32

Radionuclides Important to Mean Dose Early (E) and Late (L)



33


YM Venn Diagram Representing Sets of Futures Associated with Events
Sandia National Laboratories
N
S
I
EF
N = nominal; I = igneous; S = seismic; EF = early failure
The overlap of areas indicates that these futures are independent and not mutually exclusive.
[Source: SNL 2008, Figure 6-2; YM SAR Figure 2.2-2].
34


YM Venn Diagram Representing Sets of Futures Associated with Events
Sandia National Laboratories
N
S
I
S∩I
S∩I∩EF
I∩EF
S∩EF
EF
N = nominal; I = igneous; S = seismic; EF = early failure; S∩I = seismic/igneous;
I∩EF = igneous/early failure; S∩EF = seismic/early failure; S∩I∩EF = seismic/igneous/early failure;
These futures are independent and mutually exclusive.
[Source: SNL 2008, Figure 6-3; YM SAR Figure 2.2-3].
35

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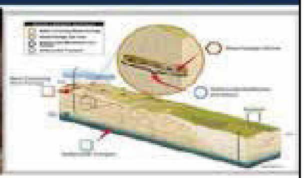

Scenario Comprehensiveness and Completeness in the U.S.

Geoff Freeze, Ross Kirkes, and Christi Leigh
Sandia National Laboratories

NEA IGSC Scenario Development Workshop
June 1-3, 2015
Paris, France

ENERGY NNSA

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Overview of US Programs

- US programs (YM and WIPP) have undergone FEP and scenario completeness reviews by regulators

	SNF /HLW	SNF /HLW (Generic)	Transuranic (TRU)
Site	Yucca Mountain, Nevada (YM)	N/A	Waste Isolation Pilot Plant (WIPP)
Implementer	Office of Civilian Radioactive Waste Management (OCRWM)	Dept. of Energy, Office of Nuclear Energy (DOE-NE) Used Fuel Disposition Campaign (UFD)	Dept. of Energy, Office of Envir. Management (DOE-EM)
Regulator	Nuclear Regulatory Commission (NRC) 10 CFR 63 Envir. Protection Agency (EPA) 40 CFR 197	Nuclear Regulatory Commission (NRC) 10 CFR 60 ? Envir. Protection Agency (EPA) 40 CFR 191 ?	Envir. Protection Agency (EPA) 40 CFR 191, 40 CFR 194

2

Scenario Comprehensiveness, Completeness, and Sufficiency

- It is impossible to demonstrate comprehensiveness or completeness, in the sense that it is impossible to exhaustively identify all possible FEPs and interactions within a complex and evolving system [NEA 1999]
- It is possible, however, to list a range of broadly-defined FEPs that might be relevant to consider in safety assessments [NEA 1999]
- "Reasonable expectation" [40 CFR 197.14 and 10 CFR 63.102(j)]
  - Requires less than absolute proof because absolute proof is impossible to attain … due to uncertainty of projecting long-term performance
  - Does not exclude important parameters … simply because they are difficult to precisely quantify to a high degree of confidence

3

Scenario Comprehensiveness, Completeness, and Sufficiency

- A variety of methods should be used to formulate an initial list [NEA 1992, p. 23]. Some common FEP identification methods include [NEA 1999, pp. 26-27]:
  - Development from existing lists of FEPs
  - Brainstorming
  - Top-down elicitation from a classification schemes
  - Hybrid procedures
- Confidence can be gained through a combination of [BSC 2005]:
  - Formal and systematic reviews (both top-down and bottom-up)
  - Audits and comparisons with other FEP lists
  - Application of more than one classification scheme

4

YM Scenario Development Timeline

Years		Scenario Classes	FEP Analysis
1982 - 84	PA-EA	Nominal (undisturbed) Igneous (eruption)	Informal
1991 - 95	PA-91 PA-93 PA-95	Nominal (with early WP failure) Igneous (intrusion) Human Intrusion	Informal
1998	TSPA-VA	Nominal (with early WP failure and igneous and seismic WP damage) Igneous (eruption) Human Intrusion	Semi-formal (from 1261 NEA)
2000	TSPA-SR	Nominal Igneous (intrusion, eruption) Human Intrusion	Formal 328 YM FEPs
2008	TSPA-LA	Nominal (undisturbed) Early WP/DS failure Igneous (intrusion, eruption) Seismic (ground motion, fault displace.) Human Intrusion	Formal 374 YM FEPs

Formal, iterative FEP and Scenario development

5

YM TSPA-LA FEP
Regulator (NRC) Guidance (NUREG-1804)

- Acceptance Criterion 1 - Identification of a List of FEPs is Adequate
  - Review Method 1 (Identification of a List of FEPs)
    - Verify that the [YM FEP List] includes all features, events, and processes having a potential to influence repository performance.
    - Use knowledge gained reviewing the Yucca Mountain site and regional [data] to assess the completeness of the features, events, and processes list.
    - The staff should use, as appropriate, available generic lists of features, events, and processes (e.g., NEA, 1997), as a reference to determine the completeness of the [YM FEP List].
- Acceptance Criterion 3 - Identification of Scenario Classes is Adequate
  - Review Method 3 (Formation of Scenario Classes)
    - Determine whether the resulting scenario classes are mutually exclusive and include all events that have not been screened from the performance assessment.
    - The comprehensive features, events, and processes list includes, but is not limited to, potentially disruptive events ...

6

YM TSPA-LA FEP Comprehensiveness and Completeness

- Comprehensiveness of the YM FEP List derives initially from its development from:
  - The NEA International FEP Database, V1.0
    - the best available compilation of FEPs from multiple programs.
  - YM documents identified issues unique to the YMP design and setting (unsaturated fractured tuff)
    - top-down event tree logic diagrams for certain events and processes
    - site characterization; igneous, seismic, and tectonic activity, climate change, and criticality reports
  - Brainstorming by subject matter experts during technical FEP identification workshops

7

YM TSPA-LA FEP Comprehensiveness and Completeness

- Comprehensiveness and completeness of the YM FEP list was enhanced by:
  - Application of multiple FEP classification schemes
    - NEA-basis, TSPA-SR scheme, re-categorized TSPA-LA scheme
  - Audit against the updated NEA International FEP Database V2.0
    - No new FEPs were identified
  - Audit performed against an alternate independent top-down generated YMP FEP list (BSC 2005, Appendix B)
    - No new FEPs were identified
  - Use of the FEP matrix
    - Mapping of FEPs to matrix boxes (intersections of the features axis and the process/event axis) provides a top-down "check" against the bottom-up FEP identification
  - Potential FEP Log
    - Formal tracking and resolution of "issues" (i.e., potential new FEPs)

8

YM TSPA-LA FEP Comprehensiveness and Completeness

- Confidence in the completeness of the YM FEP list was demonstrated through continual reviews by subject matter experts, licensing and performance assessment team members, external reviewers, and others
  - As the FEP list evolved, fewer new potential FEPs were identified during each successive review cycle.
  - Over time, the nature of those potential FEPs also changed, so that they were predominantly variants or finer details of existing FEPs, rather than new unique issues.

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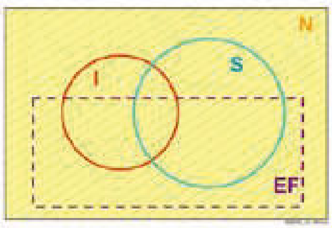
YM TSPA-LA Scenario Comprehensiveness and Completeness

- 4 Scenario Classes (nominal, seismic, igneous, early failure)
  - Derived from scenarios from past TSPA analyses
  - All included FEPs captured in at least one scenario class
  - Independent, but not mutually exclusive
- Human Intrusion evaluated separately



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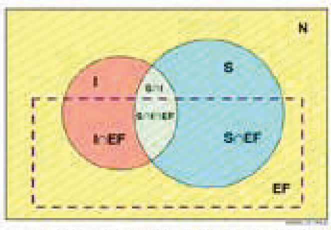

N = nominal; I = igneous; S = seismic; EF = early failure

The overlap of areas indicates that these futures are independent and not mutually exc
(Source: SNL 2008, Figure 6-2; YM SAR Figure 2.2-2)

N = nominal; I = igneous; S = seismic; EF = early failure; S∩I = seismic/igneous; I∩EF = igneous/early failure; S∩EF = seismic/early failure; S∩I∩EF = seismic/igneous/early failure;
These futures are independent and mutually exclusive.
(Source: SNL 2008, Figure 6-3; YM SAR Figure 2.2-3)

10

YM TSPA-LA Scenario Comprehensiveness and Completeness

- Nominal Scenario Class
  - Contains FEPs that are expected to occur (probability near 1.0, but with uncertain consequences)
  - Represents the most plausible evolution of the repository system
- Seismic, Igneous, and Early Failure Scenario Classes
  - Contain combinations of FEPs that have low probability of occurrence (but greater than screening criteria), but might produce potentially adverse conditions
  - Contain many of the nominal FEPs
  - Represent low-probability permutations of the expected evolution of the repository system

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UFD FEP Comprehensiveness

- UFD FEPs are mapped to the FEP Matrix organizational structure
  - Comprehensiveness indicated by presence/absence of "empty" matrix cells
  - Completeness cannot yet be demonstrated
    - Need site-specific FEP identification and screening
- UFD Scenarios not yet developed
  - Undisturbed only to date

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WIPP FEP and Scenario Chronology

- 1978-1988 (Site Characterization)
  - No systematic FEP approach
  - Scenarios developed based on current scientific understanding and level of concern
  - Major scenarios were identified during this period
    - Undisturbed Performance
    - Human Intrusion
- 1989-1992 (Preliminary Performance Assessment)
  - NRC FEP approach using short list of 23 FEPs, based on past literature
  - Major scenarios refined, no new scenarios developed
- 1993-1998 (Certification)
  - Full FEP implementation

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WIPP FEP Comprehensiveness and Completeness

- Lessons learned from early (up to 1992) WIPP FEP work:
  - FEPs were sufficient to identify major scenarios and focus preliminary PA modeling
  - Work was not sufficient to demonstrate comprehensiveness
    - Many FEPs weren't discussed
    - No systematic documentation
    - Some screening arguments lacked sufficient rigor to satisfy technical reviewers (exclusion by assertion)
  - Some important processes were overlooked in experimentation and modeling
    - E.g., colloidal transport
- Conclusion – Regulatory process (certification) would need more structured FEP analysis

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WIPP FEP Comprehensiveness and Completeness

- Confidence in the comprehensiveness and appropriateness of the 1996 WIPP FEP list was supported by:
  - Development from other FEP lists
    - Nine lists from different countries used as a starting point
      - Swedish SKI was single most important source
    - Participation in the International FEP Database
  - List extended through review of WIPP project literature
  - Classification into 3 main categories
    - Natural, Waste and Repository-Induced, and Human-Initiated
  - Documented simplification of list by aggregation and elimination of redundancy
  - Formal reviews
    - Formal presentations and reviews with stakeholders and regulator
    - Formal documented reviews within the project
    - Cross-mapping requested by regulator

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WIPP Scenario Comprehensiveness and Completeness

- Preliminary PAs (1989-92) were used develop major scenarios

- PAs leading to Certification (1993-95) used refined scenarios based on full FEP implementation
  - Evolving regulations and input from stakeholders and peers led to refinement and development of appropriate scenarios
    - Undisturbed Performance (UP)
    - Disturbed Performance (DP)
      - Human (Drilling) Intrusion (E1, E2)
      - Mining (M)

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Backup Slides

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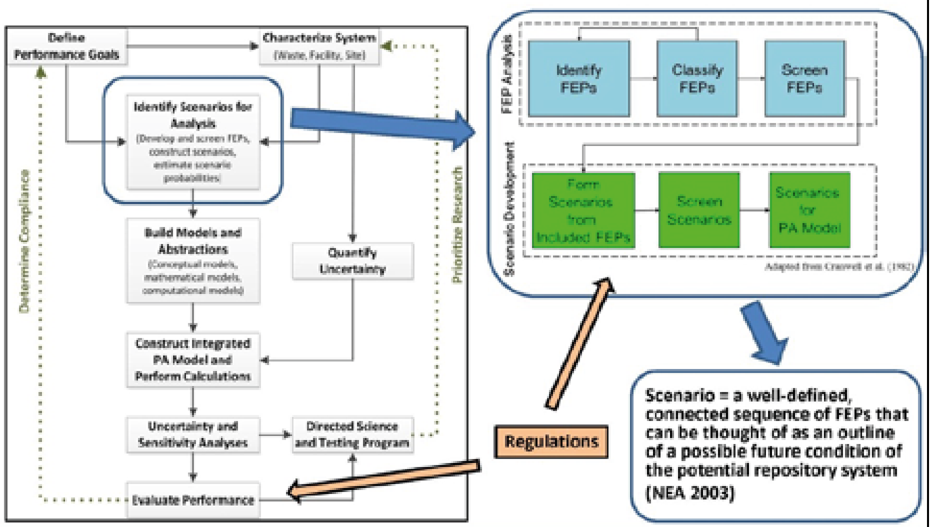
PA Methodology



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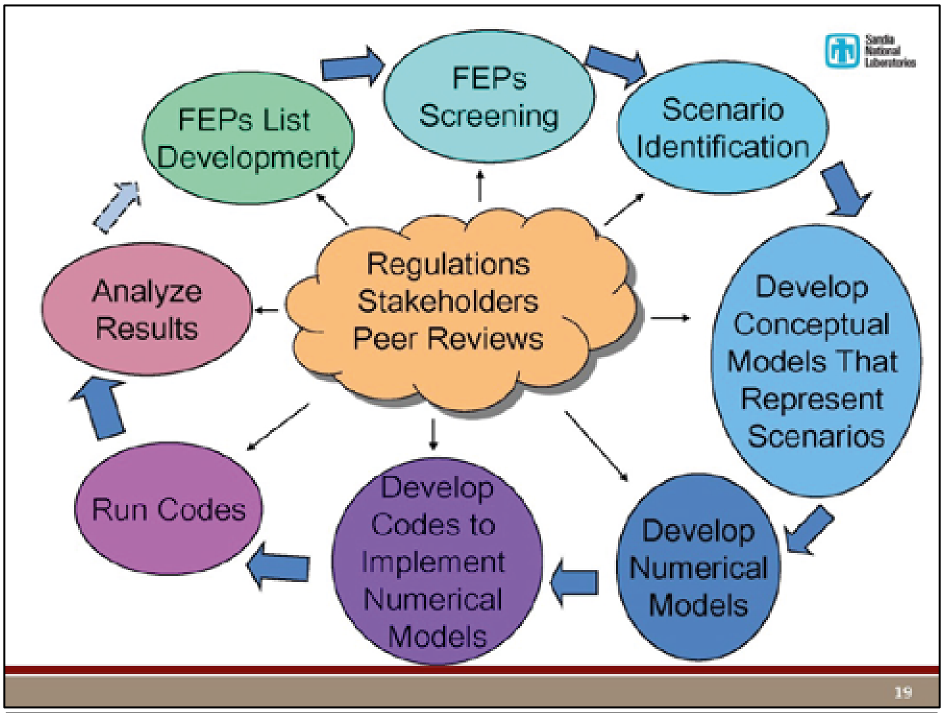
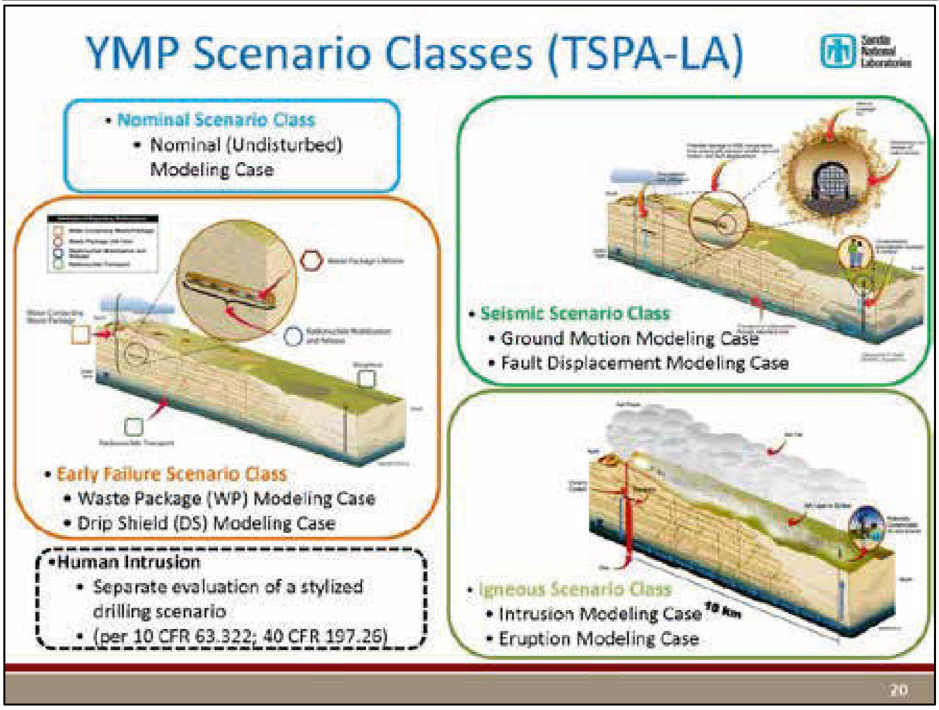

FEPs List Development
FEPs Screening
Scenario Identification
Develop Conceptual Models That Represent Scenarios
Develop Numerical Models
Develop Codes to Implement Numerical Models
Run Codes
Analyze Results
Regulations Stakeholders Peer Reviews
19


YMP Scenario Classes (TSPA-LA)
• Nominal Scenario Class
• Nominal (Undisturbed) Modeling Case
• Early Failure Scenario Class
• Waste Package (WP) Modeling Case
• Drip Shield (DS) Modeling Case
•Human Intrusion
• Separate evaluation of a stylized drilling scenario
• (per 10 CFR 63.322; 40 CFR 197.26)
• Seismic Scenario Class
• Ground Motion Modeling Case
• Fault Displacement Modeling Case
• Igneous Scenario Class
• Intrusion Modeling Case
• Eruption Modeling Case
19 km
20

YM FEP Matrix

- Process or event acting upon or within a feature or features
- Similar to interaction matrices and influence diagrams
  - SKB Rock Engineering System (RES)
  - UK Nirex Master Directed Diagram (MDD)

Total FEPs 152 Included 222 Exclude	REPOSITORY PROCESSES AND EVENTS											
REPOSITORY SUBSYSTEM PHYSICAL ELEMENTS AND FEATURES	Hydrologic and Thermal Hydrologic	Chemical and Thermal Chemical	Mechanical and Thermal Mechanical	Microbiological	Radiological	Characteristics	Transport	Igneous	Seismic	Criticality	Early Failure	Human Intrusion
Topography and Surficial Soils	I=8 X=3	I=0 X=1	I=0 X=1			I=2 X=1		I=0 X=1	I=0 X=1			
Unsaturated Zone Above	I=35 X=29	I=2 X=7	I=1 X=5	I=0 X=2		I=7 X=9	I=0 X=6	I=2 X=4	I=2 X=5			
Emplacement Drifts	I=27 X=18	I=22 X=33	I=3 X=24	I=3 X=8	I=0 X=4	I=9 X=20	I=11 X=20	I=6 X=5	I=5 X=8	I=0 X=4		I=3 X=7
Backfill/Seals	I=0 X=6	I=0 X=9	I=1 X=0			I=0 X=6	I=0 X=3					
Drip Shield	I=1 X=3	I=2 X=10	I=6 X=15	I=0 X=2	I=0 X=1	I=7 X=0		I=1 X=0	I=3 X=1		I=1 X=0	I=1 X=0
Waste Package	I=0 X=2	I=11 X=14	I=7 X=17	I=1 X=1	I=0 X=1	I=3 X=1	I=2 X=0	I=1 X=2	I=2 X=3	I=0 X=8	I=1 X=0	I=1 X=0
Cladding	I=0 X=1	I=3 X=17	I=7 X=18	I=0 X=2	I=0 X=1	I=2 X=1	I=1 X=0	I=1 X=0	I=3 X=1			
Waste Form	I=0 X=2	I=17 X=16	I=8 X=13	I=1 X=3	I=0 X=1	I=15 X=4	I=14 X=4	I=1 X=0	I=3 X=1	I=0 X=6		I=1 X=0
Pallet	I=0 X=1	I=2 X=3	I=4 X=6	I=1 X=1	I=0 X=1	I=1 X=0		I=1 X=0	I=3 X=1			
Invert	I=4 X=4	I=11 X=4	I=4 X=10	I=0 X=4	I=0 X=1	I=3 X=1	I=12 X=10	I=1 X=1	I=3 X=2	I=0 X=4		
Unsaturated Zone Below	I=18 X=11	I=3 X=11	I=0 X=4	I=1 X=2		I=7 X=11	I=7 X=12	I=2 X=5	I=2 X=6	I=0 X=4		
Saturated Zone	I=13 X=13	I=4 X=5	I=0 X=3	I=1 X=2		I=12 X=7	I=10 X=11	I=2 X=5	I=2 X=5	I=0 X=4		
Biosphere	I=4 X=0	I=1 X=1			I=6 X=3	I=23 X=17	I=23 X=12	I=3 X=1				
System	I=2 X=0		I=0 X=1		I=1 X=0	I=13 X=30		I=3 X=3	I=3 X=0			I=3 X=10

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WIPP FEP Comprehensiveness and Completeness

- How do you build a comprehensive FEP list?
  - Review FEP lists from other programs (e.g., NEA FEP Database)
  - Review WIPP project literature
    - FEP identification begins with site characterization
  - Include everything initially
    - Wait until the next step to begin screening
  - Document consideration of every issue that was raised
  - Use FEP Classification to facilitate review for comprehensiveness
  - Use FEP Screening to further demonstrate comprehensiveness and completeness

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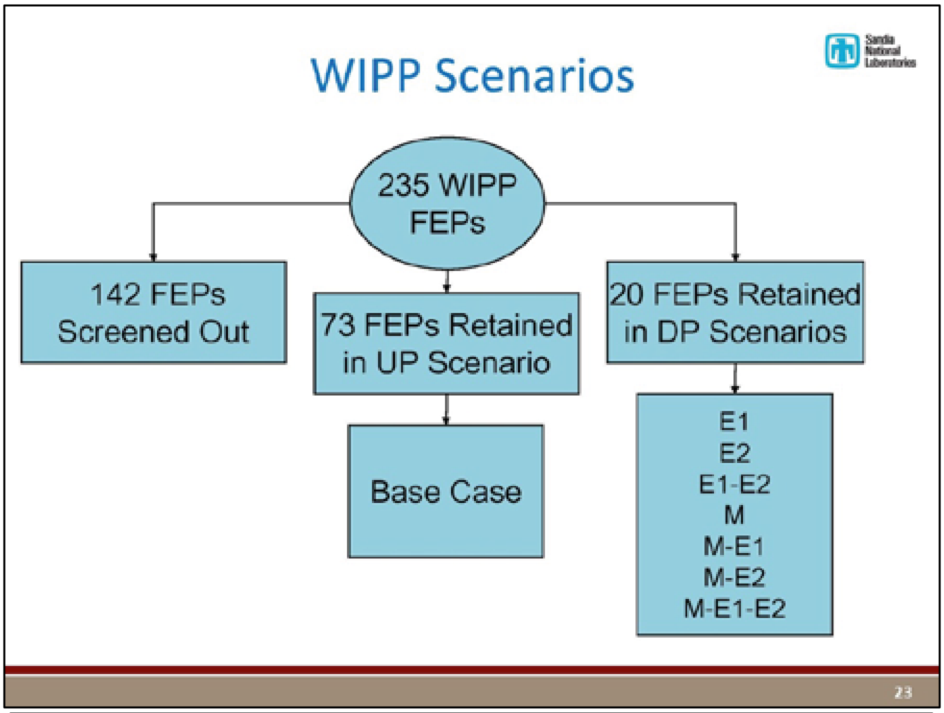

WIPP DP Scenarios

- E1 – drilling intrusion into pressurized brine pocket
- E2 – drilling intrusion that does not hit brine
- E1-E2 – drilling intrusion into the repository that was previously hit by an intrusion that intercepted a brine pocket
- M – mining
- M-E1 – mining in combination with E1
- M-E2 – mining in combination with E2
- M-E1-E2 – mining in combination with E1-E2

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2015 IGSC Scenario Development Workshop

1-3 June 2015

Chair's Summary

Perspectives on regulatory requirements

- Regulatory requirements are set out formally in documents, but important guidance can also come from interactions/dialogue and review
  - important to consider both aspects
  - dialogue is an ongoing process
  - the less prescriptive the regulatory documents, the greater the demands/emphasis on dialogue
- All regulations prescribe general principles/objectives for scenario development
  - transparency of process, traceability of decisions, comprehensiveness, etc.
  - requirements are often developed to address gaps identified in review/dialogue
- Regulatory expectations regarding the application of these principles likely to increase as a programme progresses
  - methods need to be developed and applied to ensure principles are adhered to

Perspectives on regulatory requirements [2]

- Many implementer & regulators see advantages to less prescriptive approach in regulatory documents:
  - broadly applicable irrespective of details of site, design or programme stage
  - regulatory documents may still need periodic updates based on lessons learnt from previous stages or advances in international practice/standards, but not too often (transparency and flexibility)
  - puts responsible for developing the safety case primarily on the implementer
  - maintains independence of the regulator in reviewing the safety case
- Dialogue can promote common understanding on more detailed aspects of scenario development or at least confirmation that the implementer's approach is in line with expectations
  - dialogue is a step-wise process
  - aspects covered by dialogue will increase as programmes progress
  - both the implementer and regulator need independent expertise to review scenarios

Perspectives on regulatory requirements [3]

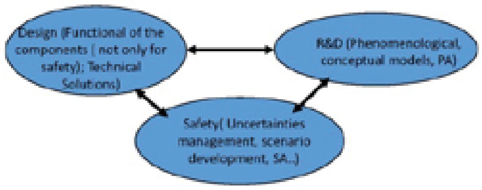
- Some regulatory documents also include more specific requirements or guidance on some aspects
  - FEPs to be included/excluded (or at least probability cut-off) , aspects of methodology (probabilistic vs. deterministic), treatment of human intrusion
  - However, it is not usually the case that the methods/tools to reach the objectives are prescribed
- No pressing demands from implementers for more (or less) prescriptive requirements/guidance in their own national regulations
  - Even though the degree to which guidance is prescriptive varies greatly
  - Implies guidance reflects country-specific boundary conditions, context, culture etc.

Objectives in scenario development

- Integral part of the safety case, but, in addition, …
- Seen as key part of the overall management of uncertainties, and provides guidance to/help steer R&D and design development
  - uncertainties need to be avoided, reduced (by R&D), mitigated by design?
- Detailed objectives, as well as the FEPs included in scenarios, may vary as programme matures
  - Derivation of siting criteria/site selection
  - Design optimisation
  - ….
- Key issue is whether all uncertainties have been identified and accounted for (in scenarios or otherwise)

Role in integration

- Scenario development needs, but can also help promote, safety/pheno/design interdisciplinary communication "integration tool"
  - Importance to maintain traceability of decisions, e.g. design change
  - Integration in management systems?



Scenario classification

- Base/reference/normal evolution scenario ("realistic", likely)
- Other, generally lower probability scenarios, sometimes subdivided into e.g. less likely and very unlikely
- What/-if? scenarios to test robustness, account for "unknown unknowns"
  - These may yield high consequences
  - Need to be carefully explained/communicated
- Human intrusion scenarios generally classified and treated separately

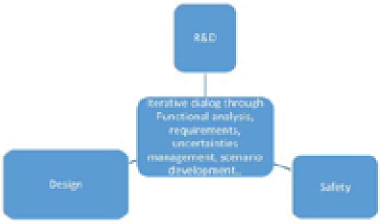
- Comprehensiveness of scenario coverage and clear documentation more important than harmonisation of terminology/definitions

Evolution of approaches

- Scenario development methodologies significantly revised over the past decade in many programmes
- Approaches more thoroughly documented
- Emphasis on transparency and traceability of decisions

Evolution of approaches [2]

- Provide more visible links between the three pillars of safety assessment, design/engineering and science ("pheno")
  - necessary when comparing potential design solutions (components, layouts)
  - also when planning R&D programme



- Some convergence apparent in main steps adopted by national programmes [next slide]
  - in spite of differences in terminology/definitions/detailed tools

Broad steps in scenario development

- Start by developing integrated phenomenological view of system evolution and related uncertainties ("conceptual model" or reference evolution)
- Combination of top-down (safety-driven) and bottom-up (FEP/phenol-driven) elements
- Key roles of both safety functions and FEPs (and FEP screening)
- Scenarios developed by establishing which FEPs/uncertainties may compromise the safety functions fulfilled by components
- How to develop biosphere scenarios (no biosphere safety functions)?

- Need for further consideration of combination/complex scenarios?

Tools for implementing the broad steps

- NEA FEP lists
- Storyboards
- QSA
- Safety statements/ safety features
- Phenomenological analysis
- Conceptual models
- Safety function indicator criteria, performance targets
- Sensitivity cases
- Safety/R&D/design meetings
- Use of expert judgement (necessary, but does not replace data collection)
- Peer review

Proceedings- Future?

- Please send abstracts to NEA secretariat
- Proceedings :
  - Will include abstracts
  - Will include PP presentations (all presentations)
  - WG synthesis
  - Questionnaire and answers including analysis

  Draft will be sent next month or two ..

- NEA R report : on-line publication electronic

- THANKS TO ALL !
- THANKS TO PC MEMBERS!
- THANKS TO THE NEA SECRETARIAT AND IN PERTICULAR GLORIA, KATIA AND HIROOMI !

Appendix D. NEA scenarios questionnaire

1. Introduction

The Scenario Development and Practices workshop held in Madrid in 1999 [NEA 2001] made an assessment of developments in scenario methodologies and applications in safety assessments. Since, different NEA projects, in particular INTESC and the safety case symposium held in Paris in 2007 [NEA 2008 b], but also the European project PAMINA underlined the evolution of national approaches for scenario development. They have been described in various NEA publications (Cf. §5), the most recent one being the MeSA project (2010).

According to those publications, scenarios are still a fundamental basis for achieving and demonstrating post-closure safety and the development of scenarios constitutes a key element of the management of uncertainties.

The 1999 workshop in Madrid concluded that one noticeable progress was the application in practice of methods for FEP analysis. National and International FEP Databases have been developed and are regularly updated. At that time, the use of emerging concept such as the use of safety functions concept were introduced but not discussed in detail for the derivation of scenarios.

The outcomes from the different NEA and European projects now indicate wider use and application practices of safety function concept, their categorization, their use in derivation of scenarios, and the evaluation of their performance using some indicators. They introduce new bases for scenario development but also enhance the overall safety analysis. They also underline that the derivation of scenarios is not a strictly Top-down or Bottom-up approach but rather a combination of both.

It is proposed to make a new assessment of the state of art in order to review national developments since 1999 in terms of scenario development and feedback from application practices in safety cases. This initiative is in continuity with the previous NEA and European projects and aims in this respect at targeting some specific key concerns related to scenario development.

In order to draw the national developments realised since 1999 and the experience acquired in using those approaches in safety cases, it is proposed to hold a new workshop in 2014.

The following questionnaire is submitted to prepare the discussions of this future workshop. This questionnaire is in the continuity of the one performed for the previous workshop in Madrid and the one realised through the topic 3 of MeSA project and, in that respect, addresses some key concerns raised during those projects.

It is to note that this questionnaire will be complementary to some other NEA projects, particularly the project dedicated to updating the NEA FEP Database. Uses of NEA FEP Database have been reported in many safety assessments, either to derive scenario, or to check that proposed national/specific FEP list was sufficiently complete. Due to their link to scenario development they will be part of the discussions during the workshop.

2. Background of the questionnaire

a. Background

Work related to the scenario development topic can be found in NEA documentation [NEA 1992, 2001, 2002, 2003, 2004, 2006, 2008a and 2008b, MeSA project 2010] which includes brochures, symposium and workshop proceedings as well as the documentation of a Topical Session held during the Annual Meeting of the Integration Group for the Safety Case (IGSC-8). It also includes the European project PAMINA (Performance Assessment Methodologies in Application to Guide the Development of the Safety Case, [PAMINA 2006-2009]). The Scenario Development workshop held in Madrid [NEA 2001] reviewed developments in scenario methodologies and applications in safety assessments since 1992. In this document, it is admitted that scenario development constitutes the overall framework for the discussion of the possible evolutions of the disposal system and the calculation cases examined in the safety assessment and their results, as well as failures or degradation of the system, attributed to unknown or less known mechanisms [NEA, 2001].

It was acknowledged in NEA 2001 that large differences in the application of scenario development existed. Since then, new methods for scenario development have emerged. New concepts such as the use of safety functions, their categorization, and the evaluation of their performance using some indicators introduce new bases for scenario development but also enhance the overall safety analysis. In the framework of the MeSA project [NEA, 2010] it was outlined that straight forward Top-down or Bottom-up approach probably never existed, and consider a combination of both. In many projects, the approach relies on a comprehensive list of relevant and specific features, events and processes (FEP). They are supported by detailed description and organization of the FEP. In that respect, new approaches in structuring the scientific knowledge in time and space have emerged (for example: Phenomenological Analysis of Repository Situations PARS, storyboards).

b. Key concerns

The topics in the questions have been defined in line with two previous NEA projects:

- The NEA 2001: Scenario Development Methods and Practice. An Evaluation Based on the NEA Workshop on Scenario Development, Madrid, Mai 1999, Spain. OECD/NEA, Paris, France.
- The NEA MeSA project: System description and scenarios (2010), Klaus-Jürgen RÖHLIG, et al. The group performed a survey on scenario development, use of FEPs and safety functions.

Among the outcomes from the NEA MeSA project [NEA, 2010], it was concluded that the role of the safety function to derive scenarios requires further development. It was also outlined that the quality of scenario development may depend on expert judgment, e.g. judgments of PA specialists and technical subject specialists.

Based on the outcomes from NEA 2001, and MeSA project, it is proposed to discuss further in the framework the workshop the following issues:

- The derivation of scenarios using safety functions.
- The categorisation of scenarios (including human intrusion). It also refers to the classification of base scenario and alternative scenarios; in particular with regard to probability (or plausibility) within various time frame (and associated uncertainties). In that respect, the regulatory aspects could be further developed.
- The analysis of relationships between developed scenario and calculation cases.
- The analysis of similarities and differences of development methodologies.
- The analysis of similarities and differences of developed scenarios which take into account same/similar processes and/or events (e.g. timing and probability of occurrence, evaluation period, impact on system performance).
- The externalisation of expert judgements used through scenario development (e.g. definition of importance and/or occurrence of processes and events, use of external knowledge (safety cases, international FEP's database, expert panels for the completeness checking in scenarios).

3. Aims of the exercise

The questionnaire, contained in the present document, is designed to elicit background information for a future workshop, in order to:

- Review the current status and on-going discussions on the handling of issues related to the scenario development approach.
- To provide a clear overview of the progress that has been made since 1999.

- To provide a clear overview of the feedback and lessons learned from application practices for scenario development in safety cases.
- To provide a state of art report to support discussions within the framework of a workshop.
- To identify areas in which further co-operation at the international level is desirable.

4. Guidance on providing responses

Questions are organised around a number of subject areas in parts 1 through 4 of the questionnaire, namely:

1. General/Context/Regulatory requirement/Regulatory requirement.
2. Summaries of changes since NEA Scenario workshop held in Madrid.
3. Detail regarding Scenario approach currently in use by project.
4. Discussion on the current scenario definition and analysis approach /Expert Judgement.

The questionnaire focuses mainly on post-closure safety.

Please identify the most recent work and safety reports produced at your organisation relevant in the context of scenario development and use. In general, it is preferable if the sources of material for responses are published documents. It is emphasised that the responses or opinions provided should nevertheless represent the view of the organisation and not the individual answering the question. Respondents may therefore choose to subject their response to a review within their organisation.

Part of some previous questionnaires (ex: NEA INTESC and MeSA projects, and EC PAMINA project) can be used as source material.

PRIOR TO FILLING OUT THIS QUESTIONNAIRE PLEASE CAREFULLY READ THE INTRODUCTORY MATERIALS TO UNDERSTAND ITS CONTEXT AND PURPOSE

1. General/Context/Regulatory requirement:

a. Name of organisation:____

b. Select role of organisation: implementer, licensing authority, decision maker, regulatory TSO, research organization, others (please specify) _____

c. Stage of the national program and disposal concept

[Suggested length several paragraphs, max 1 page; if a project overview document exists, please reference here, and provide the internet link if one is available.]

d. Legal and/or regulatory requirements on the definition and consideration of scenarios in safety evaluations

This section should describe the role of current national laws and regulations in defining scenarios.

[Suggested length several paragraphs,; give references and include internet links if available.]

In the description, please address the following issues:

- Any prescriptive requirements regarding FEP, scenarios, or approaches for scenario development and/or classification?
- Any specifications on how compliance with requirements could be demonstrated? (including consideration of non-human biota)
- Any requirements on providing convincing arguments that relevant physical phenomena have been considered in an appropriately comprehensive manner
- Any guidance to limit arbitrary speculations (ex: future human behaviour?)
- Any guidance on the role and/or use of the safety functions concept?
- Any requirements to estimate quantitative probabilities for scenarios?
- Any requirements on Time cut-off to account for in scenario development?

2. SUMMARIES of changes since the 1999 NEA Scenario Workshop held in Madrid

a. In one or several paragraphs, please summarize the changes made in defining scenarios, describe the reasons for changes and discuss how they affect the definition or the use of scenarios, give references and internet links if available.

In the summary of changes, please indicate if changes are made in response to which of the following categories [Note: for each category, provide reference to the most recently published safety case or other relevant documents]:

- **Changes in law, regulations or guidance regarding geological disposal since 1999** [describe the salient changes and discuss how they affect the definition or the use of scenarios]
- **External and/or regulatory reviews in any in-progress or planned reconsideration of scenario definition or use** [Describe any salient suggestions from independent, external and/or regulatory reviews of the safety case or safety assessment and discuss how they affected the definition or the use of scenarios].
- **A new approach to building a safety case including safety assessment methodologies** [discuss the changes in the way the safety case is being built. If those changes involve defining 'safety functions' and building scenarios based on their potential failure modes, provide references to this new approach if it exists in published materials, otherwise just discuss the approach and how it affects the definition, use and explanation of scenarios.]
- **New potentially safety-relevant information or a knowledge refinement** [discuss and provide references to the new information if it exists in published materials, otherwise just discuss the nature of the new information and how scenarios are or may be changed by its consideration.]
- **International practices** [specify which one]
- **A combination of one or more of the foregoing reasons for a change in how scenarios are developed or used** [describe the combination of reasons and discuss how they affected the definition or the use of scenarios]
- **If no changes have been made in defining the scenarios, please explain briefly why no changes since 1999.**

3. DETAIL Regarding Scenario Approach Currently in Use by Project

If there exists a document describing scenario-development and scenario use in the safety analysis and it is readily available on the internet or can be attached, use of it as a reference.]

a. What are the objectives and scope of scenario development in recent PA?

Indicate also if scenarios used for other issues (than strictly safety assessment) like comparison between design options, sites, etc.

b. Describe the approach in detail to defining scenarios

Address the following in your description:

- **Terminology and associated definition.**
- **Classes of scenarios and the role of these classes in your assessment. Indicate also:**
  - The role of "what-if" and/or "stylised" scenarios in the current approach (If they are used, please, indicate their objectives).
  - The place of human intrusion scenarios
- **Steps of your methodology.**
  - **Bottom up**, i.e. FEPS-combinations-based – *[Discuss the use of FEP compilations / databases and / or process reports, or other means to compile scientific knowledge on which system description and scenario derivation are based]: building blocks for scenarios or check list.*
  - **Top down**, i.e. "safety-function" based - *[discuss the derivation of top-level and lower-level functions and their use, e.g. when defining scenarios, calculation cases or evaluating compliance],* or
  - **A combination approach**. *Describe*

- **Indicate the uses of international guidance documents and databases such as the NEA's FEPs database.**
- **Approach to go from scenarios to safety models and/or calculation cases.**
- **Use of deterministic / probabilistic approach, or a combination of both.**
- **Consideration for temporal sequences in scenario (time cut-off, climate evolution, other events or processes).**
- **Indicate the use of formal tools (e.g. software-based tools).**
- **Indicate the use of formal expert elicitation processes.**
- **How is the propagation of uncertainties managed?**

4. Discuss why the current scenario definition and analysis approach is appropriate for this project at present

a. **Describe the process used to determine if your project's contributors internally agree that the set of scenarios carried into the safety analysis is sufficiently complete / comprehensive for the purpose at hand.**

b. **Provide details of the following:**

- Acceptance in terms of regulatory compliance feedback and/or outcomes of external reviews;
- Experience base for judging the current approach provides transparency in communicating the basis of the safety case;

c. **Describe the externalisation of expert judgements used through scenario development (To elicit FEPs? To review scenario development?).**

Addendum: Presently, a revision of the NEA FEP database is carried out by IGSC. The objective and scope is described in the proposal [NEA 2012a, b]. After having replied to the above questions, did any additional ideas about desirable features of the revised database come up?

5. References

NEA 1992: Systematic approaches to scenario development. Report of the NEA Working Group on the Identification and Selection of Scenarios for Performance Assessment. OECD Publications, Paris, France.

NEA 2000: Features, Events and Processes (FEPs) for Geologic Disposal of Radioactive Waste. An International Database. Vers. 1.2. OECD/NEA Publ., Radioactive Waste Management, Paris, France.

NEA 2001: Scenario Development Methods and Practice. An Evaluation Based on the NEA Workshop on Scenario Development, Madrid, Mai 1999, Spain. OECD/NEA, Paris, France.

NEA 2002: The Handling of Timescales in Assessing Post-closure Safety of Deep Geological Repositories, Workshop Proceedings, Paris, France, 16-18 April 2002. OECD/NEA, Paris, France.

NEA 2003: Features, Events and Processes Evaluation Catalogue for Argillaceous Media. OECD/NEA, Paris, France.

NEA 2004a: Post-closure safety case for geological repositories – Nature and purpose. Organisation for Economic Co-operation and Development, Nuclear Energy Agency, Paris, France.

NEA 2005: Management of Uncertainty in Safety Cases and the Role of risk. Workshop Proceedings, Stockholm, Sweden, 2-4 February 2004.

NEA 2006: Summary record of the 8th meeting of the IGSC, Issy-les-Moulineaux, France, 25-27 October 2006. Report NEA/RWM/IGS (2006)5, OECD/NEA, Paris, France.

NEA 2008a: IGSC - International Experiences in Safety Cases: Outcomes of the NEA INTESC Initiative; Final draft report –2008

NEA 2008b: Safety Cases for Deep Geological Disposal of Radioactive Waste: Where Do We Stand? Symposium Proceedings, Paris, France, 23-25 January 2007. NEA No. 6319, OECD/NEA, Paris, France.

NEA 2010: System description and scenarios. MeSA, Klaus-Jürgen RÖHLIG, *et al.*

PAMINA, http://www.ip-pamina.eu/

NEA 2012a:Updating the NEA International FEP List – Identification and Review of Recent Project-specific FEP Lists.

NEA 2012b: Updating the NEA International FEP List – Proposed Revisions to the NEA International FEP List.

Appendix E. Compilation of questionnaire responses

Scenario Development in Safety Cases State of the Practices Synthesis report on the Questionnaire results (December 2014)

5. Context

In the framework IGSC, it was proposed to make a new assessment of the state of art in terms of scenario development and feedback from application practices in safety cases in order to review national developments since the 1999 workshop in Madrid. This initiative is in continuity with the previous NEA and European projects and aims in this respect at targeting some specific key concerns related to scenario development.

In order to draw the national developments realised since 1999 and the experience acquired in using those approaches in safety cases, it is proposed to hold a new workshop in 2015.

Therefore the questionnaire was designed to elicit background information for a future workshop, in order to:

- Review the current status and on-going discussions on the handling of issues related to the scenario development approach.
- To provide a clear overview of the progress that has been made since 1999.
- To provide a clear overview of the feedback and lessons learned from application practices for scenario development in safety cases.
- To provide a state of art report to support discussions within the framework of a workshop.
- To identify areas in which further co-operation at the international level is desirable.

A NEA questionnaire was submitted with four main questions (see annex 5):

1. General/Context/Regulatory requirement.

2. SUMMARIES of changes since the 1999 NEA Scenario Workshop held in Madrid.
3. DETAIL Regarding Scenario Approach Currently in Use by Project.
4. Discuss why the current scenario definition and analysis approach is appropriate for this project at present.

A total of fourteen completed questionnaires have been received by the NEA relating to eleven different national programmes. Seventeen organisations responded in total, as three of the questionnaires were joint responses. The responding organisations and their roles are given in Table 1.

The aim of this document is to provide a short summary of communalities/differences or specificities for each issues rose in the questionnaire. It also aims at review major evolution since the 1999 workshop in Madrid.

In order to realise this analysis, the answers provided by each respondent have been compiled in tables, each dedicated to main issues raised in the questionnaire. Then, the compilation was used to extract the main feature and to propose a short synthesis. The full responses of the organisations are given in a separate document (To be discussed).

Table 1: Roles and Nationalities of Responding Organisations

Organisation	Country	Role	Notes
Federaal Agentschap voor Nucleaire Controle/Agence fédérale de contrôle nucléaire (FANC/AFNC)	Belgium	Regulator	
Organisme national des déchets radioactifs et des matières fissiles enrichies/Nationale instelling voor radioactief afval en verrijkte splijtstoffen (ONDRAF/NIRAS)	Belgium	Implementer	
Nuclear Waste Management Organisation (NWMO)	Canada	Implementer	
Radioactive Waste Repository Authority (RAWRA)	Czech Republic	Implementer	
POSIVA Oy	Finland	Implementer	
Agence nationale pour la gestion des déchets radioactifs (Andra)	France	Implementer	
BundesamtfurStrahlenschultz (BfS)	Germany	Implementer	Joint response with GRS

Organisation	Country	Role	Notes
Gesellschaftfur Angalden- und ReaktorsicherheitmbH (GRS)	Germany	Research Organisation	Joint response with BfS
Japan Atomic Energy Agency (JAEA)	Japan	Research Organisation	Joint response with NUMO
Nuclear Waste Management Organisation of Japan (NUMO)	Japan	Implementer	Joint response with JAEA
Korea Atomic Energy Research Institute (KAERI)	South Korea	Research Organisation	
Swedish Nuclear Fuel and Waste Management Co. (SKB)	Sweden	Implementer	
Swedish Radiation Safety Authority (SSM)	Sweden	Regulator	
Environment Agency (EA)	UK (England, Wales, and Northern Ireland)	Regulator	Response appended to that of RWMD
Radioactive Waste Management Directorate in the Nuclear Decommissioning Authority (RWMD)	UK	Implementer	
US Department of Energy Office of Nuclear Energy (US DOE NE) (for spent nuclear fuel and high level waste)	USA	Implementer	Joint response with US-DOE EM/CBFO
US Department of Energy Office of Environmental Management Carlsbad Field Office (US DOE EM/CBFO) (for transuranic waste)	USA	Implementer	Joint response with US-DOE NE

Identification of key issues:

- Regulatory perspectives. There are considerable changes since 1999, particularly next to safety cases and as a consequence moving forward in the project (site, licencing, knowledge refinement...). Some other implementers indicate no changes. Those regulations have clear requirements for scenario development, giving classes, probability of events, FEPs to consider (internal and external), safety functions, process understanding, uncertainty management, and compliance to respect (dose, risk, and chemical impact). Human intrusion is also considered in most regulations, but with different level of prescription. Protections of non-human biota have been introduced.

Examples are available, and the extend of prescription by regulators could be discussed.

- Evolution of most laws, guidances since the 1999 workshop in Madrid. Objectives of scenarios, classes to be addressed, FEPS to account for, Safety functions and evaluation of performance.

  To what extent are guidances prescriptive for scenario development? FEPs, Safety functions, management of uncertainties.

- What can be expected from scenario development: since 1999 there is a large feedback from experiences and submission of safety cases. Example of evolution and consolidation of methods are given. Notion of safety functions (or safety concepts) is more widely used since 1999. The new regulations or guidances recommend the evaluation of performances in addition to dose and in that respect the notion of safety function is in the regulation. Such approaches are sometimes meant to address potential loss of a safety function and evaluate the robustness of the repository system.

- Scenario and model formulation. Overall answers should considerable evolution in development of method for scenario development. Since 1999, various method are available to develop scenario, with three majors methods that have been applied:

  - Methods qualified of top-down, based on safety function: more widely used than in 1999. Examples of application of this method are available among the answers.
  - Methods qualified of bottom-up, based on identifying and screening FEPs: tools to manipulate FEPs have evolved, as well the international NEA FEP database is updated and enriched with additional database develop by implementers. Examples of application of this method are available.
  - A combination of approach, based on both safety function and FEPs screening. Examples of application of such combination of approach are also available.

International practices and sharing of safety assessment method appear to be a major reference in scenario development (AEN working group and/or workshop are commonly cited.

- Completeness, comprehensiveness, and sufficiency. Since 1999, some implementers submitted safety cases. Regulatory reviews have become more important, but not only. Most of the cases benefited international peer review as well. Answers also show organisation of internal reviews, and/or brainstorming aimed at completeness, elicitation and comprehensiveness. Development or consolidations of approach integrate remarks and recommendations issued from internal or external reviews. Examples are available.

6. General/Context/Regulatory requirement

6.1 Stage of the national program and disposal concept

Most of the respondent gave quite detailed answers (see Table 2).

All organisations don't have the same feedback, some being more advanced than the other.

However, as can be seen hereafter, development of scenarios is a key element of the safety case in most of the answer. Differences relies on the input data (site or not).

Most of the respondents (either regulators or implementers) refer to laws, technical guides and/or safety rules for scenario developments (see table 3):

- FANC and Ondraf (Belgium) refer to laws and technical guides (RPC 2011, SAR 2012)
- NWMO (Canada) cites the CNSC guide G320
- POSIVA (Finland) states that the formulation of scenarios is constrained by government decrees (VNA 736 GD736/2008) and the Finish regulatory STUCK's draft Guide YVL D.5
- Andra (France) refers to laws and the 2008 NSA guide which sets the safety principles
- GRS (Germany) cites the 2010 safety requirements of the federal ministry
- SSM (Sweden) cites two publications of the Swedish radiation authority's (SSMFS 2008:21, and SSMFS:37)
- RWMD (UK) refers to regulatory guidance of 2009 (GRA) but explains that prescription only concern human intrusions.
- JAEA (Japan) refers to a guide published by the Nuclear Regulatory Authority
- DOE (USA) cites the US standard 40CFR191.12 and the US code of Federal Regulations DCFR 60

For the other implementers who do not have yet formal regulatory document:

- KAERI (South Korea) refers to a draft guideline of "General Standard on Deep Geological Disposal Facility for HLW".
- RAWRA (Czech republic) indicates there is no formal requirement and refers to a methodological procedure.

6.2 Question 1.c Any prescriptive requirements regarding FEP, scenarios, or approaches for scenario development and/or classification?

6.2.1 *Synthesis of the answer*

Most of the references given in the respondents were issued since the 1999 Madrid workshop (see also Table 10). The regulation/safety rules/ guidances listed above don't refer to the same level of requirements regarding scenario development, some being more prescriptive than other. However, a classification of scenarios is proposed in most of those regulations.

Most of the regulations require some kind of "base case" scenario, supplemented by a number of "altered" or "disruptive" scenarios. Definition is rarely presented, instead the requirement focusses on what FEP those scenario should content, their likelihood/probability, and their potential effect on the evolution of the repository.

Regulators are more prescriptive. Through the terminology being used, regulations refer to a concept used of FEPs database/use of safety functions. It appears clearly that some regulators recommend/prescribe to study the performance of the disposal system and to address scenarios with potential loss of safety functions.

The categories listed above generally rely upon probable/likely events or development. However, most regulations and guidances don't require quantification of the probability.

If scenarios to be addressed are listed in regulations, there is not always a formal methods associated.

Prescriptive requirements regarding FEPs are only reported by FANC, NWMO, Posiva and DoE. However, regarding requirements listed in table 3, most regulations/guidances refer to some phenomena, processes and events to account for in scenario development (e.g. geological and climatic events (or natural events) but also for processes due to the presence of the repository and associated overall degradation processes of waste and engineered barrier, or human actions).

6.3 Summary of differences/communalities

From table 3, the regulators requirements in terms of scenarios to consider can be sorted out in four major categories. To note that the terminology is the one used in the answer, in bracket the organisation giving the answer.

- The first category refers to as:
  - A "scenario representative of the expected evolution" (FANC).
  - A "central scenario of the normal, or expected evolution of the site and the facility over time" (NWMO),
  - A "normal evolution" (RAWRA).
  - An "expected evolution scenario" [...] high probability, which can be caused by interactions occurring in the disposal facility, by geological or climatic phenomena or by human action (POSIVA).
  - A "reference situation" that includes events due to the presence of the repository and the most probable natural events (Andra).
  - "Probable developments" e.g. refer to normal development forecasted for the site (GRS).
  - A "likely scenario" (probable and normally expected scenario) (JAEA).
  - A "main scenario" which should cover a probable evolution of the repository (SSM).

- The second category refers as to :
  - “Unexpected (but possible) scenarios” (FANC).
  - “Additional scenarios that examine the potential impact of disruptive events” (NWMO).
  - An “altered evaluation” scenario (RAWRA).
  - “Unlikely events” impairing long-term safety (POSIVA), caused by geological phenomena or by human action.
  - “Altered situations” refer to events with low probability yet plausible or human actions likely to alter the expected evolution (Andra).
  - “Less probable developments” […] under unfavourable geological or climatic conditions that have rarely occurred (GRS).
  - “Less likely scenarios” (considered for important variations) (JAEA) and to address scenario uncertainty and cover alternative events (SSM).
- The third category consider stylised type scenarios, defined by
  - Penalising scenarios (FANC).
  - Improbable developments (GRS), refers to development that are not expected to occur at the site.
  - Very unlikely scenarios related to very unlikely natural events (JAEA).
  - Residual scenarios, studied irrespective to the scenario probability for different purposes, ex: consequences of human intrusion and consequences of not sealing the repository (SSM).

Human intrusion scenarios are usually mentioned in regulation, they refer to:

- FANC: Human intrusion scenarios,
- RAWRA: Intrusion,
- POSIVA: Unlikely events caused by human action,
- Andra: Human intrusion (as an altered situation, inadvertent intrusion considering loss of memory of the repository at 500 y after closure),
- GRS: Unintentional human penetration of the final repository (stylized scenarios)),
- JAEA: Inadvertent human actions,
- RWMD: 3 classes defined i) intrusion with full knowledge ii) intrusion without knowledge of the GDF, and iii) intrusion with knowledge of the repository but without understanding what it contains,
- SSM: as residual scenario,
- DoE: Human intrusion (exploratory drilling).

Only RWMD refers to intrusion with knowledge of the existence of underground working, other organisations referring to inadvertent intrusion. The date of occurrence is rarely mentioned, Andra indicates that according the guide intrusion is to be considered after loss of memory considered at 500 years.

The level of prescription for consideration of human intrusion may vary, some being more prescriptive with a list of human activity to consider.

6.4 Any requirements on providing convincing arguments that relevant physical phenomena have been considered in an appropriately comprehensive manner

Completeness, process understanding and management of uncertainties are required by regulators.

Providing convincing arguments that relevant physical phenomena have been considered in an appropriately comprehensive manner is considered as a part of the safety demonstration (see table 4):

- The technical guides mentioned by FANC and Ondraf require a representative and understood set of scenarios, based on comprehensive FEPs.
- The CNSC guide G320 cited by NWMO requires "sufficiently comprehensive scenarios" based on FEPs.
- The guide YVL D.5 cited by Posiva, requires scenarios to be systematically constructed from FEPs which may be of importance for long term safety.
- The safety guide cited by Andra, recommends for scenario development to take into account the overall phenomena governing the evolution of the waste repository including the underground water circulation modelling with radionuclides transfers.
- JAEA indicates that scenario development has to account for physical or chemical processes.
- GRS states that scenarios must be comprehensive, defined by future events and processes and comprise relevant physical phenomena.
- The US standard 40CFR191.12 referred to by DoE explains that "US regulations require a comprehensive consideration of FEPs".
- RWMD also define their scenarios on the basis of FEPs.

In addition, the handling of uncertainties is thoroughly discussed by FANC, Posiva, SSM and Doe, and Andra.

6.5 Any specifications on how compliance with requirements could be demonstrated? (including consideration of non-human biota)

Andra also indicates that both Radiological and chemical impacts are to be evaluated. Most of the cited regulations define target human annual doses (in Sv/year) that may depend on the category of the scenarios (Table 5). Risk also mentioned by a few organisations (Ondraf, SSM):

- Ondraf: 0.1 mSv/year or 0.3 mSv/year for the expected evolution, and risk (10^{-6}/y) for unexpected evolutions where probability can be quantified (except for human intrusion), and 3 mSv for penalizing scenarios.

- Posiva: annual dose must remain below 0.1 mSv/year for the most exposed people,
- Andra: below 0.25 mSv/year for the “reference situation”
- GRS: for probable developments an additional effective dose in the range of 0.01 mSv/year for individuals, 0.1 mSv/year for the less probable development, for improbable development, no value is given but optimisation is to be investigated for such situation.
- JAEA: below 0.01 mSv/year for the likely scenario, below 0.3 mSv/year for the less likely scenario, and no exceed 10-100mSv per year for the very unlikely.
- DoE: committed effective dose below 0,15 mSv/year to any member of the public.
- FANC, NWMO, RAWRA, KAERI and RWMD do not give any specification on how compliance should be demonstrated.
- SSM indicates that for risk calculation purposes, scenario probability should be estimated requirements and performance target.
- Andra, FANC, also and justified as far as possible. In addition to demonstrating dose/risk target values, safety should be used to identify appropriate functional
- indicate that the performance of components is to be evaluated according to their guidance.

Concerning non-human biota:

- POSIVA indicates regulation requirements for the protection of living species (fauna and flora) and that it should be demonstrated by assessing the typical radiation exposure of terrestrial and aquatic populations.
- No explicit dose limit for non-human biota but this aspect is part of the protection goals for GRS.
- For Andra, there are no explicit requirements but part of the fundamental objectives of protection of the human and the environment.
- For D0E, potential dose are to be calculated to human, not biota, but the human dose calculation assumes contamination in foodstuffs.
- RWMD also take into account the non-human biota (and more generally the environment), but no specific dose is given.

6.6 Any guidance to limit arbitrary speculations (ex: future human behaviour?)

As listed above, most respondents indicate that regulations require human intrusion to be considered for scenario development (Table 6).

Categorisation may be different, can be to be integrated in the normal evolution (POSIVA) or altered evolution or penalising scenarios for other.

According to the answer very few requirements are listed in regulations/guidances for limiting arbitrary speculations related to future human behaviour. .

- ASN guide of France indicates that the same level of technology is to be considered. Various possible forms of human intrusion are to be considered regardless of the probability of the event, after memory of the existence of the disposal is lost (estimated at 500 years). A series of human intrusion are listed in the guide. The guide also recommends accounting for climatic events in the definition of biosphere leading to the description of biospheres typical of the different climatic states that can be foreseen in the future.
- POSIVA: requirements are stated in the finish STUCK's regulations, "unlikely events" caused by human actions to be considered shall include at least boring a medium deep water well at the site.
- GRS: As future human activities cannot be forecasted, a variety of reference scenarios for unintentional human penetration of the final repository, based on common human activities at the present time, shall be analysed.
- DOE NE/ DOE CBFO gives a quite detailed list of requirement (see table 6): § 194.25 Future state assumptions indicates that performance assessments and compliance assessments conducted shall assume that characteristics of the future remain what they are at the time the compliance application is prepared, provided that such characteristics are not related to hydrogeologic, geologic or climatic conditions. [...]
- The DOE NE/ DOE CBFO should not any project changes in society, the biosphere (other than climate), human biology, or increases or decreases of human knowledge or technology. In all analyses done to demonstrate compliance with this part, DOE must assume that all of those factors remain constant as they are at the time of license application submission to NRC.

6.7 Any guidance on the role and/or use of the safety functions concept?

In line with requirements for evaluating the performance of components, the concept of safety function is explicitly mentioned in regulations/guidances listed by FANC, Posiva, Andra, GRS, SSM, and RWMD. On the contrary, DOE NE/ DOE CBFO do not have any requirements for safety functions (Table 7).

- Main safety functions to consider are sometimes listed, they refer to protection of man and environment, isolation from surface phenomena and human activity, and resistance to water circulations, radioactivity confinement are defined by Andra.
- NWMO refers to the multi-barrier system for containment
- In addition, JAEA, and Kaeri deal with safety barriers
- GRS indicates that if safety functions are part of the safety function they are not mandatory for development of scenario.

6.8 Any requirements to estimate quantitative probabilities for scenarios?

Quantitative probabilities are accounted for by Posiva and DOE NE/ DOE EM/CBFO, who weight resulting impacts with probabilities (Table 8).

Among respondents who distinguish likely and unlikely scenarios, Ondraf, GRS SSM and RWMD quantify the probability of scenarios.

Posiva, NWMO, RWMD and DOE NE/ DOE EM/CBFO discard very improbable cases.

SSM indicates that the residual scenarios must be studied irrespective to their probability.

6.9 Any requirements on Time cut-off to account for in scenario development?

The question of a time cut-off is little discussed. Beyond the period of control, performance assessment must cover the maximum dose (Table 9). More specifically:

- Posiva and DOE NE/ DOE EM/CBFO consider a 10,000 years period,
- GRS consider 1 million years,
- RAWRA and JAEA specify the absence of time cut-off

Other participants did not address time cut-off in question 1d7. The time cut-off is also discussed in question 3b7.

7. Question 2: Summaries of changes since the 1999 NEA Scenario Workshop held in Madrid

7.1 Changes in law

Salient changes in law, regulations or guidance affecting the definition or the use of scenarios are reported by (Table 10):

- FANC and Ondraf refer to safety requirements (royal decree) developed in 2011 and a technical guide (SAR) developed in 2012,
- NWMO was created in 2002 and CNSC published its P-290 policy and G-320 guide in 2004 and 2006, respectively.
- For Posiva, the most salient change was the YVL guide published in 2011,
- Andra reports the 28th June 2006 act ‘law of program relative to radioactive waste and nuclear material management and 2008 NSA guide),
- GRS refers to the new safety requirements published in 2010 by the federal ministry of environment,
- JAEA recalls the establishment of NUMO in 2000 and new laws and procedures issued since 2007 establishing the Nuclear Regulations Authority (NRA) and providing a basic framework of safety assessment
- SSM cites the guidance and regulation guides published in 2008, raising a number of issues listed in Table 11

No significant change is reported by RAWRA, Posiva, KAERI, RWMD and DoE.

7.2 External, regulatory reviews in progress or planned reconsideration of scenario definitions

Ondraf, NWMO, Andra, GRS, JAEA, KAERI, SKB and SSM report external reviews handled by regulators or led in the scope of international workshops or peer reviews organized by NEA (Table 11):

- Ondraf has enriched its PROSA methodology. In addition, the NUMO-NAGRA workshop (2010) has enhanced the reflections about safety functions indicators and uncertainties processing,
- Next to a CNSC informal review, NWMO has to account for glaciation, seismicity, material deterioration and gaz generation, among others,
- Several external reviews are indicated by Andra, they may be national safety authority and councils, which lead to recommendations or requirements for the definition or the use of scenarios. Andra consolidated its overall safety approach, in particular the QSA.
- The German Nuclear Waste Management Commission suggested GRS to perform a systematic scenario analysis on the basis of FEPs,
- According to regulation established by the NSC, JAEA has to classify its scenarii according to their probability, and safety functions are to be discussed. Regulatory review will be carried out.

- Next to the regulation SSMFS 2008:21 and the SR-Can assessment, SKB's scenario methodology has performed considerable developments since 1999. The IAEA review conducted in 2012 did not bring explicit comments on the SSM regulation.

7.3 A new approach to building a safety case including safety assessment methodologies

Several changes and improvements are reported by respondents (Table 12):

- As a general trend, Ondraf notices an evolution towards a generalised methodology which takes into account the implementation of the scientific knowledge and its subsequent simplification,
- For NWMO, the process of defining scenarios has not changed. Changes in the repository design however result in changes to the safety assessment model,
- Posiva has implemented a top-down approach based on safety functions and FEPs. Two examples (the repository system and the biosphere) illustrate this methodology,
- Andra has consolidated its approach using the safety functions and developed its qualitative safety analysis (QSA) for treatment of uncertainties,
- GRS has developed a FEP-based scenario development methodology that includes an analysis of safety functions.
- NUMO has developed basic procedures for evaluating long term safety. Safety functions were defined based on technical requirements,
- DOE NE/ DOE EM/CBFO updates its FEPs catalogue and scenario descriptions next to process changes proposed in WIPP repository.

7.4 New potentially safety-relevant information and/or knowledge refinement

New potentially safety-relevant information and/or knowledge refinements are reported by (Table 13)

- NWMO: the FEPs analyses were updated next to recent case studies (4CS and 5CS) and changes in repository design,
- Andra: important knowledge improvements have been achieved since 1999. They have been widely published (Dossier 2005),
- JAEA: improvement in knowledge and comprehension, implemented in the NUMOs procedure described in question 2-3.
- Thanks to the input from other FEP lists, KAERI has gradually extended its FEP list,
- DOE NE/ DOE EM/CBFO got little knowledge improvement but the feedback of WIPP repository helped refining some estimates.

7.5 International practices

International developments are listed (Table 14)

- The input from NEAs international FEP list (2000) and safety case (2004) is mentioned by NWMO, Andra and JAEA.
- DOE NE/ DOE EM/CBFO also intends to incorporate new international developments into the FEPs/scenarios approaches
- Furthermore Andra has taken part into and benefits from international exchanges led by OECD/NEA (about FEP list), AIEA (human intrusion) and EC (european projects).

7.6 A combination of one or more of the foregoing reasons for a change in scenarios are developed or used

NWMO, Andra and DOE NE/ DOE EM/CBFO recall that the development of scenarios benefits from previous reviews (Table 15):

- Scenarios are now developed in a more systematic and transparent fashion following to comments by reviewers (NWMO)
- The definition of scenarios accounts for new regulations and new information as regards to an iterative approach to achieving safety (Andra)
- A new performance assessment requires re-evaluating potentially affected FEPs (DOE NE/ DOE EM/CBFO)

7.7 If no changes have been made in defining the scenarios, please explain briefly why no changes since 1999

A few respondents indicated no major changes (Table 16)

- According to RWMD and DOE NE/ DOE EM/CBFO, the main lines of the methodology (definition of the scenarios and the implementation of the FEPs) were developed before 1999, and the recent evolutions are minor.
- RAWRA report no change in Atomic Law since 1999. The safety report for reference repository system has actualized in 2010.

8. Question 3 DETAIL Regarding Scenario Approach Currently in Use by Project

8.1 What are the objectives and scope of scenario development in recent PA?

The answers to question 3a depend on the progress of the repository project. To outline main objectives, some key arguments have been listed from Table 17):

- NWMO: "the purpose of scenario identification is to develop a comprehensive range of possible future evolutions against which the performance system can be assessed".
- Posiva: results and analysis of scenario is used to give feedback to design and technical options
- Andra: NES answer several objectives, fulfils the safety objectives assigned to the repository, confirm that the performance achieved (with chosen indicators) is consistent with the predefined threshold values, verify the performance of the three main functions, simulation of overall repository expected evolution (identification of key processes). The altered evolution scenario assess the robustness of the system in case of loss of safety function.
- GRS: "primary goal of scenario is to tackle uncertainties" (cf probability classes of scenarios)
- JAEA: scenario development focusses on post-closure safety for HLW and TRU, and being extended to SF
- KAERI: "to identify key processes and features of the repository site and disposal concept and determine preliminary scenarios to be analysed. To check if disposal concept can satisfy safety goal".
- SKB: …"exploring all possible routes to failure of the system (i.e. loss of safety functions) …only used in safety assessment to demonstrate compliance but also to address the issue of best available technique" (BAT).
- RWMD: currently developing a safety narrative
- DOE NE/ DOE EM/CBFO: was intended to provide initial guidance into research and development needs. DOE/CBFO WIPP: primary objective is to demonstrate continuity regulatory compliance. Second objective: evaluate potential long term safety implications of proposed repository operational changes….

For most of the respondent, scenario development is being used to demonstrate post-closure safety compliance. However, the listed key words above outline a large use of scenario development for design purpose, performance of the system, robustness relative to loss of safety functions, understanding of repository evolution (key processes) and management of uncertainties.

They confirm that development of scenario is considered as a key element of the safety approach.

8.2 Terminology and associated definition and classes of scenarios and the role of these classes in your assessment.

This issue concerns only implementers. Without surprise, proposed classes of scenarios by implementers are in line with their national regulatory requirements (table 18).

If they can globally be ranked in five categories, the associated terminology remains quite large:

- First category:
  - Normal Evolution Scenario (Ondraf, NWMO, RAWRA, likely future evolutions and natural probable events Andra),
  - Base and variant Scenarios (most likely lines of evolution Posiva)
  - Reference Scenario (probable potential developments of the disposal system, GRS)
  - Likely (JAEA)
  - Reference evolution (account for predefined external conditions SKB)
  - Main scenario (as defined in SSM2008:21, split in two variants of the reference scenario Weichselian and global warming, SKB)
- Second category:
  - Altered Evolution Scenario (Ondraf, RAWRA, unlikely events and based on a breakdown of safety function, include human intrusion Andra);
  - Disruptive Scenarios (including human intrusion for NWMO),
  - Disturbance Scenarios (unlikely event or processes, Posiva)
  - Alternative Scenarios (less probable development, GRS)
  - Less-likely (JAEA)
  - Additional scenario (less probable scenario, potential loss of safety function, SKB)
- Third category (What-if scenario):
  - what-if cases (with a stylised approach Posiva)
  - what-if scenario (stylised hypothesis that may not represent any physically possible situation, Andra); (extreme limits and sometimes unrealistic values to test robustness, GRS)
  - very unlikely (JAEA)
  - Other residual scenarios (SKB)
  - Human intrusion (RWMD)
- Fourth category (Human intrusion):
  - Human intrusion Ondraf, RAWRA, JAEA
  - (Unintentional) Human intrusion: Andra
  - Stylised scenario (GRS)

- (Inadvertent) Future human actions (as advertant human intrusion is not to be treated, SKB)

- Fifth category:
  - Combination of scenarios (SKB)

JAEA indicates that such categorised evolutions will be classified into four classes of scenarios for safety assessment taking their probability /plausibility and impact into account.

What-if scenarios are avoided by US DOE NE/ DOE EM/CBFO. They may be useful in illustrating an upper bound but potentially create confusion for non technical audiences. To be completed

Such a variety of terminology is linked, not only with the objectives given to scenario development, but also in the methodology referring to the use of safety functions (top-down) or FEPS (bottom up) or a combination of both.

The first category of scenario doesn't refer to only likely or probable events, but also to a system that should function as defined by the conception (i.e. safety functions are realised with a given performance assessed with appropriate indicators other than dose). This category corresponds in fact to a domain of normal evolution which includes some variants but with no major impair on the functioning of the system (safety functions always realised)

As a result, the second category of scenarios includes loss of safety functions generally due to unlikely or less probable event and processes.

8.3 Steps of your methodology:

Most of the respondent gave quite detailed description of their methodology in scenario development (see table 19 for details).

The questionnaire referred to some base:

- Top down, i.e. "safety-function" based -
- Bottom up, i.e. FEPS-combinations-based –
- A combination of both approaches.

As a first approach, results of the questionnaire were classified according this terminology. The purpose is not to summarise the approaches described by implementers (cf table 3.3), but to extract some key words/sentences in order to classify the approach within those three categories. :

- Top-down:
  - Ondraf: follows a top-down safety statements tree providing a way to structure the information will be used to derive scenario (instead of FEPs list).

- Posiva: follows a top-down approach in first identifying the safety functions that are required of the repository system, then considering the effects of single FEPs or combinations of FEPs on those functions to check that the scenarios are comprehensive, and also to evaluate the effects of uncertainties within the expected lines of evolution.
- Andra: the approach can be qualified of “top-down” as the safety functions are used to decline scenarios. The normal evolution scenario considers that safety functions are realised. The agency use a qualitative safety analysis (QSA) to analyse the effects of uncertainties on Andra’s repository FEPs on safety functions… It leads to identification of a series of calculation cases and as a result, the derivation of scenarios and sensitivity analysis.
- RWMD/EA: currently being developed. It is indicated that they will primarily adopt a ‘top-down’ approach to safety case development, but this is complemented by a ‘bottom-up’ check against relevant FEPs and consideration of ‘what if?’ scenarios.

- Bottom up:

  - NWMO: Normal evolution scenario is developed from consideration of the External FEPs and the Internal FEPs (with reasoned extrapolation of the hypothetical site)
  - RAWRA: the bottom up option is used with respect to the stage of repository development.
  - GRS: qualified of bottom up approach. GRS developed a methodology for scenario development that relies first on the definition of initial barriers. Then individual scenarios are characterised by FEPs that may influence the future development of the disposal system, and their associated characteristics. The reference scenario results by considering all probable FEPs. Derivation of alternative scenario considers less probable FEPs or less probable characteristics of the FEPs that may impair the functionality of the barriers.
  - KAERI: uses FEPs to build scenarios (identification, classification and screening of FEPs.

- A combination of both approach

  - JAEA: a combination of top-down approach and bottom-up approach. JAEA developed a procedure that highlights safety functions and treatment of scenario uncertainty and likelihood of occurrence. In this procedure FEPs are used to check completeness of scenario for safety assessment.
  - SKB’s scenario approach is a combination of top-down and bottom-up. The use of safety functions to identify scenarios is a top-down approach, whereas both the reference evolution, lying the foundation for the main scenario and the scenario selection, and each scenario are systematically analysed by considering all initial state factors, processes and external conditions relevant for them. The latter is a bottom-up approach built on identification of relevant FEPs.

- DoE NE & EM/CBFO: Combination approach: Identify scenarios, compare/audit the scenarios against FEP lists for completeness (i.e. check if there are any included FEPs that might define, augment, or alter a scenario), screen the scenarios for applicability, screen them for regulatory exclusions, the comprehensively catalogue and describe them.

8.4 Indicate the uses of international guidance documents and databases, e.g. NEA's FEP database

Overall answers indicate several types of international documentation (Table 20). However references given in this section are not fully exhaustive and some reference may be listed elsewhere in other part of the questionnaire. The major one are reported here:

- The NEA's FEP database (Ondraf, NWMO, Posiva, Andra, GRS, JAEA, KAERI, SKB, RWMD/EA and US DOE NE/ DOE EM/CBFO).
- Methodological developments or practices
- AEN document (MeSA, Scenario development, ...): (Ondraf, Andra)
- EU document (PAMINA): Andra
- NEA documentation relative to deep geological repositories (Ondraf, Andra, US DOE NE/ DOE EM/CBFO)
- AIEA guides (Ondraf, GRS)
- ICRP (Andra)

8.5 Approach to go from scenarios to safety models and/or calculation cases

All implementers (except RWMD) give details concerning their approach from scenarios to safety models (see table 21). As for previous issues, only a few words are extracted:

- Ondraf: uses conceptual models where parameters are defined according to FEPs impacts (alternative choices of parameters, and alternative values.
- NWMO: conservative approach when developing computer codes and models (to not result in under estimation of the potential risks)
- RAWRA: robust approach was used – near field evaluations were based on container life time data and instant partial release of critical radionuclides, with combination of four potential far field (host structure) descriptions.
- POSIVA: The scenarios are defined first to illustrate simplistically different possibilities for how the repository system may evolve and perform over time in terms of situations leading to radionuclide releases. Then calculation cases are defined for each of the repository system scenarios following STUK's scenario hierarchy taking into account uncertainties in the models and parameter values used to represent radionuclide release, retention and transport.
- Andra: Once the scenario is described, the models and parameters are set. Models may depend on parameters fitting and adjustment. Such adjustments are based on available experimental data. A standard terminology for

qualifying the models and parameters have been defined to ensure that the « safety » choices are made on a standardised basis depending on the knowledge acquired for each phenomenon or material (best estimate, conservative, specified).

- GRS: This implies the abstraction of scenarios in models with the need to make assumptions and simplifications or the identification of covering calculation cases with less complexity. At the end of the VSG project it was realized that a systematic approach or formalised procedure to transform scenarios in calculation cases would be more than helpful. In this context, the mentioned aspect was adopted to the list of future R&D work as one of the outcomes of the project (not published yet).
- JAEA: application of a procedure
- KAERI provides specifications (in terms of risk and dose) and has developed a code for risk assessment.
  SKB cites the document (SKB, 2011) where the established procedure is detailed.
- US DOE NE/ DOE EM/CBFO report that safety models or calculation cases require simplifications or abstractions due to the complexity of fully coupled physical phenomena.

8.6 Use of deterministic / probabilistic approach, or a combination of both

Some approaches are purely deterministic or purely probabilistic. However a few organisation mention using both (Table 22)

- Ondraf: deterministic approach and stochastic methods of calculation applied, no probabilistic approach foreseen
- NWMO: both deterministic and probabilistic simulations are performed
- RAWRA: probabilistic evaluation
- Posiva: combination of both deterministic and probabilistic approach for analysis of the calculation cases
- Andra: Approach mainly deterministic, preliminary probabilistic studies have been performed.
- GRS: deterministic basis
- JAEA: categorisation of potential future evolution considering probability/plausibility and impact on safety functions
- Kaeri: deterministic approach
- SKB: combination of both deterministic and probabilistic approach
- RWMD: modelling approach tends to be prominently probabilistic
- Calculations performed by US DOE NE/ DOE EM/CBFO, are exclusively probabilistic.

8.7 Consideration for temporal sequences in scenario (time cut-off, climate evolution, other events or processes

Very few examples of formal time cut-off required by regulations are listed. Most of implementers refer to events and processes and may in some cases derive time-cut off on this basis. Most of the examples are relative to climatic evolution including glaciation cycle (Table 23):

- Performance assessment takes into account the climate changes (NWMO, Posiva, Andra, GRS and SKB).
- Evolution of the repository system (degradation of canisters, closing components and other THMCR processes) is also indicated (Posiva, Andra, GRS).
- The represented period is 10 000 years (Posiva, DOE NE/ DOE EM/CBFO), 1 000 000 years (NWMO, GRS, SKB) or long enough to represent the maximum dose (Andra, JAEA). A stylized biosphere or human intrusion beyond 10 000 years is also mentioned by US DOE NE/ DOE EM/CBFO.

8.8 Indicate the use of formal tools (e.g. software-based tools)

Different formal tools are listed by implementers (Table 24). They are closely associated to:

- FEP Databases: Formal tools for the management of FEP Database are used by GRS and SKB.
- Tansports: Numerical tools aiming to calculate radionuclide’s migration (and dose) are listed by Ondraf (PORFLOW and Comsol), Posiva (GoldSim and Marfa) and Andra (hydraulic and chemical transport simulation tools linked together by the ALLIANCES platform).
- Biosphere: numerical tool (UNTAMO) and assessment tools (including ERICA) are listed by POSIVA.
- Scenarios: Andra recalls the complementary formal tools used in safety assessments: functional analysis (FA), phenomenological analysis (PARS) and qualitative safety analysis (QSA). RWMD is developing its generic modelling tools including uncertainties.
- JAEA uses formal tools for arguments, safety functions and scenario development.
- NWMO and KAERI use no formal tool for scenario development.
- DOE NE/ DOE EM/CBFO and Posiva also use manage data using database tools.
- FANC, RAWRA and SSM do not answer this question.

8.9 Indicate the use of formal expert elicitation processes

- The expert elicitation of models and parameters was formalised by Ondraf (for SFC1, in the framework of “interaction meetings”). Ondraf also introduced expert range and source range for parameters.
- Posiva performed a formal expert elicitation for transport and chemical parameters.
- Andra organised an internal review process involving scientists’ experts.

- Ondraf, NWMO, Andra, GRS, KAERI and DOE NE/ DOE EM/CBFO's processes to define scenarios and FEPs are reviewed by the experts. However this expertise is internal at NWMO, GRA and DOE NE/ DOE EM/CBFO.
- Andra: Formal internal reviews are implemented and recorded in order to get experts' views and make decision. Externalisation of expert judgment may be integrated. Such reviews were organized for the dossier 2005 concerning the choice of the scenarios to be quantified and related choices of models and parameters of the safety calculation. Expert elicitation process is also formalised in the way models and parameters values are presented for internal review process.
- SKB did not use formal expert elicitation
- FANC, RAWRA, JAEA, SSM and RWMD did not answer this question

8.10 How is the propagation of uncertainties managed?

Management of uncertainties is developed by most of the implementers (Table 26):

- Uncertainty analysis and propagation of uncertainties is formally managed by Posiva, Andra, GRS and SKB.
  - Posiva defines a "Formulation of Radionuclide Release Scenarios",
  - Andra performs QSA with a special attention on the possible propagation of uncertainties and
  - GRS manages uncertainties with alternative scenarios and performs a sensitivity analysis for probable scenarios.
- Uncertainties and their propagation are key features for SKB.
- DOE NE/ DOE EM/CBFO manages uncertainties thanks to their probabilistic approach.
- Uncertainties are also taken into account (with no formal method for uncertainty propagation) by NWMO who performs probabilistic simulations based on parameter distribution range.
- JAEA studies the uncertainty/factors tree.
- Ondraf hasn't defined a process to derive scenarios with uncertainty management yet.
- RAWRA, KAERI, SSM and RWMD did not answer this question.

9. Discuss why the current scenario definition and analysis approach is appropriate for this project at present.

9.1 Discuss why the current scenario definition and analysis approach is appropriate for this project at present

Posiva, GRS, JAEA, Kaeri and RWMD gave a global answer to question 4:

- Posiva presents the TURVA-2012 safety case portfolio and concludes that it is appropriate,
- For GRS, the scenario development was appropriate for VSG project and future developments (concerning reproducibility and probabilities) will be undertaken,
- JAEA will further check the appropriateness of its scenario development process,
- At this stage, RWMD do not have an active programme of work for scenario definition.

9.2 Describe the process used to determine if your project's contributors internally agree that the set of scenarios carried out in the safety analysis is sufficiently complete / comprehensive for the purpose at hand

NWMO, Posiva, Andra, SKB and DOE NE/ DOE EM/CBFO hold exchanges with internal experts in view to improve the definition of scenarios and related models:

- NWMO holds a series of meetings with internal experts in geosciences, engineering and repository safety
- For Posiva, internal contributors could add comments on scenarios in the scope of meetings and workshops
- In the scope of ISO9001, Andra organised groups of review aiming to discuss about scenarios and related models and parameters
- For SKB, members of the project and internal experts reviewed the assessment report
- DOE NE/ DOE EM/CBFO held internal meetings between data providers and data users, allowing some improvements in the models

9.3 Provide details of acceptance in terms of regulatory compliance feedback, outcomes of external reviews

NWMO, Posiva, Andra, JAEA, SKB and DOE NE/ DOE EM/CBFO report about regulatory feedback and external reviews (Table 29):

- According to NWMO, the methodology is determined by the applicant. CNSC however confirmed that the guiding principles of CNSC Guide G-320 were followed.

- Posiva is undergoing an acceptance process in terms of regulatory compliance feedback.
- Andra is subject to various external councils (presented in Table 11). Their remarks and recommendations are taken into account.
- JAEA had no requirements on the definition and consideration of scenarios yet. However, NUMO intends to hold reviews with stakeholders and experts.
- For SKB, the SR-Site assessment is currently under review by the Swedish regulator SSM. Its safety case has also been reviewed by an international review team.
- The US NUREG has satisfactory reviewed and certified DOE NE/ DOE EM/CBFO's methodology for FEPs.

9.4 Provide details of experience base for judging the current approach provides transparency in communicating the basis of the safety case

NWMO, JAEA, SKB and DOE NE/ DOE EM/CBFO have got a good feedback from communicating about their approach (Table 30):

- NWMO regularly communicates via reports, website, peer reviews, conferences, journals and collaborations
- JAEA's current scenario development approach (not used yet) will improve transparency and traceability
- SKB had a positive experience of communicating its scenario approach
- DOE NE/ DOE EM/CBFO says that communication to non-technical audiences can be improved

9.5 Describe the externalization of expert judgements used through scenario development (To elicit FEPs? To review scenario development?)

ONDRAF, NWMO, Posiva, Andra, JAEA, KAERI, SKB and DOE NE/ DOE EM/CBFO describe their use of external expert judgements, while Posiva had not externalization of expert judgements yet:

- Ondraf: a workshop was organised in 2011, allowing fostering discussions (about interaction processes) with experts.
- NWMO participates in the international radioactive waste management program,
- Andra mentions hat QSA, scenarios and calculation cases, models and parameters will be submitted to formal reviews. Andra also indicate a series of internal revues.
- JAEA explains that a general template will support externalization of knowledge.
- KAERI perform expert elicitation of FEPs.
- For DOE NE/ DOE EM/CBFO, peer reviews were used to evaluate models and FEPs.

9.6 Addendum: Additional ideas about desirable features of the revised database?

NWMO, Posiva and DOE NE/ DOE EM/CBFO propose some recommendations for the AEN FEP database:

- NWMO gives some recommendations which concern the international FEP database
- Posiva deals with biosphere related FEPs
- RWMD approach was favourably reviewed by an NEA review team. Their previous approach for scenario definition will be reviewed and applied to specific site.
- DOE NE/ DOE EM/CBFO benefited from the NEA FEP database, but they notice that their organisation would be more appropriate in a matrix form rather than in their current list form.

Annex 1: General/Context/Regulatory requirement

Table 2 Answers to the Question 1: Stage of the national program and disposal concept

Organisation / Role	Stage of the national program and disposal concept
FANC Regulator	2011: ONDRAF/NIRAS submitted a Waste Plan to the Federal Government for a decision-in-principle. July 2013: the decision of the government is still pending. SFC1: the first Safety and Feasibility Case, devoted to the assessment of the safety and feasibility of disposal systems in Boom and Ypresian Clays, located in one or several potentially suitable zones with a view to supporting a decision of the type "go for siting". SFC 2: the second Safety and Feasibility Case would be site-specific, provides evidence of the absence of any major safety- or feasibility-related obstacle to implementation. Based on the SFC 2, a go-ahead for launching the detailed site-specific studies needed to prepare the license application could be given
Ondraf/Niras Implementer	The last major safety assessment exercise dates back to 2001 (SAFIR 2). The assessment was based on the Boom Clay as reference site: Mol. A preliminary assessment of Ypresian Clays has been also undertaken. A peer review of the SAFIR 2 report and made the following statements: • The focus on the poorly indurated argillaceous formation, Boom Clay, is considered to be promising and justified. • The studies on the Ypresian Clays as an alternative to the Boom Clay are considered to be appropriate • SAFIR 2 presents a strong platform for planning the future work, as it presents a comprehensive summary of the work done on methodological development. • The Belgian programme for the disposal of high-level and long-lived radioactive waste is well developed and sufficiently advanced to address the siting issue. Based on this review, Ondraf/Niras established a new geological programme to compile its first Safety & Feasibility Case (SFC1) dedicated to the reference & alternative rocks as potential formation to host a geological disposal (focus should be mainly or entirely on clay host rocks). Different milestones were accomplished on the way to SFC1: • The realisation of a SEA in 2010 (Strategic Environment Assessment) for the "waste Plan" that compares the environmental impacts of different impacts: Deep boreholes, Long term storage, Storage awaiting advanced nuclear technologies and Geological disposal

	• The realisation and presentation to the public of the so-called Ondraf/Niras Waste plan (2011) that explains the ins and outs of the different options. • "R&D programme: Status" that will be published in the coming months, presenting an overview of the on-going research programme (2014) Note that a decision on the long-term management of radioactive waste was requested by Ondraf/Niras to the government upon publication of the "Waste Plan" in order to precise the scope and the aim of the SFC 1. Since the Belgian authorities have not yet taken any position Ondraf/Niras has decided to publish the R&D programme status report to communicate the work done so far.
NWMO Implementer	In 2002, the Government of Canada passed the Nuclear Fuel Waste Act, resulting in the creation of the Nuclear Waste Management Organization (NWMO) to develop and implement a plan for the long-term care of the nation's used nuclear fuel. The Nuclear Fuel Waste Act requires the nuclear fuel waste owners – Ontario Power Generation, New Brunswick Power Corporation, Hydro-Québec (HQ), and Atomic Energy of Canada Limited – to establish segregated trust funds to finance the NWMO's operations and the long-term management of used fuel. 2005: the NWMO submitted a proposal to the Minister of Natural Resources for the management of used nuclear fuel and a recommended approach. 2007, the Government of Canada supported the APM approach for the long-term management of used nuclear fuel. Technically, APM has as its end point the containment and isolation of used nuclear fuel in a deep geological repository constructed in an appropriate rock formation where the used fuel will be safely and securely contained by engineered barriers and the surrounding geology. 2010: The NWMO initiated the siting process to all interested communities in Saskatchewan and Ontario. The site selection process is designed to ensure, above all, that the site selected is safe, secure, and located in an informed and willing host community. The process must meet the highest scientific, professional and ethical standards. The safety and appropriateness of any potential site will be evaluated through a series of progressively more detailed scientific, technical and social assessments over a series of steps spanning many years. A robust safety case will need to demonstrate with confidence that the project can be safely implemented at the site and can meet or surpass the requirements of regulatory authorities. These studies include a series of community well-being assessments, each designed to develop a profile of the social, economic and cultural factors that need to be taken into consideration when determining the project's potential impact on community life, and technical assessments to see whether the local geology could support a strong safety case for the used nuclear fuel repository. The NWMO is now in the fourth year of implementing the siting process. The large number of communities engaged in learning more about the project – 21 by the end of 2012 – illustrates the success of this approach and that it continues to reflect the values and priorities of the Canadian public. The NWMO has suspended new expressions of interest from potential host communities.
RAWRA Implementer	Seven potential sites (6 in granite, one in metamorphic structure) are potential sites for DGR. Till 2015, two sites have to be defined as candidates. Direct disposal in steel containers is the preferred option for disposal of spent fuel produced by existing six reactors. For future nuclear units, reprocessing and disposal of HLW is considered. HLW should be disposed in vitrified form. Start of operation of repository is still planned

	to 2065
POSIVA Oy Implementer	Posiva Oy has submitted a construction license application (CLA) for a geological disposal facility of spent nuclear fuel (SNF) to the Finnish government at the end of 2012, supported by a post-closure safety case assessing the long-term safety of the facility. The repository site, Olkiluoto, located in the crystalline geology, has been extensively studied since the early 80s including the construction of the underground disposal facility ONKALO, started in 2004. Posiva's current reference repository design, KBS-3V, is based on a multi-barrier principle where copper-iron canisters containing spent nuclear fuel are emplaced individually in vertical deposition holes, surrounded by bentonite buffer. Deposition holes are located in deposition tunnels (at the depth of 400 to 450 m) which are to be backfilled and plugged. The design of the repository system (along with the layout) is at the mature level required for the CLA and has evolved in a step-wise fashion incorporating new knowledge of the Olkiluoto site and improved understanding of the engineered barrier system evolution and updates in SNF inventory
ANDRA Implementer	The December 30, 1991 French Waste Act [1] entrusted Andra, the French national agency for radioactive waste management, with the task of assessing the feasibility of deep geological disposal. This Act initiated a research programme to define methods for the long-term management of intermediate-level-long-lived and high-level radioactive waste (IL-LL/HL) with the objective to produce a report after 15 years of investigations, including (i) a feasibility-assessment report on clay formations namely the dossier 2005 Argile based notably on the work conducted on the site of the Meuse/Haute-Marne Underground Laboratory and in foreign laboratories. The law of 1991 states the main principles to be taken into account in the research initiative, and in particular, the necessity of working "by respecting the protection of the nature, environment and health" and "taking into consideration the right of future generation". Three main iteration loops have been identified since 1991, each corresponding to a major milestone of the program: License application for construction and operation of the underground research laboratory (in 1996), submission of the Dossier 2001 (in December 2001), and the submission of the Dossier 2005 (in December 2005), the feasibility assessment report. In that framework, the "Dossier 2005 Argile" [2], presents the studies carried out for the deep disposal project in a geological formation and proposes a repository design in the Callovo-Oxfordian clay host rock, a 150 m thick clay layer at an approximate mean depth of 500 m, located in the Meuse/Haute-Marne area, East of France. In this dossier, an area of 250 km² (transposition zone (ZT)) was defined. Accompanying the publishing of the dossier 2005 Argile, three main steps occurred: ▪ From July to December 2005, reviews of the Dossier 2005 were conducted by the regulatory authority (Nuclear Safety Authority, NSA, with the help of the technical support IRSN, Institut de Radioprotection et de Sûreté Nucléaire), by the National Evaluation Council (CNE) and by an international review team under the auspices of the NEA (see also Question 2). ▪ September 2005 to January 2006, a national public debate was organised. ▪ On 28 June 2006, the new 2006 French Programme Act is published [3]. The 28th June 2006 Act entitled Programme National de Gestion des Matières et Déchets Radioactifs (National program for radioactive waste and nuclear material management) has set the deep geological repository in clay host rock as the selected solution for IL-LL and HL waste disposal in France.

	According to this 2006 Act, reversible waste disposal in a deep geological formation and corresponding studies and investigations shall be conducted with a view to selecting a suitable site and to designing a repository. On the basis of the conclusions of those studies, the application for the authorisation of such a repository will be reviewed in 2015 and, subject to that authorisation; the repository will be commissioned in 2025. The Act stipulates that a national plan of management of the materials and the radioactive waste ("PNGMDR") makes an assessment of existing modes of management of the materials and radioactive waste. It is transmitted to the parliament and updated every three years. During the examination of the authorization of creation, the safety of the center is estimated with regard to the various stages of its management, including its permanent closure. Only a law can authorize this one. The authorization fixes the minimal duration during which, as precaution, the reversibility of the repository must be insured. This duration cannot be lower than 100 years. Since the publication of the Act, the "dossier 2009", comprising among others a safety option report and a site selection document which has proposed a 30 km² area (ZIRA) within the transposition zone for detailed geological investigations in view of the underground implementation of the disposal has been transmitted to the Nuclear Safety Authority. Since 2011, the project has entered an industrial design development phase and has become the Centre industriel de stockage en milieu géologique (Cigéo). In the present document, the « Dossier 2005 Argile » is used as reference, but other primary references may be used as much as necessary, such as French Act, Guidance and safety rules issued by the Nuclear Safety Authority. Other references such as the presentation made at the symposium hold in Paris in January 2007 [4], and the INTESC questionnaire [5] have been used when applicable.
GRS / BfS Research institute / Implementer	Radioactive waste disposal policy in Germany is based on the decision that all types of radioactive waste are to be disposed of in deep geological formations. Konrad: disposal site for short-lived and long-lived radioactive waste with negligible heat generation, licensed on 22 May 2002, in charged by BfS. The safety analysis for Konrad was performed in the 1980s. Morsleben: was used as a repository for low- and intermediate-level radioactive waste from 1971 until 1998. Until 1998, a waste volume of about 37,000 m3 with a total activity of approx. 4.5·1014 Bq had been disposed of. The license for operating Morsleben does not include the license for the closure of the repository. BfS prepared a closure license application in 1990. The respective documents were submitted to the licensing authority and published in 2009. Citizens that are concerned about the project were given the opportunity to address their objections to the licensing authority. The filed objections were discussed within a public hearing organized by the licensing authority in mid of October 2011. In addition to the evaluations of the licensing authority a peer review of the safety case has been performed by the German Entsorgungskommission (ESK – Nuclear Waste Management Commission). This repository is not directly comparable with a newly constructed repository in an undisturbed host formation. Gorleben: a potential site for heat-generating waste since late 1970s. Neither a decision in favour of Gorleben as repository site nor a final statement on the actual suitability of the site until now. A Preliminary Safety Analysis for Gorleben (VSG), has been conducted from July 2010 to March 2013 to sum up the results of the Gorleben

	investigation achieved so far, to update the concepts like for emplacement, repository layout, sealing and performance assessment and to compile remaining open questions /18/. In addition two other studies concerning disposal of heat generating waste have previously been performed in Germany. In the project ISIBEL a new strategy for the safety case for disposal of HLW in rock salt has been developed /4/. Another activity was the project VerSi that was launched by the BfS with the aim to develop a methodology based on long-term safety assessments to compare two waste repository sites in different host rocks. In this context ÅF Colenco, GRS Cologne and GRS Braunschweig developed a set of scenarios to be investigated for comparison of the two sites /5/.
JAEA / NUMO Implementer / Research	Programme stage: Open solicitation of municipalities nationwide, seeking areas to investigate their feasibility as a possible location of a final repository Disposal concept: Waste: HLW (vitrified waste) and TRU waste Concept: a multi-barrier system consisting of engineered and natural (geological) barriers Project overview document： "Geological Disposal of Radioactive Waste in Japan" (2008) <http://www.numo.or.jp/en/publications/pdf/HLW_200808.pdf>
KAERI Research	National program has not been decided yet. The Korean government and nuclear industry have sought to propose a national policy for the safe management of spent fuel. The Atomic Energy Commission, a top-policy making body of nuclear energy in Korea, reviewed and confirmed "A Long-term Development Plan for Future Nuclear Energy System" at the 255th meeting, which was held on December 22, 2008. The plan is based on the draft R&D action plan prepared by the Ministry of Education, Science and Technology (MEST) in 2007, and includes the R&D efforts on SFR fuel cycle with proliferation-resistant pyro-processing, whereby spent PWR fuel can be converted into a metal fuel and recycled back into the SFRs. Korea is expected to significantly reduce its accumulated amount of spent fuel via pyro-processing, and thus reduce the number and size of the required repositories, as well as reducing the decay time. However, the Long-term Development Plan for Future Nuclear Energy System remains an R&D plan, there is no any official policy in in Korea for the disposal of the HLW wastes from a pyro-processing facility. For the disposal concept of a spent fuel, the depth of the repository is 500 m below. The canister consists of (i) an outer shell for corrosion resistance, and (ii) an insert for mechanical strength. Similar types of canister were introduced in countries such as Sweden and Finland. Copper and nodular cast iron are selected as the materials for the outer shell and the insert, respectively. For the disposal concept of high-level waste from pyro-processing, high-level waste and metal waste are disposed of at 500m and 200m level, respectively. Two cylindrical are emplaced in a storage canister and one disposal canister accommodates 14 storage canisters by 2 layers. Similar to the disposal concept of a spent fuel, the disposal canister consists of an inner container for the structural strength and radiation

	shielding, and an outer shell for corrosion resistance. The inner container is made of cast-nodular iron to resist static loads by the groundwater pressure and swelling pressure of the buffer material. The outer shell is made of copper to resist corrosion loads in the disposal environments. Metal waste consists of hull materials and support frames, which generate negligible heat and radiation. However, they are polluted with a very small amount of TRU. Then, nine storage canisters are placed in a metal waste disposal package (MWDP) made of polymer concrete. The size of MWDP is 130 cm × 130 cm × H 127 cm. The disposal package is sealed with an unsaturated polyester paste. The MWDP is placed at a 200 m deep disposal tunnel. The gap between packages and tunnel is filled by compact bentonite and backfill materials.
SKB Implementer	The following refers to SKB's program for the handling of spent nuclear fuel. Several decades of research and development has led SKB to put forward the KBS-3 method for the final stage of spent nuclear fuel management. An interim storage facility and a transportation system are today (September 2013) in operation. Two principal remaining tasks in the programme are to build and operate i) a final repository for spent nuclear fuel and ii) an encapsulation plant in which the spent fuel will be emplaced in canisters to be deposited in the final repository. SKB has carried out site investigations for a final repository in the municipalities of Östhammar (Forsmark area) and Oskarshamn (Laxemar area). In June 2009, the Forsmark site was selected by SKB as the site for the final repository. In March 2011, applications to build a final repository for spent nuclear fuel at Forsmark and an Encapsulation plant at Oskarshamn were made. The safety assessment SR-Site (SKB, 2011) supports the licence application for the final repository.
SSM Regulator	On 16 March 2011, SSM received a license application submitted by the Swedish Nuclear Fuel and Waste Management Company (SKB) for construction of a spent nuclear fuel repository to be located in Forsmark, Östhammar Municipality, and in addition an encapsulation facility for spent nuclear fuel in Oskarshamn. SSM is currently reviewing the license application and this is expected to continue until at least early 2015 when the SSM statement to the Swedish Land and Environment Court should be completed according to the present time plan. The main hearing of the Court is expected to commence later that year.
RWMD/EA Implementer	In the UK it is Government policy that the preferred option for long-term management of higher activity radioactive wastes is geological disposal, preceded by a period of surface storage. (Note, in Scotland the policy is interim near-surface, near-site storage.) The UK Government has also announced that a site for a geological disposal facility will be found through a process of voluntarism and partnership. The Managing Radioactive Waste Safely (MRWS) process was launched in 2008 as a staged approach to finding a volunteer community and implementing geological disposal. There is currently a consultation and review of this process and a new process is expected to be launched in 2014. Therefore, at the current time there is no site identified for a geological disposal facility (GDF). As the disposal concept and design will be intimately dependent on the geological setting of the GDF location, there is also no preferred concept or design. NDA-RWMD's work is therefore currently generic. Our generic safety case is based on three different generic geological settings: higher strength rock, lower strength sedimentary rock and evaporites – with illustrative concept examples for each of these settings based on those developed internationally.
DoE NE &	Defence transuranic wastes are being disposed of in WIPP, a deep geologic repository

EM/CBFO Implementer	in salt, in south-eastern New Mexico. It has been operating 14 years. High-level radioactive wastes (HLW) and used nuclear fuel (UNF) are being stored at multiple locations. A recent statement of the policy for managing these materials is available in a document called the Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste http://energy.gov/downloads/strategy-management-and-disposal-used-nuclear-fuel-and-high-level-radioactive-waste The two programs (WIPP and the Used Fuel Disposition (UFD) program of DOE-NE) use essentially the same FEP approach, and historically have shared resources. Because of the mature status of WIPP as an operating facility, its FEPs baseline is updated as part of each recertification application, but mainly focuses on the existing (baseline) FEPs for WIPP. These updates are minimal and usually reflect advances in human activities (such as drilling or mining) and any new monitoring data that might alter previous screening decisions. Active FEP development work relevant to the purpose of this questionnaire primarily occurs within the DOE-NE UFD program. The DOE-NE UFD FEPs are generic in nature; they are applicable to a range of disposal concepts and geologic settings.

Table 3 Responses to question 1d: Any prescriptive requirements regarding FEP, scenarios, or approaches for scenario development and/or classification

Organisation Role	1d. Any prescriptive requirements regarding FEP, scenarios, or approaches for scenario development and/or classification?
FANC Regulator	Laws and technical guides are giving regulatory requirements on the definition and consideration of scenarios in safety evaluations. Four categories of scenarios are defined: • A scenario representative of the expected evolution; • Unexpected (but possible) scenarios • Human intrusion scenarios • Penalising scenarios to represent the evolution of the system when the performances of the disposal system can no more be assessed correctly.
Ondraf/Niras Implementer	Scenarios are discussed mainly in two guidances (written in French) intitled: • Guide technique « Critères de Radioprotection pour l'évaluation de la sureté post-opérationelle des dépots de déchets radioactifs », 2011 [RPC, 2011] • Projet de guide technique « Analyse de la sûreté post-fermeture des établissements de stockage définitif de déchets radioactifs », [SAR, 2012] [Categories of scenarios are defined but] the guidances do not mention how these scenarios should be developed. They mention that the implementer should strive for completeness of the uncertainties + show a transparent, traceable and appropriate process.
NWMO Implementer	Safety assessments must address the expectations of the Canadian Nuclear Safety Commission (CNSC), as outlined in CNSC Guide G-320, Assessing the Long Term Safety of Radioactive Waste Management. They are designed to support the safety case for a licence application to construct a used fuel repository. A safety case is defined as the integration of arguments and evidence that describe, quantify and substantiate the safety, and the level of confidence in the safety, of the deep geological repository and associated facilities. This definition is consistent with the CNSC Guide G-320 as well as international guidance. Key objectives for long-term management are containment and isolation of the waste, in accordance with the CNSC Guide G-320. The guide states, "containment can be achieved through a robust design based on multiple barriers providing defence-in-depth. Isolation is achieved through proper site selection and, when necessary, institutional controls to limit access and land use". CNSC Guide G-320 addresses the need for scenarios in the safety assessment and the need to adequately document the selection process. The scenarios should be "sufficiently comprehensive to account for all of the potential future states of the site and the biosphere. It is common for a safety assessment to include a central scenario of the normal, or expected, evolution of the site and the facility over time, and additional scenarios that examine the potential impact of disruptive events or modes of containment failure." "A safety assessment should present and justify the techniques and criteria used to develop the scenarios that are analysed. Scenarios should be developed in a systematic, transparent, and traceable manner through a structured analysis of relevant features, events, and processes (FEPs) that are based on current and

	future conditions of site characteristics, waste properties, and receptor characteristics and their lifestyles. The approach to scenario development should be consistent with the rigor of the assessment, taking into consideration the purpose of the assessment, the hazard of the waste, and the nature of the decision for which the assessment is being undertaken. Accordingly, scenario development can range from "brainstorming" to formal analysis of FEPs and extrapolation of current lifestyle information.
RAWRA Implementer	There are no special legal requirements for development of scenarios and classification and its specifications described below. In fact, there exists just a methodical procedure described as a potential content of safety report. In practice, it is required that the time frame of safety assessment covers all maximum doses in evaluated scenarios. Scenarios have to cover normal evolution, altered evaluation and intrusion
POSIVA Oy Implementer	The formulation of scenarios is constrained by the Government Decree VNA 736 (GD 736/2008) and the Finnish regulatory STUK's draft Guide YVL D.5 (STUK 2011) as follows: GD 736/2008, Chapter 1, Section 2 and definitions "13) expected evolution scenario shall refer to such change affecting the performance of the barriers that has a high probability of causing radiation exposure during the assessment period and which can be caused by interactions occurring in the disposal facility, by geological or climatic phenomena or by human action; and 14) unlikely events impairing long-term safety shall refer to such potential events significantly affecting the performance of the barriers that have a low probability of causing radiation exposure during the assessment period and which can be caused by geological phenomena or by human action." According to these definitions, the base and variant scenarios as defined in Guide YVL D.5 belong to the expected evolution taking into account the uncertainties highlighted in the assessment of the expected evolution (POSIVA 2012-04), and the disturbance scenarios take into account unlikely events impairing long-term safety (see Figure 1). ***Figure 1.*** *Scenario classification according to Guide YVL D.5 (draft 4, STUK 2011).* The scenarios are constructed from FEPs taking them systematically into account to check when, where and how the safety functions of each of the components in the repository system might be affected. The technical compliance with the design requirements, which will influence the evolution of the system, and therefore a constraint to be taken into account in formulating the scenarios, is given in a series of Production Line reports and in the Description of the Disposal System report (POSIVA 2012-05). In fact, the scenarios are the result of the interplay between the initial state of the disposal system, the FEPs affecting it, and assessments of the performance of the system over time. Moreover, in formulating the scenarios the experience gained in previous safety assessments, and the improvements in knowledge on technical capabilities and of the site, are taken into account while continuing to keep in mind the regulations given by STUK and by the Government.
ANDRA Implementer	For the Dossier 2005, the Basic Safety Rule RFS III.2.f of 1991 [6] provided a framework for long term safety expectations with respect to disposal design principles, favourable geological media choice criteria and study modalities. It

	presents the basic objectives which must serve as guidelines for the work on a geological disposal:
	• "The protection of people and the environment in the short and long term is the basic objective assigned to a waste repository in a deep geological formation"
	• The long term safety of the repository must not "depend on an institutional control on which we cannot absolutely rely beyond a limited period".
	Furthermore, studies should show the ability to limit potential consequences to a level as low as reasonably possible (ALARA). The concept should include a multiple barrier system (namely the packages containing the waste, the engineered barrier, the geological medium itself), and rely on passive repository evolution without institutional control beyond a given timeframe (500 years).
	The revised version of the Basic Safety Rule in 2008 (French Nuclear Safety Authority guide of 2008 [7]) keeps the same objectives of protection of people and the environment but indicates the major expectations with respect to a potential site, set the safety principles and the design bases of the repository bound to the safety, and set the method for the demonstration of the repository safety. It also indicates that both Radiological and chemical impacts are to be evaluated.
	It accounts for dispositions from the Environmental Code, from the Public Health Code and from the June 28th French Act. It also account for international recommendations (AIEA, NEA, and CIPR).
	The guide requires safety to be quantitatively evaluated by the means of "situations" that encompass different possible evolutions of the repository that can be reasonably foreseen. The safety guide stipulates that two kinds of situations have to be addressed in the safety demonstration, « a reference situation » and « altered situations »:
	• The " reference situation" refers to knowledge of the phenomena governing the evolution of the waste repository including the underground water circulation modeling with radionuclides transfers. Events to consider are:
	  - Events due to the presence of the repository, and to the overall degradation processes of waste packages and engineered components (thermal effect, gas, mechanical effects, transient processes such as desaturation…).
	  - A set of most probable natural events (climate change, seismic activity, subsidence or uplift, sedimentation and erosion cycles).
	• « Altered situations » refer to events with low probability, yet plausible, occurring in case of natural events (high seismic activity, unusual glaciation...), or human actions likely to alter the expected behaviour. (…)

GRS/BfS Research / Implementer	Reference /6/ is the fundamental regulatory basis for the scenario development for a repository for heat generating (high-level) waste. A corresponding regulatory basis for a low- and intermediate-level waste repository does not exist. In the following the essential requirements of /6/ regarding the mentioned issues in the questionnaire are cited (quotes are indicated with quotation marks). The relation to the scenario development issue is given in the following overall safety requirement /6/: "7.2 Prior to any major decision pursuant to chapter 5.1, a comprehensive, site specific safety analysis and safety assessment covering a period of one million

	years must be carried out to provide evidence of long-term safety. This shall comprise all information, analyses and arguments verifying the long-term safety of the final repository, and shall justify the reasons why this assessment is to be trusted. In particular, this assessment and the documentation thereof should include the following points (…) The comprehensive identification and analysis of safety-relevant scenarios and their allocation to probability categories pursuant to chapter 6 (…)" There are three defined classes of developments (/6/ chapter 2. Definitions and explanations of terms): Note: The used term development is a synonym for scenario. "Probable developments refer to normal developments forecasted for this site, and developments normally observed at comparable locations or similar geological situations. The forecasted normal development of properties should be used as a basis when considering the technical components of the final repository. If quantitative data on the probability of a certain development occurring is available, and the probability of it occurring in relation to the reference period is at least 10%, this shall be considered a probable development." "Less probable developments refer to developments which may occur for this site under unfavourable geological or climatic assumptions and which have rarely occurred in comparable locations or comparable geological situations. A consideration of the technical components of the final repository should be based on the normal forecasted development of their properties upon occurrence of the respective geological development. Any unfavourable developments in the properties of the technical components that deviate from normal development should also be investigated. Repercussions on the geological environment should be considered. Apart from such repercussions, anticipated geological developments should also be taken into account. Within such a development, the simultaneous occurrence of several unrelated faults should not be assumed. If it is possible to make a quantitative statement on the probability of a certain development or an unfavourable development in a technical component's properties, this should be taken into account if the probability in relation to the reference period is at least 1%." "Improbable developments refer to developments which are not expected to occur at the site even under unfavourable assumptions, and which have not been observed in comparable locations or comparable geological situations. Statuses and developments for technical components which can be more or less excluded by taking certain action, as well as the simultaneous, independent failure of several components, are classed as improbable developments." The assignment of safety-relevant scenarios to probability classes is also addressed in the ESK (Nuclear Waste Management Commission) guideline /7/.
JAEA / NUMO Implementer / Research	There have been no concrete and formal regulatory requirements on the definition and consideration of scenarios specified for geological disposal of HLW and TRU waste yet. While, Nuclear Regulatory Authority published "Commonly Important Issues for the Safety Regulation of Radioactive Waste Disposal"1), which highlighted the importance of applying a risk-informed approach to safety regulations to allow appropriate handling of the uncertainties associated with the long-term assessments required for the period after active control. This requirement has been applied to a discussion on a sub-surface disposal for low-level radioactive waste2) and the risk-informed safety regulations involved

	categorization of scenarios for safety assessment in terms of their likelihood of occurrence and comparison of the assessment results with target doses assigned for each scenario category (scenarios are divided into four categories: likely scenario (probable and normally expected scenario); less-likely scenarios (scenarios considered for important variations); very unlikely scenarios (scenarios considered for very unlikely natural events); and human intrusion scenarios (scenarios considered for inadvertent human actions). The target doses for the assessment are defined2): 1) not exceed 10 μSv per year for the likely scenario, 2) not exceed 300 μSv per year for the less-likely scenarios, 3) not exceed 10-100 mSv per year for the very unlikely scenarios and 4) not exceed 10-100 mSv per year for the human intrusion scenarios. This set of target doses is under rethinking at Nuclear Regulatory Authority (see the response to Question 2.a.).
KAERI Research	Scenarios in safety evaluations are defined in draft guideline of "General Standard on Deep Geological Disposal Facility for HLW" and represent an assumed set of conditions used to estimate release and transport of radionuclides, and resulting radiological consequences.
SKB Implementer	See response from the Swedish Radiation Safety Authority, SSM.
SSM Regulator	In Sweden, legal and/or regulatory requirements on the definition and consideration of scenarios in safety evaluations of geological disposal of radioactive wastes are in the following publications: • The Swedish Radiation Safety Authority's regulations concerning safety in connection with the disposal of nuclear material and nuclear waste, SSMFS 2008:21 • The Swedish Radiation Safety Authority's Regulations Concerning the Protection of Human Health and the Environment in Connection with the Final Management of Spent Nuclear Fuel and Nuclear Waste, SSMFS 2008:37 Both of these two documents contain two parts: one which includes the regulatory requirements and another which includes guidelines on the application of the mandatory regulations. The role of scenarios is addressed in SSMFS2008:21 covering safety in connection with the disposal of nuclear material and nuclear waste. The most basic requirement of safety analysis it that it shall cover features, events and processes that can lead to spreading of radioactive substances after sealing of the facility (9§). More information is provided in appendix 1 containing the required content of safety assessment covering post-closure safety, e.g. the following items related to scenarios shall be included: • A reporting of how one or several methods have been used to describe the passive system of barriers and its evolution in time. The method(s) shall give a clear picture of how features, events and processes can affect the barriers and the barrier functions. • A reporting of how one or several methods have been used to identify scenarios for event sequences and circumstances that affect the future evolution of the repository. There shall be a main scenario which covers the most probable natural evolution of the repository and its surroundings. • The safety analysis shall include descriptions of the geosphere, biosphere and repository evolution for the selected scenarios including the main

	scenario and those shall also address the impact on the surroundings. The scenarios shall consider malfunctions of engineered barriers and other identified uncertainties. In the guidance associated with these regulations SSMFS 2008:21, three types of scenarios are identified: • A main scenario which should cover a probable evolution of the repository and its surrounding environment based on realistic assumptions (although conservative assumptions may be used for internal conditions when needed). A distinction is made between external conditions such as the climate evolution and internal conditions such as those driven by the properties of the nuclear waste. The main scenario should cover events that are likely to occur and events that cannot be proven to be unlikely to occur. Imperfections such as those caused by manufacturing processes should be addressed. A range of the known uncertainties should be covered in the main scenario by for instance inclusion of several different calculation cases. • A number of less likely scenarios should be developed to address scenario uncertainty. These scenarios should cover alternative event and time sequences and uncertainties that are not addressed in the main scenario. • A number of residual scenarios which are studied irrespective of scenario probability for different purposes. One purpose is to strengthen confidence in the application of the multibarrier principle through the understanding of the role of individual barriers and barrier functions in the overall safety case. Another purpose is to study consequences of human intrusion and consequences of not sealing the final repository after its operational phase. The judgment regarding the protective capability of a final repository should be based on a number of scenarios which together illustrate the most significant developments and events of key importance for the repository performance. It is acknowledged in the guidance that considerable uncertainties exist regarding the evolution of climate in distant time scales. The risk analysis can therefore be simplified such that it includes a few feasible climate evolution sequences. These should include the most important and reasonably foreseeable climate states and their effect on the repository performance and consequences in the environment and on human health. Each case should include consistent biosphere objects (with the climate state) and should individually fulfill the regulatory target value. For the longer time periods addressed in the safety assessment, results should be regarded as illustrations of the repository evolution and its protective capability assuming a range of given conditions.
RWMD/EA Implementer	The relevant regulatory guidance for the implementation of geological disposal in the UK is [Geological Disposal Facilities on Land for Solid Radioactive Wastes: Guidance on Requirements for Authorisation, February 2009] – the GRA – issued by the UK environment agencies. This guidance sets out 5 principles and 14 requirements for the development of a GDF. There are no prescriptive requirements regarding FEPs, scenarios or approaches for scenario development and/or classification. The only scenarios mentioned in the regulatory guidance relate to human intrusion. A risk guidance level is stated as follows: “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.” However, this risk

	guidance level does not apply to human intrusion after the period of authorisation, where the relevant requirement states: "The developer/operator of a geological disposal facility should assume that human intrusion after the period of authorisation is highly unlikely to occur. The developer/operator should consider and implement any practical measures that might reduce this likelihood still further. The developer/operator should also assess the potential consequences of human intrusion after the period of authorisation." The regulatory guidance identified three classes of human intrusion: 1) intrusion with full knowledge of the existence, location, nature and contents of the GDF; 2) intrusion without prior knowledge of the GDF; and 3) intrusion with knowledge of the existence of underground workings but without understanding what they contain. Only the second two classes need to be considered in the safety case. The regulatory guidance states that due to the uncertainty in the timing and type of human intrusion events they should be explored as 'what-if' scenarios, separate from the scenarios representing evolution of the disposal system undisturbed by human intrusion. These human intrusion scenarios should be based on human actions using technology and practices similar to those available today and based on past and presently observed habits and behaviours of people. The regulatory guidance also states: "Scenarios should include all human actions associated with any material removed from the facility, including considering what is then done with this material. The number of people involved in actions associated with intrusion should be assessed, and may be assumed to be similar to the typical number involved in similar actions now or historically. Similarly, the number of people who might be exposed as a result of occupying the site or neighbourhood after the intrusion should also be assessed." (GRA, para 6.3.44).
DoE NE & EM/CBFO Implementer	US regulations require a comprehensive consideration of FEPs. For example the generic standard published by the Nuclear Regulatory Commission for high-level waste and used nuclear fuel disposal requires that [salient words highlighted]: [US Code of Federal Regulations (CFR), title 10, part 60 (10 CFR 60)—Disposal of high-level radioactive wastes in geologic repositories] § 60.112 Overall system performance objective for the geologic repository after permanent closure. The geologic setting shall be selected and the engineered barrier system and the shafts, boreholes and their seals shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency with respect to both anticipated processes and events and unanticipated processes and events. § 60.2 Definitions. *Unanticipated processes and events* means those processes and events affecting the geologic setting that are judged not to be reasonably likely to occur during the period the intended performance objective must be achieved, but which are nevertheless sufficiently credible to warrant consideration. Unanticipated processes and events may be either natural processes or events or processes and events initiated by human activities other than those activities licensed under this part.

	The Environmental Protection Agency standard deferred to in the above citation is 40 CFR 191, Subpart B - Environmental Standards for Disposal, says the following: 40 CFR 191.12 - Definitions *Performance assessment* means an analysis that: (1) Identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates shall be incorporated into an overall probability distribution of cumulative release to the extent practicable.

Table 4 Answers to question 1d. Any requirements on providing convincing arguments that relevant physical phenomena have been considered in an appropriately comprehensive manner

Organisation Role	**Response to item 1d3: Any requirements on providing convincing arguments that relevant physical phenomena have been considered in an appropriately comprehensive manner**
FANC Regulator	These requirements address also the following topics: • building confidence in the assessment; • performance assessment (i.e. the ability of the system and of its components to fulfil their safety functions); • radiological impact assessment. In order to establish the confidence in the assessment, the regulatory body requires among others that: • the assessment rests on best available knowledge; • the disposal system is well understood; • the identification and treatment of FEPs is traceable, well-founded and considered in an appropriately manner; • a set of scenarios representative and bounding of the possible evolutions of the system is developed; • models are shown to be appropriate to the objectives of the modelling through a justification, verification and validation process; • the uncertainties are properly analysed and treated. The regulatory body requires also that the radiological impact is not underestimated. The assessment period has to be defined so that it is possible to determine the maximum of the impact
Ondraf/Niras Implementer	The guidances do not mention how these scenarios should be developed. They mention that the implementer should strive for completeness of the uncertainties + show a transparent, traceable and appropriate process.
NWMO Implementer	CNSC Guide G-320 addresses the need for scenarios in the safety assessment and the need to adequately document the selection process. The scenarios should be "sufficiently comprehensive to account for all of the potential future

	states of the site and the biosphere. It is common for a safety assessment to include a central scenario of the normal, or expected, evolution of the site and the facility over time, and additional scenarios that examine the potential impact of disruptive events or modes of containment failure." "A safety assessment should present and justify the techniques and criteria used to develop the scenarios that are analysed. Scenarios should be developed in a systematic, transparent, and traceable manner through a structured analysis of relevant features, events, and processes (FEPs) that are based on current and future conditions of site characteristics, waste properties, and receptor characteristics and their lifestyles. The approach to scenario development should be consistent with the rigor of the assessment, taking into consideration the purpose of the assessment, the hazard of the waste, and the nature of the decision for which the assessment is being undertaken. Accordingly, scenario development can range from "brainstorming" to formal analysis of FEPs and extrapolation of current lifestyle information. "The safety assessment should demonstrate that the set of scenarios developed is credible and comprehensive. Some FEPs or scenarios may be excluded from the assessment if there is an extremely low likelihood that they would occur, or if they would have trivial impact. Considering the range of scenarios that can be developed for different waste management systems at different stages in their life cycles, applicants are expected to propose the criteria for excluding FEPs and scenarios and consult with CNSC staff as to their acceptability. The approach and screening criteria used to exclude or include scenarios should be justified and well-documented.
RAWRA Implementer	
POSIVA Oy Implementer	Guide YVL D.5, Appendix 1 A1.4 states: …"The scenarios shall be systematically constructed from features, events and processes which may be of importance to long-term safety and which may arise from interactions within the disposal system, caused by radiological, mechanical, thermal, hydrological, chemical, biological or radiation induced phenomena external factors, such as climate changes, geological processes or human actions." YVL D.5 307 states: "In applying the dose constraints, such environmental changes need to be considered that arise from changes in ground level in relation to sea. The climate type as well as the human habits, nutritional needs and metabolism can be assumed to remain unchanged." YVL D.5 317 states: "Disposal shall not affect detrimentally to species of fauna and flora. This shall be demonstrated by assessing …assuming the present kind of living populations."
ANDRA Implementer	(…) The guide set the main safety functions (declined from the first function of protection of people and environment): • Resisting water circulation, • Confine radioactivity, • Isolate waste from surface phenomena and human activity. Demonstration of safety must rely upon: • Verification of the performance of the components • Evaluation of disturbances induced by the repository • Evaluation of individual effective dose

	• Situations taken into account (reference situation and altered situations).
	The guide requires safety to be quantitatively evaluated by the means of "situations" that encompass different possible evolutions of the repository that can be reasonably foreseen. The safety guide stipulates that two kinds of situations have to be addressed in the safety demonstration, « a reference situation » and « altered situations »:
	• The « reference situation » refers to knowledge of the phenomena governing the evolution of the waste repository including the underground water circulation modeling with radionuclides transfers. Events to consider are:
	  Events due to the presence of the repository, and to the overall degradation processes of waste packages and engineered components (thermal effect, gas, mechanical effects, transient processes such as desaturation…).
	  A set of most probable natural events (climate change, seismic activity, subsidence or uplift, sedimentation and erosion cycles).
	For this situation, the calculated individual effective Dose shall not exceed the value of the 0.25mSv/year.
	(…)
	• « Altered situations » (…)

GRS/BfS Research / Implementer	There are no requirements which refer explicitly to this issue. But the above mentioned paragraph 7.2 /6/ requires a comprehensive consideration of safety-relevant scenarios. According to /6/ (chapter 2) a scenario is defined inter alia by future events and processes. These factors comprise also relevant physical phenomena.
JAEA / NUMO Implementer / Research	There have been no concrete and formal regulatory requirements on the definition and consideration of scenarios specified for geological disposal of HLW and TRU waste yet. While, Nuclear Regulatory Authority published "Commonly Important Issues for the Safety Regulation of Radioactive Waste Disposal"1), which highlighted the importance of applying a risk-informed approach to safety regulations to allow appropriate handling of the uncertainties associated with the long-term assessments required for the period after active control. In this discussion, considering physical and chemical evolution of repository system, division of time frame in defining repository conditions, as base of scenario development, was proposed. It is required for demonstration of compliance that the results of safety analyses for scenarios developed in all categories should satisfy the targeted dose defined for each category. No time cut-off is given for safety assessment.
KAERI Research	
SKB Implementer	See response from the Swedish Radiation Safety Authority, SSM.
SSM Regulator	The role of scenarios is addressed in SSMFS2008:21 covering safety in connection with the disposal of nuclear material and nuclear waste. The most basic requirement of safety analysis it that it shall cover features, events and processes that can lead to spreading of radioactive substances after sealing of the facility (9§). More information is provided in appendix 1 containing the required content of safety assessment covering post-closure safety, e.g. the following items related to scenarios shall be included: • A reporting of how one or several methods have been used to describe the passive system of barriers and its evolution in time. The method(s) shall

	give a clear picture of how features, events and processes can affect the barriers and the barrier functions. • A reporting of how one or several methods have been used to identify scenarios for event sequences and circumstances that affect the future evolution of the repository. There shall be a main scenario which covers the most probable natural evolution of the repository and its surroundings. • The safety analysis shall include descriptions of the geosphere, biosphere and repository evolution for the selected scenarios including the main scenario and those shall also address the impact on the surroundings. The scenarios shall consider malfunctions of engineered barriers and other identified uncertainties.
RWMD/EA Implementer	
DoE NE & EM/CBFO Implementer	Yes. The afore-cited definition of performance assessment includes these words: "releases caused by all significant features, events, processes, and sequences of events and processes" –the word "all" indicating that a case needs to be made for completeness. The regulatory criteria applicable to WIPP is more specific, note the last three statements in this list of requirements, especially the last requirement which involves explaining why a FEP was not considered: [40 CFR 194--Criteria for the certification and re-certification of the waste isolation pilot plant's compliance with the 40 CFR part 191 Disposal regulations § 194.32 Scope of performance assessments] (a) Performance assessments shall consider natural processes and events, mining, deep drilling, and shallow drilling that may affect the disposal system during the regulatory time frame. (b) Assessments of mining effects may be limited to changes in the hydraulic conductivity of the hydrogeologic units of the disposal system from excavation mining for natural resources. Mining shall be assumed to occur with a one in 100 probability in each century of the regulatory time frame. Performance assessments shall assume that mineral deposits of those resources, similar in quality and type to those resources currently extracted from the Delaware Basin, will be completely removed from the controlled area during the century in which such mining is randomly calculated to occur. Complete removal of such mineral resources shall be assumed to occur only once during the regulatory time frame. (c) Performance assessments shall include an analysis of the effects on the disposal system of any activities that occur in the vicinity of the disposal system prior to disposal and are expected to occur in the vicinity of the disposal system soon after disposal. Such activities shall include, but shall not be limited to, existing boreholes and the development of any existing leases that can be reasonably expected to be developed in the near future, including boreholes and leases that may be used for fluid injection activities. (d) Performance assessments need not consider processes and events that have less than one chance in 10,000 of occurring over 10,000 years. (e) Any compliance application(s) shall include information which: (1) Identifies all potential processes, events or sequences and

	combinations of processes and events that may occur during the regulatory time frame and may affect the disposal system; (2) Identifies the processes, events or sequences and combinations of processes and events included in performance assessments; and (3) Documents why any processes, events or sequences and combinations of processes and events identified pursuant to paragraph (e)(1) of this section were not included in performance assessment results provided in any compliance application.

Table 5 Answer to question 1d: Any specifications on how compliance with requirements could be demonstrated? (including consideration of non-human biota)

Organisation Role	**Response to item 1d2: Any specifications on how compliance with requirements could be demonstrated? (including consideration of non-human biota)**
FANC Regulator	The regulatory body requires also that the radiological impact is not underestimated. The assessment period has to be defined so that it is possible to determine the maximum of the impact.
Ondraf/Niras Implementer	6.2. **Scénarios d'évolution attendue** 6.2.1. Conformément à l'Arrêté Royal Déchets, la contrainte de dose applicable dans le cas d'un dépôt est déterminée dans les conditions de l'autorisation de création et d'exploitation de ce dépôt et sera au maximum de 0.3 mSv/an pour l'exposition de personnes du public. 6.2.2. Dans le cas du dépôt cAt en surface à Dessel et d'un dépôt géologique, l'AFCN proposera de fixer, dans les conditions de l'autorisation de création et d'exploitation de ces dépôts, une contrainte de dose de 0.1 mSv/an. 6.2.3. Cette contrainte de dose s'applique exclusivement aux situations d'exposition planifiée imputables au dépôt et couvertes par le(s) scénario(s) d'évolution attendue (scénario(s) EES). Au-delà de quelques milliers d'années, la valeur de cette contrainte ne constitue qu'une valeur de référence utilisée pour apprécier l'acceptabilité de l'impact associé à ce(s) scénario(s). 6.3**. Scénarios d'évolution non attendue mais possible** 6.3.1. La contrainte de risque s'applique aux expositions potentielles raisonnablement envisageables qui sont imputables au dépôt et qui sont couvertes par les scénarios représentant les évolutions non attendues mais possibles du système de dépôt et / ou de son environnement autres que celles associées à l'intrusion humaine (scénarios AES) [3, 7]. Cette contrainte s'applique à chaque scénario AES dont la probabilité d'occurrence peut être quantifiée. La contrainte de risque ne s'applique pas aux scénarios pénalisants. 6.3.2. L'acceptabilité de l'impact d'une exposition non-attendue mais raisonnablement envisageable dont la probabilité d'occurrence ne peut être quantifiée devra être appréciée compte tenu de l'impact potentiel exprimé en termes de dose efficace, d'indicateurs complémentaires et de la vraisemblance de cette exposition. Dans ce cas, la contrainte de dose est considérée comme une valeur de référence. 6.3.3. Il revient à l'opérateur de justifier que la probabilité de l'impact d'une

	exposition non attendue mais raisonnablement envisageable n'est pas quantifiable. 6.3.4. Au-delà de quelques milliers d'années et tant que l'on se situe dans la phase de préservation des performances, la contrainte de risque ne constitue qu'une valeur de référence utilisée pour apprécier l'acceptabilité de l'impact. 6.3.5. Le risque de détriment individuel2 imputable aux expositions potentielles doit être inférieur à 10-6/an. 6.4. **Scénarios pénalisants** 6.4.1 La valeur de dose de référence utilisée pour juger l'acceptabilité de l'impact associé aux scénarios dits « pénalisants » de [3] est de 3 mSv/an.
NWMO Implementer	
RAWRA Implementer	
POSIVA Oy Implementer	YVL D.5 306 states: "Disposal of nuclear waste shall be planned so that as a consequence of expected evolution scenarios: 1) the annual dose to the most exposed people shall remain below the value of 0.1 mSv, and 2) the average annual doses to other people shall remain insignificantly low. These constraints are applicable in an assessment period, during which the radiation exposure of humans can be assessed with sufficient reliability, and which shall extend at a minimum over several millennia (GD 736/2008)". YVL D.5 307 states: "In applying the dose constraints, such environmental changes need to be considered that arise from changes in ground level in relation to sea. The climate type as well as the human habits, nutritional needs and metabolism can be assumed to remain unchanged." YVL D.5 317 states: "Disposal shall not affect detrimentally to species of fauna and flora. This shall be demonstrated by assessing …assuming the present kind of living populations." Detailed requirements on unlikely events and non human biota are stated in The Finnish STUK's regulations in the following way: […] "The importance to safety of such incidental event shall be assessed and whenever practicable, the resulting annual radiation dose or activity release shall be calculated and multiplied by its estimated probability of occurrence. The obtained expectation value shall be below the radiation dose constraint given in paragraph 306 or the activity release constraint given in paragraph 312. The probability of such radiation exposure which might imply deterministic radiation impacts (at least a dose of 0,5 Sv), shall be extremely low." ***Protection of other living species*** "Disposal shall not affect detrimentally to species of fauna and flora. This shall be demonstrated by assessing the typical radiation exposures of terrestrial and aquatic populations in the disposal site environment, assuming the present kind of living populations. The assessed exposures shall remain clearly below the levels which, on the basis of the best available scientific knowledge, would cause decline in biodiversity or other significant detriment to any living population."
ANDRA Implementer	For the Dossier 2005, the Basic Safety Rule RFS III.2.f of 1991 [6] provided a framework for long term safety expectations with respect to disposal design principles, favourable geological media choice criteria and study modalities. It presents the basic objectives which must serve as guidelines for the work on a geological disposal:

	• "The protection of people and the environment in the short and long term is the basic objective assigned to a waste repository in a deep geological formation" • The long term safety of the repository must not "depend on an institutional control on which we cannot absolutely rely beyond a limited period". Furthermore, studies should show the ability to limit potential consequences to a level as low as reasonably possible (ALARA). The concept should include a multiple barrier system (namely the packages containing the waste, the engineered barrier, the geological medium itself), and rely on passive repository evolution without institutional control beyond a given timeframe (500 years). The revised version of the Basic Safety Rule in 2008 (French Nuclear Safety Authority guide of 2008 [7]) keeps the same objectives of protection of people and the environment but indicates the major expectations with respect to a potential site, set the safety principles and the design bases of the repository bound to the safety, and set the method for the demonstration of the repository safety. It also indicates that both Radiological and chemical impacts are to be evaluated. Demonstration of safety must rely upon: • Verification of the performance of the components • Evaluation of disturbances induced by the repository • Evaluation of individual effective dose • Situations taken into account (reference situation and altered situations). (…) For this ["reference"] situation, the calculated individual effective Dose shall not exceed the value of the 0.25mSv/year.
GRS/BfS Research / Implementer	The following requirements refer to specific conditions (e.g. effective dose) for the classes of development /6/: "6.2 For the post-closure phase, evidence must be provided that for probable developments through the release of radionuclides from the emplaced radioactive waste, an additional effective dose in the range of only 10 microsieverts per year can occur for individuals. Individuals with today's life expectancy and with a lifetime of exposure are to be taken considered." "6.3 For a less probable development in the post-closure phase, evidence must be provided that the additional effective dose caused by the release of radionuclides from the emplaced radioactive waste does not exceed 0.1 millisieverts per year for the individuals affected. Here too, individuals with today's life expectancy and with a lifetime of exposure are to be considered. For these types of developments, higher releases of radioactive substances are admissible because the occurrence of such developments is less probable." "6.4 For improbable developments, reasonable risks or reasonable radiation exposure have not been quantified. However, where such developments may lead to high radiation exposure, it is necessary to investigate, within the context of optimisation, whether it is possible to reduce such effects with a reasonable input. However, this must not impair optimisation in relation to other developments." "6.5 For developments associated with unintentional penetration of the isolating rock zone, reasonable risks or reasonable radiation exposure have not been quantified." There are no explicit dose limits for non-human biota but this aspect is part of the

	protection goals of the safety requirements in general. A fundamental aim of the safety requirements /6/ is to outline the purpose, basic principles and requirements for preventive and protective measures in order to protect man and the environment from the harmful effects of ionising radiation. The following requirements in form of a protection goal and a protection principle refer to the environmental aspect in more detail /6/: Protection goal: “3.1 To permanently protect man and the environment from ionising radiation and other harmful effects of such waste” Protection principal: “4.3 Final disposal must not endanger species diversity. Provided man as an individual is protected from ionising radiation, it is assumed that terrestrial ecosystems and other species are also protected.” There are no requirements which refer explicitly to this issue. But the above mentioned paragraph 7.2 /6/ requires a comprehensive consideration of safety-relevant scenarios. According to /6/ (chapter 2) a scenario is defined inter alia by future events and processes. These factors comprise also relevant physical phenomena.
JAEA / NUMO Implementer / Research	This requirement has been applied to a discussion on a sub-surface disposal for low-level radioactive waste2) and the risk-informed safety regulations involved categorization of scenarios for safety assessment in terms of their likelihood of occurrence and comparison of the assessment results with target doses assigned for each scenario category (scenarios are divided into four categories: likely scenario (probable and normally expected scenario); less-likely scenarios (scenarios considered for important variations); very unlikely scenarios (scenarios considered for very unlikely natural events); and human intrusion scenarios (scenarios considered for inadvertent human actions). The target doses for the assessment are defined2): 1) not exceed 10 μSv per year for the likely scenario, 2) not exceed 300 μSv per year for the less-likely scenarios, 3) not exceed 10-100 mSv per year for the very unlikely scenarios and 4) not exceed 10-100 mSv per year for the human intrusion scenarios. This set of target doses is under rethinking at Nuclear Regulatory Authority (see the response to Question 2.a.).
KAERI Research	Scenarios in safety evaluations are defined in draft guideline of “General Standard on Deep Geological Disposal Facility for HLW” and represent an assumed set of conditions used to estimate release and transport of radionuclides, and resulting radiological consequences.
SKB Implementer	See response from the Swedish Radiation Safety Authority, SSM.
SSM Regulator	For risk calculation purposes, scenario probability should be estimated and justified as far as possible (although this does not cover residual scenarios). In addition to demonstrating compliance with risk/dose target values, safety assessment should identify appropriate functional requirements and performance targets for construction of the repository and its components. In this context, the guidance suggests that identified and analyzed scenarios should be used to establish design basis cases as a basis for functional requirements and performance targets. The judgment regarding the protective capability of a final repository should be based on a number of scenarios which together illustrate the most significant developments and events of key importance for the repository performance. It is

	acknowledged in the guidance that considerable uncertainties exist regarding the evolution of climate in distant time scales. The risk analysis can therefore be simplified such that it includes a few feasible climate evolution sequences. These should include the most important and reasonably foreseeable climate states and their effect on the repository performance and consequences in the environment and on human health. Each case should include consistent biosphere objects (with the climate state) and should individually fulfil the regulatory target value.
RWMD/EA Implementer	
DoE NE & EM/CBFO Implementer	See italicized portion of EPA's 40 CFR 191 quoted above. It is a cumulative-release standard, but the same standard also requires that potential doses be calculated to humans, but not biota, although the human dose calculation assumes the degree of contamination in foodstuffs (plant and animal) eaten by a local resident: § 191.15 Individual protection requirements. (a) Disposal systems for waste and any associated radioactive material shall be designed to provide a reasonable expectation that, for 10,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual committed effective dose, received through all potential pathways from the disposal system, to any member of the public in the accessible environment, to exceed 15 millirems (150 microsieverts). The EPA standard that applied only to the one time proposed Yucca Mountain repository stipulated a compliance demonstration similar to the 191.15 Individual protection requirement: [40 CFR Part 197, Public Health and Environmental Radiation Protection Standards for Yucca Mountain, NV - Subpart B—Public Health and Environmental Standards for Disposal - § 197.12 What definitions apply in subpart B?] *Performance assessment* means an analysis that: (1) Identifies the features, events, processes, (except human intrusion), and sequences of events and processes (except human intrusion) that might affect the Yucca Mountain disposal system and their probabilities of occurring during 10,000 years after disposal; (2) Examines the effects of those features, events, processes, and sequences of events and processes upon the performance of the Yucca Mountain disposal system; and (3) Estimates the annual committed effective dose equivalent incurred by the reasonably maximally exposed individual, including the associated uncertainties, as a result of releases caused by all significant features, events, processes, and sequences of events and processes, weighted by their probability of occurrence.

Table 6 Any guidance to limit arbitrary speculations (ex: future human behaviour?)

Organisation Role	**10. Response to item 1d4: Any guidance to limit arbitrary speculations (ex: future human behaviour?)**
FANC Regulator	Four categories of scenarios are defined: • A scenario representative of the expected evolution; • Unexpected (but possible) scenarios • Human intrusion scenarios • Penalising scenarios to represent the evolution of the system when the performances of the disposal system can no more be assessed correctly.
Ondraf/Niras Implementer	6.5. Intrusion humaine 6.5.1. Les critères de radioprotection à utiliser pour apprécier l'acceptabilité de l'impact associé aux scénarios d'intrusion humaine dans un dépôt en surface font l'objet du guide technique spécifique [8].
NWMO Implementer	CNSC Guide G-320 addresses the need for scenarios in the safety assessment and the need to adequately document the selection process. The scenarios should be "sufficiently comprehensive to account for all of the potential future states of the site and the biosphere. It is common for a safety assessment to include a central scenario of the normal, or expected, evolution of the site and the facility over time, and additional scenarios that examine the potential impact of disruptive events or modes of containment failure."
RAWRA Implementer	
POSIVA Oy Implementer	YVL D.5 307 states: "In applying the dose constraints, such environmental changes need to be considered that arise from changes in ground level in relation to sea. The climate type as well as the human habits, nutritional needs and metabolism can be assumed to remain unchanged." YVL D.5 317 states: "Disposal shall not affect detrimentally to species of fauna and flora. This shall be demonstrated by assessing …assuming the present kind of living populations." The regulations state that human actions are to be regarded as external factors to the disposal system. Posiva understands this as all human actions being external factors to the repository system, but that this is not the case in the surface environment. The evolution of the surface environment, the fate of radionuclides released into it and the exposure of humans, plants and animals are strongly coupled with human actions, especially how humans utilise the site and its resources. Hence, some human actions are regarded as interactions within the disposal system, such as agricultural practices (cf. POSIVA 2012-07). Dose assessment time window. The regulations require that the dose assessment shall be carried out when it can be performed with sufficient reliability and that it shall extend at a minimum over several millennia. Uncertainties in predicting the behaviour of future human generations will rapidly increase with time; a reliable prediction beyond just a few generations would be difficult to make. However, the regulations state (Guide YVL D.5, 307) that human habits, nutritional needs and metabolism may be assumed to remain unchanged when deriving radiation dose estimates for compliance assessment. The position of Posiva is that it is appropriate to assume that present-day conditions, such as those relating to land use and demographic data, can be

	applied throughout the whole dose assessment period. This limitation on changes in the behaviour of future human generations leads to the judgement that the dose assessment can be considered to be performed with sufficient reliability until the conditions of the surface environment due to natural development are no longer sufficiently reliably predicted. Uncertainties in predicting the conditions of the natural development of the surface environment, especially in the prediction of land formation, will increase with time. The position of Posiva is that these predictions are sufficiently reliable for the purpose of a prospective dose assessment for up to ten millennia. Hence, Posiva judges that assessing radiation doses to humans can be performed with sufficient reliability in the period up to 10 000 years after disposal of the first waste canister in the repository. Detailed requirements on unlikely events and non-human biota are stated in The Finnish STUK's regulations in the following way: "Unlikely events induced by natural phenomenon to be considered shall include at least rock movements jeopardizing the integrity of disposal canisters. Unlikely events caused by human actions to be considered shall include at least boring a medium-deep water well at the site and a core drilling or boring hitting a disposal canister. In such case it is assumed that the existence of the disposed waste is not known and that the event cannot take place earliest 200 years after the closure of the disposal facility."
ANDRA Implementer	The guide requires safety to be quantitatively evaluated by the means of "situations" that encompass different possible evolutions of the repository that can be reasonably foreseen. The safety guide stipulates that two kinds of situations have to be addressed in the safety demonstration, « a reference situation » and « altered situations »: • (…) • « Altered situations » refer to events with low probability, yet plausible, occurring in case of natural events (high seismic activity, unusual glaciation...), or human actions likely to alter the expected behaviour. They concern Major climatic changes (including changes due to human activity, greenhouse effect), Exceptional vertical movements or earthquakes, Various possible forms of human intrusion, Waste package defects, and engineered barrier defects (seal defects). As regards Human intrusion, Andra should define the scenarios regardless of the probability of the event, after memory of the existence of the disposal is lost (estimated at 500 years). The guide recommends accounting for climatic events in the definition of biosphere leading to the description of biospheres typical of the different climatic states that can be foreseen in the future.
GRS/BfS Research / Implementer	The following requirement focuses on future human activities and how this safety relevant aspect has to be analysed /6/: "5.2 Optimisation of the final repository with regard to reliable isolation of the radioactive materials in the final repository from future human activities shall be carried out as a secondary priority to the aforementioned optimisation targets. As future human activities cannot be forecasted, a variety of reference scenarios for unintentional human penetration of the final repository, based on common human activities at the present time, shall be analysed. Within the context of such optimisation, the aim shall also be to reduce the probability of occurrence and its radiological effects on the general public."

	The mentioned primary "optimization targets" in paragraph 5.2 refer to • Radiation protection for the operating phase • Long-term safety • Operational safety of the final repository • Reliability and quality of long-term waste containment • Safety management • Technical and financial feasibility Note: The term reference scenario in paragraph 5.2 should not be mistaken as the used term reference scenario in the scenario development. In the case of future human activities the term reference scenarios refers to stylized scenarios. Further guidance and recommendations in the context of future human activities are given in /8/ and /9/.
JAEA / NUMO Implementer / Research	Analysis based on FEPs is referred to as a tool useful for discussion on possible future states of the system and loss of barrier functions. It is prospected that such risk-informed safety regulations would also be discussed about and applied to scenario development of geological disposal taking into account differences between sub-surface disposal and geological disposal.
KAERI Research	
SKB Implementer	See response from the Swedish Radiation Safety Authority, SSM.
SSM Regulator	In the guidance associated with these regulations SSMFS 2008:21, three types of scenarios are identified: • A main scenario which should cover a probable evolution of the repository and its surrounding environment based on realistic assumptions (although conservative assumptions may be used for internal conditions when needed). A distinction is made between external conditions such as the climate evolution and internal conditions such as those driven by the properties of the nuclear waste. The main scenario should cover events that are likely to occur and events that cannot be proven to be unlikely to occur. Imperfections such as those caused by manufacturing processes should be addressed. A range of the known uncertainties should be covered in the main scenario by for instance inclusion of several different calculation cases. • A number of less likely scenarios should be developed to address scenario uncertainty. These scenarios should cover alternative event and time sequences and uncertainties that are not addressed in the main scenario. • A number of residual scenarios which are studied irrespective of scenario probability for different purposes. One purpose is to strengthen confidence in the application of the multibarrier principle through the understanding of the role of individual barriers and barrier functions in the overall safety case. Another purpose is to study consequences of human intrusion and consequences of not sealing the final repository after its operational phase. A number of complementary scenarios should be included to address unintentional impact of future human actions including intrusion into the repository. Consequence estimates related to these scenarios should be provided but those should not be included in the overall risk summation of the scenarios related to the natural evolution of the repository.

	Other specific scenarios should address hypothetical loss of barrier functions of key importance for repository performance. These should not be included in the risk summation either, but have their main role in illustrating how the different barriers contribute to long-term safety. For the longer time periods addressed in the safety assessment, results should be regarded as illustrations of the repository evolution and its protective capability assuming a range of given conditions.
RWMD/EA Implementer	There are no prescriptive requirements regarding FEPs, scenarios or approaches for scenario development and/or classification. The only scenarios mentioned in the regulatory guidance relate to human intrusion. A risk guidance level is stated as follows: “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.” However, this risk guidance level does not apply to human intrusion after the period of authorisation, where the relevant requirement states: “The developer/operator of a geological disposal facility should assume that human intrusion after the period of authorisation is highly unlikely to occur. The developer/operator should consider and implement any practical measures that might reduce this likelihood still further. The developer/operator should also assess the potential consequences of human intrusion after the period of authorisation.” The regulatory guidance identified three classes of human intrusion: 1) intrusion with full knowledge of the existence, location, nature and contents of the GDF; 2) intrusion without prior knowledge of the GDF; and 3) intrusion with knowledge of the existence of underground workings but without understanding what they contain. Only the second two classes need to be considered in the safety case. The regulatory guidance states that due to the uncertainty in the timing and type of human intrusion events they should be explored as ‘what-if’ scenarios, separate from the scenarios representing evolution of the disposal system undisturbed by human intrusion. These human intrusion scenarios should be based on human actions using technology and practices similar to those available today and based on past and presently observed habits and behaviours of people. The regulatory guidance also states: “Scenarios should include all human actions associated with any material removed from the facility, including considering what is then done with this material. The number of people involved in actions associated with intrusion should be assessed, and may be assumed to be similar to the typical number involved in similar actions now or historically. Similarly, the number of people who might be exposed as a result of occupying the site or neighbourhood after the intrusion should also be assessed.” (GRA, para 6.3.44).
DoE NE & EM/CBFO Implementer	Yes. For example, from the regulatory guidance specific to the WIPP: [40 CFR 194--Criteria for the certification and re-certification of the waste isolation pilot plant's compliance with the 40 CFR part 191 Disposal regulations] § 194.25 Future state assumptions (a) Unless otherwise specified in this part or in the disposal regulations, performance assessments and compliance assessments conducted pursuant the provisions of this part to demonstrate compliance with § 191.13, § 191.15 and part 191, subpart C shall assume that characteristics of the future remain what they are at the time the compliance application is prepared, provided that such characteristics are not related to hydrogeologic, geologic or climatic conditions.

	(b) In considering future states pursuant to this section, the Department shall document in any compliance application, to the extent practicable, effects of potential future hydrogeologic, geologic and climatic conditions on the disposal system over the regulatory time frame. Such documentation shall be part of the activities undertaken pursuant to § 194.14, Content of compliance certification application; § 194.32, Scope of performance assessments; and § 194.54, Scope of compliance assessments. (1) In considering the effects of hydrogeologic conditions on the disposal system, the Department shall document in any compliance application, to the extent practicable, the effects of potential changes to hydrogeologic conditions. (2) In considering the effects of geologic conditions on the disposal system, the Department shall document in any compliance application, to the extent practicable, the effects of potential changes to geologic conditions, including, but not limited to: Dissolution; near surface geomorphic features and processes; and related subsidence in the geologic units of the disposal system. (3) In considering the effects of climatic conditions on the disposal system, the Department shall document in any compliance application, to the extent practicable, the effects of potential changes to future climate cycles of increased precipitation (as compared to present conditions). The guidance for the one time proposed Yucca Mountain repository with respect to human behaviour (biosphere) and the single require human intrusion evaluation is quite specific: § 197.15 How must DOE take into account the changes that will occur during the next 10,000 years after disposal? The DOE should not project changes in society, the biosphere (other than climate), human biology, or increases or decreases of human knowledge or technology. In all analyses done to demonstrate compliance with this part, DOE must assume that all of those factors remain constant as they are at the time of license application submission to NRC. § 197.26 What are the circumstances of the human intrusion? For the purposes of the analysis of human intrusion, DOE must make the following assumptions: (a) There is a single human intrusion as a result of exploratory drilling for ground water; (b) The intruders drill a borehole directly through a degraded waste package into the uppermost aquifer underlying the Yucca Mountain repository; (c) The drillers use the common techniques and practices that are currently employed in exploratory drilling for ground water in the region surrounding Yucca Mountain; (d) Careful sealing of the borehole does not occur, instead natural degradation processes gradually modify the borehole; (e) Only releases of radionuclides that occur as a result of the intrusion and that are transported through the resulting borehole to the saturated zone are projected; and (f) No releases are included which are caused by unlikely natural processes and events.

	The guidance for the WIPP repository is quite different as already cited above, requiring that "mining shall be assumed to occur with a one in 100 probability in each century of the regulatory time frame."

Table 7 Any guidance on the role and/or use of the safety functions concept?

Organisation Role	Response to item 1d5: Any guidance on the role and/or use of the safety functions concept?
FANC Regulator	These requirements address also the following topics: • building confidence in the assessment; • performance assessment (i.e. the ability of the system and of its components to fulfil their safety functions); • radiological impact assessment. In order to establish the confidence in the assessment, the regulatory body requires among others that: • the assessment rests on best available knowledge; • the disposal system is well understood; • the identification and treatment of FEPs is traceable, well-founded and considered in an appropriately manner; • a set of scenarios representative and bounding of the possible evolutions of the system is developed; • models are shown to be appropriate to the objectives of the modelling through a justification, verification and validation process; • the uncertainties are properly analysed and treated. In order to assess the performance of the system, the regulatory body requires that the implementer evaluates: • the ability of the system and of its components to fulfil their safety functions (as described in the safety concept); • the relative contribution of the different components; • the robustness of the disposal system.
Ondraf/Niras Implementer	
NWMO Implementer	Key objectives for long-term management are containment and isolation of the waste, in accordance with the CNSC Guide G-320. The guide states, "containment can be achieved through a robust design based on multiple barriers providing defence-in-depth. Isolation is achieved through proper site selection and, when necessary, institutional controls to limit access and land use".
RAWRA Implementer	
POSIVA Oy Implementer	The scenarios are constructed from FEPs taking them systematically into account to check when, where and how the safety functions of each of the components in the repository system might be affected.
ANDRA Implementer	(…) The guide set the main safety functions (declined from the first function of protection of people and environment):

	• Resisting water circulation, • Confine radioactivity, • Isolate waste from surface phenomena and human activity. Demonstration of safety must rely upon: • Verification of the performance of the components • Evaluation of disturbances induced by the repository • Evaluation of individual effective dose • Situations taken into account (reference situation and altered situations).
GRS/BfS Research / Implementer	The term safety function is defined as follows (/6/ chapter 2): "A safety function is a property or process occurring in the final repository system which guarantees compliance with safety-related requirements in a safety-related system or subsystem or individual component. The combined action of all such functions ensures compliance with all safety requirements, both during the operating phase and the postclosure phase of the final repository." Besides, the term is used throughout the safety requirements /6/. Especially as part of further definitions, e.g. barrier, containment, robustness and safety analysis (cf. /1/ chapter 2). Furthermore, the safety function philosophy is an inherent part of the safety concept both in the operational and post closure phase (cf. /6/ paragraphs 5.1, 7.1, 7.2.2, 7.2.3, 7.4, 8.1, 8.6, 8.7). However, it should be noted that safety functions in the context of scenario development are not mandatory. That is, there are no requirements whether or not to consider safety functions for the underlying methodology of scenario development.
JAEA / NUMO Implementer / Research	
KAERI Research	
SKB Implementer	See response from the Swedish Radiation Safety Authority, SSM.
SSM Regulator	See table 2.3 and 2.4
RWMD/EA Implementer	There is no formal guidance on the role or use of safety functions, although the GRA defines 'environmental safety functions' as "the various ways in which components of the disposal system may contribute towards environmental safety, e.g. the host rock may provide a physical barrier function and may also have chemical properties that help to retard the migration of radionuclides."
DoE NE & EM/CBFO Implementer	No.

Table 8 Any requirements to estimate quantitative probabilities for scenarios?

Organisation Role	Response to item 1d6: Any requirements to estimate quantitative probabilities for scenarios?
FANC Regulator	
Ondraf/Niras Implementer	6.3. Scénarios d'évolution non attendue mais possible 6.3.1. La contrainte de risque s'applique aux expositions potentielles raisonnablement envisageables qui sont imputables au dépôt et qui sont couvertes par les scénarios représentant les évolutions non attendues mais possibles du

	système de dépôt et / ou de son environnement autres que celles associées à l'intrusion humaine (scénarios AES) [3, 7]. Cette contrainte s'applique à chaque scénario AES dont la probabilité d'occurrence peut être quantifiée. La contrainte de risque ne s'applique pas aux scénarios pénalisants. 6.3.2. L'acceptabilité de l'impact d'une exposition non-attendue mais raisonnablement envisageable dont la probabilité d'occurrence ne peut être quantifiée devra être appréciée compte tenu de l'impact potentiel exprimé en termes de dose efficace, d'indicateurs complémentaires et de la vraisemblance de cette exposition. Dans ce cas, la contrainte de dose est considérée comme une valeur de référence. 6.3.3. Il revient à l'opérateur de justifier que la probabilité de l'impact d'une exposition non attendue mais raisonnablement envisageable n'est pas quantifiable. 6.3.4. Au-delà de quelques milliers d'années et tant que l'on se situe dans la phase de préservation des performances, la contrainte de risque ne constitue qu'une valeur de référence utilisée pour apprécier l'acceptabilité de l'impact. 6.3.5. Le risque de détriment individuel imputable aux expositions potentielles doit être inférieur à 10-6/an.
NWMO Implementer	"The safety assessment should demonstrate that the set of scenarios developed is credible and comprehensive. Some FEPs or scenarios may be excluded from the assessment if there is an extremely low likelihood that they would occur, or if they would have trivial impact. Considering the range of scenarios that can be developed for different waste management systems at different stages in their life cycles, applicants are expected to propose the criteria for excluding FEPs and scenarios and consult with CNSC staff as to their acceptability. The approach and screening criteria used to exclude or include scenarios should be justified and well-documented.
RAWRA Implementer	
POSIVA Oy Implementer	The formulation of scenarios is constrained by the Government Decree VNA 736 (GD 736/2008) and the Finnish regulatory STUK's draft Guide YVL D.5 (STUK 2011) as follows: GD 736/2008, Chapter 1, Section 2 and definitions "13) expected evolution scenario shall refer to such change affecting the performance of the barriers that has a high probability of causing radiation exposure during the assessment period and which can be caused by interactions occurring in the disposal facility, by geological or climatic phenomena or by human action; and 14) unlikely events impairing long-term safety shall refer to such potential events significantly affecting the performance of the barriers that have a low probability of causing radiation exposure during the assessment period and which can be caused by geological phenomena or by human action." "The importance to safety of such incidental event shall be assessed and whenever practicable, the resulting annual radiation dose or activity release shall be calculated and multiplied by its estimated probability of occurrence. The obtained expectation value shall be below the radiation dose constraint given in paragraph 306 or the activity release constraint given in paragraph 312. The probability of such radiation exposure which might imply deterministic radiation impacts (at least a dose of 0,5 Sv), shall be extremely low."
ANDRA Implementer	(see question 1d1)
GRS/BfS Research / Implementer	There are no requirements for the estimation of quantitative probabilities for scenarios. But if quantitative data on the occurrence probability of a certain development can be derived or are available then the scenarios in question can be

	assigned to the above mentioned classes of development (probable, less probable and improbable).
JAEA/NUMO Implementer/ Research	
KAERI Research	
SKB Implementer	See response from the Swedish Radiation Safety Authority, SSM.
SSM Regulator	For risk calculation purposes, scenario probability should be estimated and justified as far as possible (although this does not cover residual scenarios).
RWMD/EA Implementer	There is no explicit requirement in the GRA to estimate quantitative probabilities for scenarios; however, as the quantitative regulatory guidance level is a risk criterion, there is an implicit requirement to assess the probability of unlikely events and scenarios in order to assess their risk.
DoE NE & EM/CBFO Implementer	Yes, applicable US regulations are probabilistic regulations, hence they require that, as already cited above, performance calculations must include: "releases caused by all significant features, events, processes, and sequences of events and processes, weighted by their probability of occurrence."

Table 9 Any requirements on Time cut-off to account for in scenario development?

Organisation Role	**Response to item 1d7: Any requirements on Time cut-off to account for in scenario development?**
FANC Regulator	The regulatory body requires also that the radiological impact is not underestimated. The assessment period has to be defined so that it is possible to determine the maximum of the impact
Ondraf/Niras Implementer	6.2. Scénarios d'évolution attendue 6.2.1. Conformément à l'Arrêté Royal Déchets, la contrainte de dose applicable dans le cas d'un dépôt est déterminée dans les conditions de l'autorisation de création et d'exploitation de ce dépôt et sera au maximum de 0.3 mSv/an pour l'exposition de personnes du public. 6.2.2. Dans le cas du dépôt cAt en surface à Dessel et d'un dépôt géologique, l'AFCN proposera de fixer, dans les conditions de l'autorisation de création et d'exploitation de ces dépôts, une contrainte de dose de 0.1 mSv/an. 6.2.3. Cette contrainte de dose s'applique exclusivement aux situations d'exposition planifiée imputables au dépôt et couvertes par le(s) scénario(s) d'évolution attendue (scénario(s) EES). Au-delà de quelques milliers d'années, la valeur de cette contrainte ne constitue qu'une valeur de référence utilisée pour apprécier l'acceptabilité de l'impact associé à ce(s) scénario(s).
NWMO Implementer	
RAWRA Implementer	There are no special legal requirements for development of scenarios and classification and its specifications described below. In fact, there exists just a methodical procedure described as a potential content of safety report. In practice, it is required that the time frame of safety assessment covers all maximum doses in evaluated scenarios. Scenarios have to cover normal evolution, altered evaluation and intrusion
POSIVA Oy Implementer	Dose assessment time window. The regulations require that the dose assessment shall be carried out when it can be performed with sufficient reliability and that it shall

	extend at a minimum over several millennia. Uncertainties in predicting the behaviour of future human generations will rapidly increase with time; a reliable prediction beyond just a few generations would be difficult to make. However, the regulations state (Guide YVL D.5, 307) that human habits, nutritional needs and metabolism may be assumed to remain unchanged when deriving radiation dose estimates for compliance assessment. The position of Posiva is that it is appropriate to assume that present-day conditions, such as those relating to land use and demographic data, can be applied throughout the whole dose assessment period. This limitation on changes in the behaviour of future human generations leads to the judgement that the dose assessment can be considered to be performed with sufficient reliability until the conditions of the surface environment due to natural development are no longer sufficiently reliably predicted. Uncertainties in predicting the conditions of the natural development of the surface environment, especially in the prediction of land formation, will increase with time. The position of Posiva is that these predictions are sufficiently reliable for the purpose of a prospective dose assessment for up to ten millennia. Hence, Posiva judges that assessing radiation doses to humans can be performed with sufficient reliability in the period up to 10 000 years after disposal of the first waste canister in the repository.
ANDRA Implementer	[ASN doesn't give any cut-off time for the definition of scenarios]
GRS/BfS Research / Implementer	The limitation in time for safety analyses and safety assessments including scenario development corresponds to the demonstration period of one million years (cf. /6/ paragraphs 7.2, 7.2.1 and 7.2.2).
JAEA / NUMO Implementer / Research	In this discussion, considering physical and chemical evolution of repository system, division of time frame in defining repository conditions, as base of scenario development, was proposed. It is required for demonstration of compliance that the results of safety analyses for scenarios developed in all categories should satisfy the targeted dose defined for each category. No time cut-off is given for safety assessment.
KAERI Research	
SKB Implementer	See response from the Swedish Radiation Safety Authority, SSM.
SSM Regulator	
RWMD/EA Implementer	There is no stipulated time cut-off in the GRA, it is stated that the implementer must propose and justify an appropriate assessment timescale.
DoE NE & EM/CBFO Implementer	Yes, applicable US regulations have a time cut-off at 10,000 years, even in the case of the standards specific for the one time proposed Yucca Mountain repository which had a performance assessment required for 10,000 years, as cited above, but also had a requirement to continue this analysis until 1,000,000 years. The requirement beyond 10,000 years stipulated that only the FEPs considered important during the 10,000-year period were to be continued into the longer time period. However, there were FEPs known to only play a role after the 10,000 year initial compliance period, and they were explicitly named in the regulation and required to be included.

Annexe 1 : Summaries of changes since 1999 NEA Scenario Workshop held in Madrid

Table 10 Question 2-1 Changes in law, regulations or guidance regarding geological disposal

Organisation / Role	Question 2.1 Changes in law, regulations or guidance regarding geological disposal
FANC Regulator	A new Royal Decree and a technical guide related to scenarios were developed since 1999: • Royal Decree 30 november 2011 : safety requirements for nuclear facilities - Moniteur Belge du 21 décembre 2011. • Technical guide SAR « Long term safety assessment of radioactive waste disposals », AFCN (2012), 2012-02-28-FLE-5-4-4-FR, Rév. 0. See Question 1.d of the questionnaire for more information about the content of these documents
Ondraf/Niras Implementer	The regulator FANC has elaborated various guidances which have a direct consequence on the scenarios derivation: guidance SAR (2012) & guidance RPC-LT (2011) are the major ones. The concept of “penalizing scenarios” was introduced with the idea of assessing the safety of the system beyond the performances assessment period.
NWMO Implementer	In 2001, the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management came into force; Canada has been a Contracting Party since its inception. Contracting Parties are required to ensure that all stages of spent fuel management (which includes storage, transportation and disposal) include appropriate steps to protect individuals, society and the environment against radiological hazards. The safety of facilities used for spent fuel management must be considered prior to their construction and operation, and this must be done through environmental assessment processes. Safety requirements for existing and future radioactive waste management facilities explicitly apply to disposal of radioactive wastes. Activities in the transboundary movement of spent fuel and radioactive waste must comply with the conditions defined within the convention. In 2002, the Government of Canada passed the Nuclear Fuel Waste Act, resulting in the creation of the NWMO to develop and implement a plan for the long-term care of the nation’s used nuclear fuel. In 2004, the CNSC published its Regulatory Policy P-290 promoting the implementation of measures to manage radioactive waste so as to protect the health and safety of persons and the environment, provide for the maintenance of national security, and achieve conformity with measures of control and international obligations to which Canada has agreed. The Policy identifies the need for long-term management of radioactive waste and hazardous waste arising from licensed activities. In 2006, the CNSC published its Regulatory Guide G-320. The Guide addresses scenario development for assessment of the long term safety of radioactive waste storage and disposal methods
RAWRA Implementer	No change. Global answer moved to question 2-7

POSIVA Oy Implementer	In regulations the most salient change is the mention of safety functions and performance targets/targets properties (Guide YVL D.5, STUK 2011). Affects the formulation of scenarios striving for a systematic definition and classification
ANDRA Implementer	Following the publication of the Dossier 2005, new French Acts have been published, in particular the 28th June 2006 Act, law of program relative to radioactive waste and nuclear material management (Loi de Programme National relative à la gestion durable des matières et déchets radioactifs°). See answer to question 1-c for details. As regards to the post closure safety, the 28th June 2006 Act fixes the type of waste to consider in Cigéo and the conditions of reversibility. It also stipulated the application for the authorisation of such a repository to be reviewed *in 2015*.
GRS/BfS Research / Implementer	In 2010 the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) published new Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste /6/, cf. discussion below.
JAEA / NUMO Implementer / Research	"Designated Radioactive Waste Final Disposal Act" (in following part, "Final Disposal Act") that constitute the method of final disposal of high level radioactive waste was enacted in 2000. As an implementer of final disposal of HLW in Japan, the NUMO was established in October 2000 in accordance with the Final Disposal Act, approved by the Ministry of Economy, Trade and Industry (METI). In 2007, "Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors" was revised and the safety regulation system for the final disposal of HLW was established. Topical points were that classification and disposal methods of the radioactive waste were specified. To establish an adaptable safety regulation system for radioactive waste disposal, two classifications have been defined in the regulatory system. The conventional radioactive waste disposal of LLW was categorized as "Category 2 waste disposal" and disposal of HLW was categorized as "Category 1 waste disposal"1）. Following above amendment of the Act, ministerial ordinances prescribing detailed procedures for the Category 1 and 2 waste disposals were established and enacted in April 2008. Low-level radioactive waste containing long-lived nuclides (TRU waste) from Japanese nuclear fuel cycle was included in the object of NUMO's work with the cause of revision of the Final Disposal Act1）. Former regulatory organization of Japan (The Nuclear Safety Commission (NSC) and Nuclear and industrial safety agency (NISA) that was allocated in METI) was discontinued and new organization "Nuclear Regulation Authority (NRA)2)" was established in the Ministry of the Environment in 2012. For development safety regulation according to above-mentioned category of disposal, the NSC discussed commonly important issues for all types of disposal systems and provided a basic framework for safety assessment based on risk-informed approach for demonstrating compliance (see the answer to Question 1.d.). This framework requires more rigorous discussion on the probability/plausibility of each scenario based on available data/information and/or expert judgment in structured fashion. [1]Government of Japan (2011): Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, National Report of Japan for the Fourth Review Meeting. http://www.nsr.go.jp/archive/nisa/oshirase/2011/10/231024-3-2.pdf. [2] NRA Homepage: http://www.nsr.go.jp/english/.

KAERI Research	See question 2-4
SKB Implementer	Global answer moved to question 2-2
SSM Regulator	Global answer moved to question 2-2
RWMD/EA Implementer	Global answer moved to question 2-7
DoE NE & EM/CBFO Implementer	Regulations promulgated after 1999 were cited in the introductory part of this questionnaire. There has been no significant regulatory change in the way scenarios are to be addressed..

Table 11 Answers to question 2-2. External, regulatory reviews in progress or planned reconsideration of scenario definitions

Organisation / Role	**Question 2-2: External, regulatory reviews in progress or planned reconsideration of scenario definitions**
FANC Regulator	Not answered
Ondraf/Niras Implementer	The NUMO-NAGRA workshop (2010) on the scenarios has enhanced the reflections about the safety functions indicators and the formal way of assessing the propagation of the uncertainties. Since 2001 (SAFIR 2), the PROSA methodology (see also question 3) used to derived the scenarios from a multi-barriers perspective is now enriched with the safety functions perspective, thanks to the safety statements
NWMO Implementer	The CNSC informally reviewed an APM post-closure safety assessment in 2010. In their report, the CNSC recommended that subsequent case studies should address glaciations, seismicity, possible deterioration of seal material, and gas generation and migration; also, they recommended that the role played by institutional control should be discussed. In subsequent safety assessments, these recommendations were adopted. As a consequence of these informal reviews, the Normal Evolution Scenario in current safety assessments includes glaciation. Also, scenario identification was given a greater priority and a more systematic approach was adopted for identifying disruptive scenarios.
RAWRA Implementer	See above input of RAWRA Q2-1.
POSIVA Oy Implementer	Not answered
ANDRA Implementer	External reviews include: • The Nuclear Safety Authority (NSA), established by law [8]. Andra's safety cases are to be submitted to ASN for review and authorisation. The authority of nuclear safety examines the progress of Andra's program. It can call for the permanent group constituted by experts on the question of waste, to express an opinion on the produced documents. This one relies on a technical analysis driven by the Institute of radioprotection and nuclear safety (IRSN). In a general way, the recommendations concern the safety (post closure and operational) of the concepts proposed by Andra, and the quality of all the data which underline the safety evaluations. • Established by law, a National Commission (Commission Nationale d'Evaluation, CNE/NEC) is in charge of estimating annually the state of

	progress of the researches and studies relative to the management of the materials and the radioactive waste in reference to the fixed orientations of the PNGMDR [3]. The national commission of evaluation estimates the quality of the scientific works of the Andra. Since its creation in 91, it regularly auditions the scientists of Andra on all the themes bound to the acquisition of knowledge, to the modelling and to the engineering. The commission produces an annual report in which it expresses an opinion on the works driven by the Andra. This opinion and the concerned recommendations are input data to refine the priorities of the research program. • Established by decree, the scientific council (CS) of Andra is in charge of expressing opinions and recommendations on the priorities of the research program and to estimate the results. The CS consists of experts appointed by the ministries. • Also established by law, a local committee of information (Comité Local d'Information, CLI) is created at the underground laboratory (in Meuse/Haute-Marne) with a general mission of follow-up, information and dialogue regarding research about the management of radioactive waste in deep geologic layer. This Committee includes members from various authorities (State, Parliament, Senate, Mayor, local associations...) [3]. • International OECD/NEA Peer review of the dossier 2001 [9] and dossier 2005 [10]. As regards to post-closure safety, the present industrial design of Cigéo takes advantage from several external reviews of the 2005 Dossier and Dossier 2009. Relative to scenario development, these reviews provided recommendations on: • Methodology for treatment and management of uncertainties. • Approach for definition and description of biosphere. • Type of scenarios to consider. • Knowledge acquisition. As requested by ministers, a peer review was organized by the Nuclear Energy Agency of the OECD to evaluate the program of Andra as presented in the Dossier 2001 with regard to the international practices. The review team was constituted by international experts. The review expressed a general opinion, in particular on the quality of the documentation and the way the research program compares with the international standards. The review team emitted recommendations on a number of particular technical points, including the QSA. The report is available for the public [9]. The NEA peer review of Dossier 2005 [10] showed interest in the Qualitative safety analysis methodology, and recommended that it could be used ex ante, for the definition of future scenarios, rather than ex post. Andra's view is that the method is now mature enough to be used in such a manner. The review considered that QSA offers an integrated vision of all uncertainties, by taking into account the various types of treatment (design, scenarios and calculation cases). Some recommendations from IRSN and NSA aimed at clarifying the approach for definition and description of biospheres, in particular futures biospheres accounting for climatic evolution. Some recommendations on the type of scenarios to consider and knowledge acquisition have also been made by IRSN and NSA (see "altered situations" to consider in answer to question 1-d). The 2008 NSA guide [7] provides a list of situations and events to consider, including human intrusions.

GRS/BfS Research / Implementer	For the ERAM repository, a scenario analysis was requested by the regulator. Four scenarios or groups of scenarios were defined for this analysis /3/: (1) Undisturbed evolution, (2) Release of dissolved contaminants after fluid intrusion, (3) Release of gaseous contaminants after fluid intrusion, (4) Release of contaminants in case of unintended human intrusion. For each scenario the details were defined through expert assessment. The German Entsorgungskommission (ESK – Nuclear Waste Management Commission) suggested performing a systematic scenario analysis on the basis of a FEP catalogue as it was done in the VSG /10/, see also section 3.b. This approach will be followed in the next step of the licensing application procedure.
JAEA / NUMO Implementer / Research	Along to the basic concept on safety regulation established by the NSC (see the answers to Questions 1.d. and 2.a. above), on-going study on scenario development is in particular focusing on how to classify scenarios based on their probability/plausibility. The roles of safety functions are also being discussed in this context. Regulatory review on specified stage(s) of implementation will be carried out and will check suitability of scenarios and also future plan etc at that time [e.g. [1]). [1] http://www.numo.or.jp/en/jigyou/new_eng_tab03.html.
KAERI Research	See question 2-4
SKB Implementer	[moved from question 2-1] Since 1999, SKB's scenario methodology has considerable developments. In particular, the concept of safety functions has been introduced plays a key role in the selection of scenarios for the assessment. The scenario approach now taken is best described in (SKB, 2011), section 2.5.8 and chapter 11. The safety functions are described in chapter 8 of the same report. The development has primarily been driven by SKB's own need for a consistent and comprehensive scenario selection approach in the safety assessment. The following is also of relevance for the development since 1999: • The regulation SSMFS 2008:21 includes some requirements on scenarios, see further the response to question 1d. • A first version of the current approach was presented in the so called SR-Can assessment (SKB, 2006). Feedback regarding this first version of the approach was obtained in the regulatory review of SR-Can (Dverstorp and Strömberg 2008). The feedback was essentially positive, with some requirements for development of details and need for clarifications. These considerations were taken into account when developing the final approach described in (SKB, 2011). SKB has taken part in the international development in the field, and SKB's scenario approach is in part inspired by exchange of experiences on the international level.
SSM Regulator	The two main publication of relevance for scenario methodology in safety assessment related to geological disposal of radioactive wastes are addressed in detail above (SSMFS 2008:21 and SSMFS 2008:37). They both entered into force in February 2009 when SSM was created as a merger of the previous government agencies the Swedish Nuclear Power Inspectorate (SKI) and the Swedish Radiation Safety Authority (SSI). The SSMFS 2008:21 previously existed as SKIFS 2002:1 from April 2002 and the SSMFS 2008:37 existed as SSIFS 2005:5 from

	September 2005 (guidance part) and as SSIFS 1998:1 (regulations part). In other words, prior to 1999 there were essentially no regulatory requirements or guidance available regarding the role of scenarios although the main regulations addressing primary regulatory protection targets for geological disposal had just been published. SKI's and SSI's joint review of SKB's safety assessment SR-Can can be mentioned as an early review of SKB's implementation of the relevant regulations and guidelines. The authorities concluded that SKB's principles for selection of scenarios were in agreement with the available regulatory requirements (SKI report 2008:23, SSI report 2008:04 E). A number of issues were nevertheless raised for instance: • SKB should to a larger extent address gradual or overlapping malfunctions of barrier functions • SKB should apart from addressing tolerances of engineered components, discuss scenarios related to deviations outside the tolerance interval • SKB should further address alternative time evolution of climate states such as the extent of the temperate climate state • SKB should toward the end of safety assessment work make a final check on the completeness of the analyzed scenarios based on the experience of conducting the safety assessment, for instance check the significance of screed-out FEPs In February 2012, the IAEA conducted an integrated regulatory review service mission (IRRS) to Sweden, which to some extent included the above mentioned regulations and guidelines. No explicit comments were made regarding SSM's regulations and guidelines related to the role of scenarios. The related issues that were addressed focused on the role of operational activities in the safety case, testing and monitoring during the operational phase, as well as institutional controls after permanent closure.
RWMD/EA Implementer	See NDA's answer Q2-1.
DoE NE & EM/CBFO Implementer	The Department of Energy's NE office recognizes the potential for changes in standards and requirements, at some point in the future, that may impact future waste disposal activities, and are enhancing its FEPs approach, including a review of work done internationally. Current developments in DOE-NE's approach to FEPs are incorporated into the answers for this questionnaire.

Table 12. Question 2-3 A new approach to building a safety case including safety assessment methodologies

Organisation / Role	**Question 2-3: A new approach to building a safety case including safety assessment**
FANC Regulator	Not answered
Ondraf/Niras Implementer	[global answer to questions 2-3 … 2-7] Next to FEPs, It seems that we tend to favour tools giving an holistic view of the system (or its compartment: EBS, geological host rock…) - We use the word "abstraction" to refer to the "translation" of the scientific knowledge into the safety assessment model. This word is not discussed in the Madrid document. This "abstraction" process is quite important

	because it involves a lot of simplification that has to be properly traced. The abstraction process involves expert judgment and is not so much discussed and seems critical for us. - The simplification resulting from the abstraction process can make a phenomenological "FEPs" quite different from the SA "FEPs". For instance, the way retardation processes (through precipitation, coprecipitation, sorption) in the cementitious EBS are modelled in SA is far from being a realistic representation. The goal is actually not to strive for realism but conservatism
NWMO Implementer	Changes in the conceptual design or hypothetical geosphere have resulted in changes to the safety case and the scenarios considered within safety assessments; however, such changes are addressed through the existing process of defining scenarios. For example, excavating a repository within sedimentary rock presenting very low permeability and porosity has led to additional disruptive scenarios that illustrate potential impacts of gas generation. These scenarios were developed through the existing process of FEPs review. Scenario identification has a higher priority than in earlier assessments. Scenario identification is based on the FEPs screening analyses, the repository site and the repository design. Meetings are held for brain-storming sessions to 1) define the essential features of the Normal Evolution Scenario and 2) to identify disruptive scenarios. These meetings include personnel from the various disciplines: geosciences, engineering and safety assessment.
RAWRA Implementer	See question 2-7
POSIVA Oy Implementer	Scenarios are built for the repository environment and for the biosphere using similar methodology, but safety functions are only used for the repository environment and its components (see POSIVA 2012-08). Two examples are giving below concerning the methodology used to built scenarios for the repository environment and for the biosphere respectively: **The repository system** Posiva's methodology for scenario formulation relating to the repository system follows a top-down approach in first identifying the safety functions that are required of the repository system, then considering the effects of single FEPs or combinations of FEPs on those functions to check that the scenarios are comprehensive, and also to evaluate the effects of uncertainties within the expected lines of evolution. It is also based on the regulatory framework mentioned above and can be summarised as follows: ▪ The regulatory framework is taken into account; it is prescriptive in terminology and definitions. ▪ The safety functions for each of the repository system components are defined and a range of values for acceptable characteristics of those components (performance targets/target properties) is given whenever possible ▪ FEPs that could adversely affect one or more safety functions at a given time or place or under specific conditions within the repository are identified (i.e. FEPs that are scenario drivers within the evolution of the repository system in time and space; see POSIVA 2012-04). ▪ The effects of uncertainties in the expected evolution of the repository system are taken into account (see POSIVA 2012-04). ▪ Thus, lines of evolution that describe the evolution of the repository system and ultimately lead to canister breaching, form the basis for the definition of

	radionuclide release scenarios. Each line of evolution is then classified using STUK's scenario terminology (Figure 1). ▪ For each of the scenarios a set of calculation cases is defined to analyse the potential radiological impacts. The calculation cases take into account uncertainties in the assumptions and data through variations in the models and parameter values. **The biosphere** Formulation of scenarios for the biosphere must be consistent with the regulatory requirements, the methodology used in the formulation of scenarios for the repository system, and the current radiation protection systems for humans and the environment. Posiva's methodology for scenario formulation for the biosphere is somewhat different from that for the repository system, since the biosphere has no safety functions. Instead of identifying FEPs that could adversely affect one or more safety functions, the scenario formulation for the surface environment is based on identifying FEPs that may affect the evolution of the surface environment, fate of radionuclides in the surface environment and/or the potential radiation exposure of humans, plants and animals. The regulatory framework is also taken into account, mainly by coupling the scenario formulation to the dose constraints for humans (GD 736/2008 Section 4: "Disposal of nuclear waste shall be planned so that radiation impacts arising as a consequence of expected evolution scenarios will not exceed the constraints"), for which it is stated in YVL D.5 paragraph 307: "In applying the dose constraints, such environmental changes needs to be considered that arise from changes in the ground level in relation to sea. The climate type as well as the human habits, nutritional needs and metabolism can be assumed to remain unchanged11"). Thus, Posiva's methodology for formulating surface environment scenarios can be summarised as follows: ▪ Constraints on the scenarios arising from the regulatory framework are identified. ▪ The most important scenario drivers, i.e. key scenario drivers, with respect to the evolution of the surface environment, fate of radionuclides in the surface environment and/or the radiation exposure of humans, plants and animals are identified. This work also comprises identifying FEPs that are coupled to the key drivers, either in isolation or combined, and could induce changes in a timeline of evolution. ▪ One or several lines of evolution are defined that describe in timelines the surface environment evolution from which one or more scenarios are formulated. One credible line of evolution is identified and used to formulate the base scenario for the surface environment. • Variant scenarios are formulated, mainly by considering reasonable deviations from the lines of evolution underpinning the base scenario. Variant scenarios can include additional scenario drivers with a potentially significant effect on the fate of radionuclides in the surface environment and/or the radiation exposure of humans, plants and animals.

[11] Especially *human habits* is a very dynamic group of FEPs that likely change rapidly with time. Posiva interprets the term *unchanged* as: 'credible human habits for the time window when the dose constraints apply are how humans have behaved in the recent few years'. Furthermore, changes in how humans have behaved over the recent couple of decades are used to captures the uncertainties.

	• Disturbance scenarios are formulated, mainly by identifying unlikely FEPs or by considering unlikely deviations from the lines of evolution underpinning the base scenario. Disturbance scenarios can include additional scenario drivers with a potentially significant effect on the fate of radionuclides in the surface environment and/or the radiation exposure of humans, plants and animals. ▪ A set of biosphere calculation cases is defined to analyse the surface environment scenarios. These cases take into account uncertainties in assumptions and models, and the uncertainties and variability in parameter values applied in the models.
ANDRA Implementer	As already presented in 1999, Andra's approach considering 'safety functions' as an input for scenario development have not been questioned. Since, the Qualitative safety analysis for treatment of uncertainties has been consolidated with the benefit of the different reviews. On the overall, some adjustments have been made without modifying fundamentally the approach based on safety functions and analysis of their potential degradation or failure for definition of scenarios. See answer 3.b for details
GRS/BfS Research / Implementer	According to the Safety Requirements /6/ a comprehensive safety case shall be documented for all operating states of the repository. This shall include an analysis and representation of the robustness of the final repository system. Furthermore, the respective probabilities of impacts, failures or deviations safety-related systems, sub-systems or individual components should be calculated or assessed as far as possible, and their impacts on the corresponding safety function analyzed. Containment is the primary safety function and has to be proven by demonstrating that the radioactive waste is contained inside a defined rock zone (the containment providing rock zone (CRZ)) in such a way that it essentially remains at the site of emplacement, and at best, minimal defined quantities of material are able to leave that rock zone. From these requirements it follows, that the determination of the CRZ and the confirmation of its containment capacity are the key elements for the safety demonstration. To derive scenarios that meet these requirements the scenario development methodology is based on FEP related to an impairment of the functionality of (a subset of) barriers, that contribute to the safety function containment (called initial barriers, see section 3.b). This guarantees that the scenarios (and the consequence analyses) are directed to analyze the influences on the safety function containment.
JAEA / NUMO Implementer / Research	A basic procedures for evaluating long-term safety were developed in NUMO's 2010R 1) (fig.1) as a generic basis, taking into consideration international discussions 2) and safety cases developed in other national programmes after H12. Safety functions were defined based on technical requirements shown in the NUMO's 2010R 1) and used as main blocks to develop scenarios. (see the answer to question 3.b.) [1] NUMO(2011): Safety of the Geological Disposal Project 2010 - Safe Geological Disposal Based on Reliable Technologies - (in Japanese) http://www.numo.or.jp/topics/2011/11093022.html. English Summary report: http://www.numo.or.jp/approach/technical_report/pdf/TR-13-05.pdf. [2] OECD/NEA (2004): Post-closure safety case for geological repositories – Nature and purpose. Organization for Economic Co-operation and Development, Nuclear Energy Agency, Paris, France.

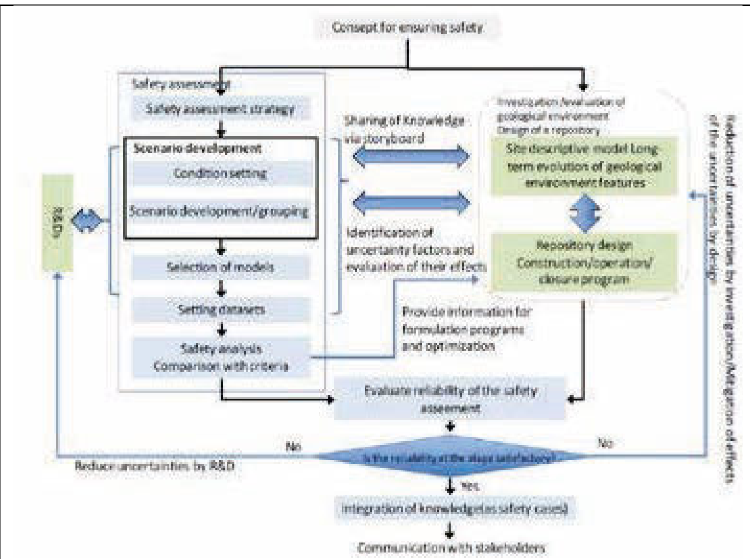
	 Fig.1 NUMO's basic procedures for safety assessment
KAERI Research	See question 2-4
SKB Implementer	See question 2-2.
SSM Regulator	Global answer moved to question 2-2
RWMD/EA Implementer	See question 2-7.
DoE NE & EM/CBFO Implementer	For DOE/CBFO, anytime there is a process change proposed in WIPP, or there is new external information that needs to be evaluated, the FEPs catalogue and scenario descriptions are reviewed and updated as needed. But there is no work underway to redo the FEPs/scenario approach that has now passed scrutiny under three permitting actions. Re-evaluations of this nature follow a process guided by a written procedure available on the internet at: http://www.wipp.energy.gov/library/cra/2009_cra/references/Others/Kirkes_2006_Performing_FEPs_Baseline_Impact_Assessment_ERMS543625.pdf For DOE-NE, this is a time of preparing (generic investigations, various geologic media) its tools and assessment approaches for the time when site selection restarts. The current state of new work to create an informative safety-case is reflected in the answers in this questionnaire.

Table 13 Question 2-4 New potentially safety-relevant information and/or knowledge refinement

Organisation / Role	**Question 2-4: New potentially safety-relevant information and/or knowledge refinement**
FANC Regulator	Not answered
Ondraf/Niras Implementer	Not answered

NWMO Implementer	The NWMO has recently carried out two safety assessments: the Fourth Case Study (4CS) for a repository in crystalline rock in 2012 and the Fifth Case Study (5CS) for a repository in sedimentary rock in 2013. The FEPs screening analyses for the 4CS were mainly based on the corresponding analyses for the Third Case Study, carried out in 2004 for a repository in crystalline rock. The repository was located at the same hypothetical site in both cases. However, the FEPs analyses were updated to reflect the new repository design, new safety relevant information and knowledge refinement. The descriptions of some FEPs were also updated to reflect current the Canadian regulatory regime. For the 5CS, as noted below the FEPs were reorganized and the FEP descriptions for the geosphere were updated to reflect more current knowledge. Also, for the 5CS, new FEP screening analyses were needed for the FEPs involving geosphere issues, repository design issues and some biosphere issues since the repository was at a different hypothetical site in a sedimentary rock formation. The repository design and biosphere were different in the 4CS and 5CS.
RAWRA Implementer	See above input of RAWRA Q2-1.
POSIVA Oy Implementer	No input
ANDRA Implementer	Since 1999, and since the 2005 Dossier, several categories of new safety-relevant information are to be taken into account for the 2015 licencing. They are of different origins: • Knowledge acquisition on site and underground research laboratory, which consolidate the host rock understanding: ◦ A large amount of data have been collected since 1999 (and since 2005) from several field investigations (surface geological survey, drillings and associated monitoring, 2D and 3D seismic surveys, hydrogeological modelling ...), ◦ The excavated galleries and series of experiments driven in the underground research laboratory form the Meuse/Haute-Marne Center in East of France (especially the geo-mechanical processes), • Technological tests in the underground research laboratory (excavation, water sampling, in situ experiments dedicated to behaviour of engineered components…) or in surface at the Espace Technologique ETe (waste packages placement...), or occasionally other locations (seal emplacement…) which supports the design. • Waste inventory of radionuclides and chemical hazardous compounds, and waste characterisation, • Scientific knowledge about engineered materials. • Evolution of the architecture, in line with the stage of the national program (see answer to question 1). The studies carried out within this framework for the deep disposal project in a geological formation are presented in the "Dossier 2005 Argile" [2]. Documentation is currently underway in view of the 2015 Authorisation Application, and will therefore be available only in 2015. Scientific knowledge has been the object of publications in scientific journals and conference
GRS/BfS Research / Implementer	Not answered

JAEA / NUMO Implementer / Research	Continuous improvement of system understanding and update for catalogue of features, events and processes are a key for progress of scenario development, taking regulatory requirements and site conditions/repository design depending on the implementation phases of disposal project, which should be reflected appropriately to develop scenarios and their classifications. For example, uplift/erosion, which was categorized as alternative scenarios in H12, could be treated as a likely scenario following regulatory requirements for sub-surface disposal (see Q-1-d answer). Definition of very unlikely scenarios with high consequence should be more carefully discussed after the big earthquake in 2011. Structuring scientific knowledge and identifying safety-relevant phenomena and uncertainties are a basis for safety assessment and in particular for scenario formulation1). The analysis of information regarding safety-relevant features, events and processes is an important process for scenario development and should be supported with a suitable systematic procedure (see Fig. 3 in Q-3-b answer). It is important to record not only the results of such analysis but also processes and decisions/judgements made in the analysis in a structured manner (e.g. structured format). This structured approach would help manage relevant data, information and knowledge to develop scenarios in more systematic, transparent and traceable way. Development of such approach would be an important target of knowledge management in disposal program. [1] OECD/NEA (2012): Methods for Safety Assessment of Geological Disposal Facilities for Radioactive Waste, Outcomes of the NEA MeSA Initiative, NEA No. 6923, ISBN 978-92-64-99190-3.
KAERI Research	From 1997 to 1999, KAERI collected FEPs listed by foreign countries and identified our own FEPs list considering domestic disposal environment. Five scenarios for post-closure safety assessments were developed for direct disposal of spent fuel. From 2000 to 2002, KAERI's FEP list was extended to 341 items by examining FEP lists of SR97, TILA99, and H12 projects. However, five scenarios were not changed. From 2003 to 2007, the FEP list was extended to 382 items through collecting expert opinions. Since 2007, in accordance with R&D action plan to develop advanced fuel cycle which adopts pyroprocessing and sodium fast reactor (SFR), the FEP list was iteratively examined to consider environment accommodating radioactive wastes generated from pyroprocessing. The FEPs have been updated from 1999, however, scenarios stayed intact. This is because we have focused on the development of disposal concept and post-closure safety assessment code.
SKB Implementer	See question 2-2.
SSM Regulator	Global answer moved to question 2-2
RWMD/EA Implementer	See question 2-7.
DoE NE & EM/CBFO Implementer	After 14 years of operations there is little new knowledge that comes in, but FEPs have been re-evaluated and changes made in response to experiments conducted at WIPP to refine and replace conservative estimates. Also, changes in mining methods in the region have caused several FEPs to be re-evaluated.

Table 14 Question 2-5. International practices

Organisation / Role	Question 2-5. International practices
FANC Regulator	Not answered
Ondraf/Niras Implementer	Not answered
NWMO Implementer	For the Fourth Case Study, which was carried out in 2012, and previous studies the FEPs were collected in a structured format following the organization developed by the NEA (2000). However, for the 5CS, the organization of the FEPs was revised by adopting some of the revisions to the NEA International FEP list that were proposed by Little (2012, private communication).
RAWRA Implementer	See question 2-7
POSIVA Oy Implementer	No input.
ANDRA Implementer	Since 1999, Andra benefited from international exchanges driven under the auspice of OECD/NEA, AIEA, and European Community. Most recent one are: ▪ Exchanges on International Experience in developing Safety Cases: References are Disposal of Radioactive Waste: Where Do We Stand? [4], INTESC [11], safety cases for deep geological disposal of radioactive waste [12]. ▪ Exchanges relative to International experience in safety assessments methodology and scenario development. Contribution of Andra to the PAMINA EC project [13], and MeSA project [14]. ▪ Exchanges relatives to human intrusion (Hidra) under the auspice of AIEA (current). ▪ Exchanges relatives to updating the NEA international FEP list (current).
GRS/BfS Research / Implementer	Not answered
JAEA / NUMO Implementer / Research	International guidance of safety case (e.g. [1]) has been referred in development of scenario procedure, especially from the viewpoint of importance of safety functions and of increase in traceability and transparency. And NEA's FEP database (e.g. [2]) has been used to check comprehensiveness of project FEPs. The review of state-of the-art scenario development methodologies3) has been referred in development of scenario procedure. [1]OECD/NEA (2004): Post-closure safety case for geological repositories – Nature and purpose. Organization for Economic Co-operation and Development, Nuclear Energy Agency, Paris, France. [2]OECD/NEA (2000): Features, Events and Processes (FEPs) for Geologic Disposal of Radioactive Waste. An International Database. Vers. 1.2. OECD/NEA Publ., Radioactive Waste Management, Paris, France. [3]OECD/NEA (2012): Methods for Safety Assessment of Geological Disposal Facilities for Radioactive Waste, Outcomes of the NEA MeSA Initiative, NEA No. 6923, ISBN 978-92-64-99190-3.
KAERI Research	See question 2-4
SKB Implementer	See question 2-2.
SSM Regulator	Global answer moved to question 2-2

RWMD/EA Implementer	See question 2-7.
DoE NE & EM/CBFO Implementer	As mentioned, DOE-NE as well as DOE-CBFO are aware of and keeping track of international developments related to FEPS/scenarios approaches. In the case of the CBFO's WIPP, however, there is a successful track record of gaining regulatory certification with the current approach. In the case of DOE's NE, there is an intent to incorporate new (including international) developments into the FEPs/scenarios approaches as part of future development of the safety case.

Table 15 Question 2-6 A combination of one or more of the foregoing reasons for a change in scenarios are developed or used.

Organisation / Role	**Question 2-6: A combination of one or more of the foregoing reasons for a change in scenarios are developed or used?**
FANC Regulator	Not answered
Ondraf/Niras Implementer	Not answered
NWMO Implementer	Scenarios are now developed in a more systematic and transparent fashion following comments by reviewers of previous safety assessments. For the same reason, scenario identification is given higher priority in the more recent safety assessments than was the case in the past. The safety assessment reports for the 4CS and 5CS include a specific chapter on scenario identification. The scenarios are identified in a systematic method by examining external FEPs that can affect the evolution of the repository system. Since these safety assessments were for a hypothetical site and intended to illustrate the safety assessment approach, it was deemed that internal "brainstorming" sessions were sufficient for scenario identification purposes
RAWRA Implementer	
POSIVA Oy Implementer	Achieving a systematic way in the building of scenarios has been the main advantage in applying the methodology referred to above.
ANDRA Implementer	The overall foregoing reasons have mostly affected the definition of scenarios in order to account for the new regulations and new information as regards to an iterative approach to achieving safety (see question 1). However, in terms of objective and scope of scenario development, the use of scenarios remains in line with previous assessment. See answer to question 3.a.
GRS/BfS Research / Implementer	Not answered
JAEA / NUMO Implementer / Research	Except for the reasons described above (see the answers to questions 1.d. and 2.), there is no specific reason for a change of scenario development.
KAERI Research	See question 2-4
SKB Implementer	See question 2-2.
SSM Regulator	Global answer moved to question 2-2
RWMD/EA Implementer	See question 2-7.
DoE NE & EM/CBFO Implementer	A list could be provided of the Planned Change Requests that have been submitted to the WIPP regulator for approval that required a new long-term safety evaluation for the WIPP repository. A new performance assessment requires re-evaluating potentially affected FEPs.

Table 16 Question 2-7 If no changes have been made in defining the scenarios, please explain briefly why no changes since 1999.

Organisation / Role	**Question 2-7. If no changes have been made in defining the scenarios, please explain briefly why no changes since 1999.**
FANC Regulator	Not answered
Ondraf/Niras Implementer	Moved to question 2-3
NWMO Implementer	Not applicable.
RAWRA Implementer	Since 1999, there are no changes in Atomic Law and related regulations that would concern the item of scenario development. In fact a safety report for reference repository system was actualized in 2010, but it has not been reviewed by regulatory body. The possession of regulatory body allows reviewing safety reports only if it is a part of an official decision process, which was not the case.
Posiva Oy Implementer	No input.
ANDRA Implementer	No input
GRS/BfS Research / Implementer	Not answered
JAEA / NUMO Implementer / Research	Changes have been made as described above.
KAERI Research	See question 2-4
SKB Implementer	See answer of SKB Q2-2.
SSM Regulator	Global answer moved to question 2-2
RWMD/EA Implementer	[moved from 2-1] The scenario development work NDA (then Nirex) undertook prior to 1999 was designed for a site-specific safety case and is documented in [Overview of the FEP Approach to Model Development, LEF Bailey and DE Billington, Nirex Science Report S/98/009, 1998] and [Development and Application of a Methodology for Identifying and Characterising Scenarios, DE Billington and LEF Bailey, Nirex Science Report S/98/013, 1998]. Since the publication of these reports, NDA safety case work has been generic. Our latest safety case, the generic Disposal System Safety Case (DSSC), [Geological Disposal: Generic Environmental Safety Case main report, NDA Report No. NDA/ RWMD/021, December 2010], refers to the 1998 Nirex reports on the FEP and scenario development work for the approach to identifying scenarios for a site-specific assessment. In the generic DSSC, no specific scenarios are presented, only illustrative calculations for releases via a stylised groundwater pathway, together with discussions of the implications of gaseous releases and human intrusion. Therefore there have been no significant changes in the approach to defining scenarios since 1999.

DoE NE & EM/CBFO Implementer	In the case of DOE-CBFO/WIPP, which started receiving waste in 1999 and has been re-certified by its regulator every five years thereafter, an effort is made to NOT change the basic approach to FEPs/scenarios, but to re-evaluate the FEPs that may be impacted by a proposed change in operations or by new information relevant to determining repository long term safety. Any such changes require regulatory approval, and in many instances also require a re-evaluation of long term safety incorporating any affected FEPs.

Annexe 2 : Detail Regarding Scenario Approach Currently in Use by Project

Table 17 Question 3a What are the objectives and scope of scenario development in recent PA?

Organisation / role	Question 3a: What are the objectives and scope of scenario development in recent PA?
FANC	See Ondraf/Niras' input
Ondraf/Niras	(moved to questions 3b1/3b2)
NWMO	As described in CNSC Guide G-320, postclosure safety is assessed through consideration of a set of potential future scenarios, where a scenario is a postulated or assumed set of conditions or events. The purpose of scenario identification is to develop a comprehensive range of possible future evolutions against which the performance of the system can be assessed. CNSC Guide G-320 specifies that both Normal Evolution and Disruptive Event Scenarios are to be considered. The Normal Evolution Scenario represents the normal (or expected) evolution of the site and facility, while Disruptive Event Scenarios examine the effects of unlikely events that might lead to penetration of barriers and abnormal degradation and loss of containment. The objective of scenario identification and development is to be consistent with CNSC Guide G-320. To this end, in December 2012, the NWMO prepared a preproject report that illustrates its approach to conducting a safety assessment for a conceptual used fuel repository within a hypothetical crystalline rock setting in the Canadian Shield. Its purpose is to show how the illustrative postclosure safety assessment approach is consistent with the CNSC Guide G-320. The NWMO submitted this report to the CNSC for review. Chapter 6 of this preproject report describes the scenario identification methodology. The review by CNSC will allow the NWMO to ascertain if the scenario identification methodology is consistent with CNSC Guide G-320
RAWRA	N/A
Posiva Oy	The result of the analysis of scenarios is used to give feedback to design and technical options in the development of the repository. Formulation of Radionuclide Release Scenarios Safety case for the disposal of spent nuclear fuel at Olkiluoto – Formulation of Radionuclide Release Scenarios. Eurajoki, Finland: Posiva Oy. POSIVA 2012-08. ISBN 978-951-652-189-6.
ANDRA	The French Nuclear Safety Authority guide of 2008 [7] provides a framework for the studies to be conducted. The protection of man and the environment are to be demonstrated. The guide requires safety to be quantitatively evaluated by the means of "situations" that encompass different possible evolutions of the repository. In accordance with the regulatory requirements, the system representation for the safety model thus developed is based on a "Normal evolution scenario" (NES) [15]. This NES answers several distinct objectives. Its main aim one is to verify that the repository, as designed and to the extent that its evolution over time is understood by contemporary science, fulfils the safety objectives assigned to it. This general objective can be broken down into several inter-related goals:

- Confirm that the performance achieved, as indicated by the chosen indicators, is consistent with the predefined threshold values. This safety objective implies the need to present a vision that exaggerates the repository's potential impact.
- Provide an overall simulation of the repository's expected evolution, in order to assess the expected behaviour in global terms, in the form of a necessarily simplified and partially conventional representation that nevertheless aims to be as representative as possible. The aim is to assess the relative importance of the main phenomena and the performance of the safety functions. This objective precludes the use of overly simplistic representations, which would make the models less representative.
- Verify the performances of the three main safety functions (see question 1-b) using appropriate indicators.
- Provide a basis on which to judge the sensitivity of the level of safety to changes in the environment and the behaviour of repository components, and to use the sensitivity analyses as a tool for quantifying the repository's robustness.

In addition, to provide an understanding of the potential impact of unlikely future evolutions related to specific system failures, a set of four “Altered evolution scenarios” (AES) were developed in 2005 [15]:

- the “Seal failure” scenario.
- the “Waste package defects” scenario.
- the “Borehole” scenario.
- the “Severely degraded evolution” scenario.

Calculation results based on these AES scenarios make it possible to evaluate overall repository robustness.

With the application of scenario development method in the context of safety assessment, the repository performance studies highlight a significant number of results for safety analysis.

Other indicators than dose can be proposed which show more clearly the repository’s intrinsic performances without requiring any assumptions on the surface environment and the biosphere. In particular, radionuclide concentration flows assessed at relevant emplacements with respect to the safety analysis of the repository (typically at the host formation outlet) allow refining the judgement on safety and overcoming some of the uncertainties. They allow comparing different situations or different design provisions in order to see which one is the most favourable with respect to the limitation of the radionuclide transfers, but they cannot be compared to thresholds.

Some indicators allow assessing the performance of individual component with respect to their safety functions (for example, molar fluxes of radionuclides reaching the roof of the Callovo-Oxfordian formation). They enable us to characterise the role of the components using a series of complementary indicators. Among the analysed indicators are:

- the overall activity leaving the waste packages, the underground structures and the host rock, as compared to the initial quantity contained in the waste packages,
- the activity flux at each of these components,
- the concentration distributions of dissolved materials in the host rock and in surrounding formations.

	Such indicators have been used in the safety analysis carried out in the Dossier 2005 Argile. Such an approach may be used to evaluate the performance of some design option relative to their assigned safety function. Safety functions are guaranteed a good level of performance, in both the reference calculation and in the sensitivity studies. For instance, results from the dossier 2005 indicated: • For the « resisting water circulation » function, the diffusive transport regime dominates in all configurations within the Callovo-Oxfordian host rock, and in most of the structures. It should be noted that this is not solely due to the efficiency of the seals: even when this is degraded in the sensitivity study, the flows remain limited overall, since the water from the Callovo-Oxfordian is insufficient to supply them. • For the function of « limiting the release of radionuclides and immobilizing them in the repository »: The low solubility of many radionuclides in the cells means that their impact is heavily restricted; this is especially the case of Selenium-79. The containers and over-packs contribute to confinement, helping to delay the occurrence of dose maxima, but without strong influence on their magnitude. The properties of the Callovo-Oxfordian attenuate the flows even in the case of transfer in a thermal environment. • For the function of « delaying and reducing the migration of radionuclides », the diffusion times are slow in the Callovo-Oxfordian and enable a decay of all the radionuclides that could contribute to the impact, except for iodine-129, chlorine-36 and selenium-79. The last two are, however, significantly reduced. The transport parameters prove sensitive in terms of the impact of these three radionuclides. Such an analysis of indicators showed that the Callovo-Oxfordian is a particularly important component, whose characteristics ensure a good level of safety function performances, even in the event of other components failure (defective containers, inefficient seals) or even of degraded properties of the geological medium itself.
GRS/BfS	<u>ERAM-repository</u> The scenario development has been performed in two consecutive steps. Firstly, the system evolution without any technical measures has been investigated to aid the development of the safety and closure concepts. In a second step final scenarios have been developed taking into account the selected closure measures (extensive backfilling of remaining open mine structures and sealing of waste emplacement areas and shafts). These scenarios are the base of the safety assessments for the proof of the post-closure safety of the backfilled and sealed repository. Based on the results of the review of the German Entsorgungskommission (ESK – Nuclear Waste Management Commission) the second step of the scenario development has to be repeated taking into account the new guidance /6/, /7/. <u>Repository for heat-generating radioactive waste</u> The primary (and so far only defined) goal of the scenario development is to tackle scenario uncertainties: The site and the repository system will undergo exactly one evolution, which will be governed both by climatic and geological processes at the site and processes induced by the repository construction and the emplacement of heat-generating waste. Despite a detailed understanding of the various influencing factors, this real evolution cannot be predicted unequivocally in all details. The resulting uncertainty with regard to the future evolution of the repository system can be reduced only marginally by additional research and site investigations. For

	example, it can be safely assumed that several cold times with permafrost formation will occur at a site in Northern Germany within the next one million years, which may be associated with glaciation of the site. An exact prediction, when these cold times will occur and which areas are affected by glaciers advancing from the north is not possible. Therefore the scenario development has to result in a set of scenarios that cover the uncertainties regarding the future evolution of the repository system. The methodology must allow the assignment of probability classes to the scenarios pursuant to the Safety Requirements /6/. It thus provides the overall framework in which the safety analyses are carried out. According to the Safety Requirements scenarios for unintentional human penetration of the final repository, based on common human activities at the present time, shall be analyzed only in the context of an optimization of the repository layout. These stylized human intrusion scenarios are developed separately from the systematic scenario development, see section 3.b. Reference /10/ serves actually as the main reference for answering the requested issues under the subject area 3.b of the questionnaire. This report comprises a novel scenario development methodology that was developed and applied in the German project VSG (preliminary safety assessment for the Gorleben site).
JAEA / NUMO	In generic R&D stage with no specific site such as current Japanese programme, it is important to provide a general procedure for scenario development which includes methodologies to combine top-down approach using e.g. safety functions and bottom-up approach using e.g. FEPs, to check completeness of scenarios for PA, to adequately classify scenarios based on risk-informed approach, to continuously improve scenarios based on update of the state of the art scientific and technical knowledge and to guide further development of PA models and databases, taking a range of potential site conditions and repository design alternatives. A coherent procedure is also discussed from scenario development to identification of calculation cases with models and datasets to be applied. The scope of scenario development is still focused on post-closure safety for HLW and TRU waste, but is being extended to SF direct disposal. After the big earthquake in 2011, very unlikely scenarios emerges an urgent issue for both operational and post-closure safety. In particular for operational safety, such scenario analysis has been used for discussion on design countermeasures.
KAERI	The main objective of scenario development is to identify key process and features of repository site and disposal concept, and to determine preliminary scenarios to be analysed. To check if disposal concept can satisfy safety goal is also important objective of scenario development.
SKB	SKB's current scenario approach, the one used in the SR-Site assessment, is best described in the SR-Site main report, (SKB, 2011), section 2.5.8 and chapter 11. In SKB's safety assessment, the scenario approach is a method of systematically exploring all possible routes to failure of the system, expressed as loss of the system's safety functions. Scenarios are thus not particularly selected with the comparison of design options or sites in mind. However, the scenarios used in the safety assessment would also be those used in such comparisons. Currently, the scenarios are only used in the safety assessment, primarily to demonstrate compliance but also to address the issue of best available technique, BAT; see section 14.3 of (SKB, 2011) [next paragraphs moved to question 3b3]

SSM	See SKB.
RWMD/EA	See above comments for Section 2. Scenario development is not a major part of NDA's current generic work programme. However, we are developing a 'safety narrative' that traces the arguments for safety back to the relevant FEPs, using the safety functions of isolation and containment. The aim is to provide a clear, generic description of the basis for safety, that can then be applied to specific disposal concept examples. We are also developing our generic modelling tools; this includes our approach to data elicitation and the development of a register of uncertainties.
DoE NE & EM/CBFO	DOE/NE: Preliminary informal generic FEP screening and scenario development was intended to provide initial guidance into research and development needs., FEPs and scenario comparisons may be useful tools in ranking sites in context of possible future DOE-NE activities. DOE/CBFO WIPP: Primary objective is to demonstrate continuing regulatory compliance. Secondary objective is to evaluate potential long term safety implications of proposed repository operational changes, and demonstrate no deleterious effects in submittals to the regulator who must approve and significant changes. [next paragraphs moved to question 3b3]

Table 18 Question 3b Terminology and associated definition, Classes of scenarios and the role of these classes in your assessment

Organisation / Role	**Response to item 3b1: Terminology and associated definition** **Response to item 3b2: Classes of scenarios and the role of these classes in your assessment.**
FANC Regulator	See Ondraf/Niras' input
Ondraf/Niras Implementer	(moved from 3a) **SAFIR2:** (ONDRAF/NIRAS, 2001b) ONDRAF/NIRAS, *SAFIR2 – Safety Assessment and Feasibility Interim Report 2*, NIROND 2001-06E, 2001 The approach for deriving scenarios was based on a combination of FEPs from a catalogue. The catalogue has been compiled starting from the international NEA FEP list. This catalogue is based on the FEP list, from which all non-relevant FEPs have been eliminated and to which some typical FEPs for disposal into clay have been added. In SAFIR 2 Scenario is defined as *one* possible evolution of the disposal system, described in terms of a combination of FEPs and their evolution over time. <u>The normal evolution scenario: T</u>his scenario takes into account all FEPs that are present or will take place with certainty or near-certainty. The normal evolution scenario therefore describes the most likely sequence of events to take place after the closure of the repository. For a systematic and coherent analysis of the disruptive/altered scenarios, the disposal system and its environment is simplified by being reduced to its two main barriers (the engineered barriers and the geological barrier) and the hydrogeological component.

All possible states of the disposal system are analysed by assuming that each of these three main components is either present (active) or absent (not effective), and the eight main states of the disposal system can be presented schematically in this way (*PROSA approach*)

All FEPs that are not included in the normal evolution scenario can be classified in the table here below according to the state of the disposal system to which they correspond. Different FEPs that can give rise to the same state of the disposal system are combined so far as possible in a single altered evolution scenario.

This approach was a tentative combination of bottom-up / top-down analysis. Although the safety functions were not used as such in this uncertainty analysis, The "barrier" can be assumed to play a similar role.

[Eight] altered-evolution scenarios (AES) were identified (see figure below)

- Reference scenario:
  - Exploitation drilling (AES2);

This scenario assumes that a water well is drilled into the aquifer beneath the Boom Clay. This scenario does not involve any intrusion into the repository itself.

  - Greenhouse effect (AES2);
  - Fault activation (AES3);
  - Glaciation (AES4);
  - Poor sealing of the repository (AES3);
  - Premature failure of an engineered barrier (AES5);
  - Gas-driven transport (AES7);
  - Exploratory drilling (AES8).

- Human intrusion scenario

It considers a case in which geological exploratory drilling takes place on the disposal site and the borehole passes through a disposal gallery. A borehole core containing radioactive waste is collected and a person who is unaware that the core contains such material analyses it in a laboratory. That person will be exposed to external radiation and to inhalation of particles suspended in the atmosphere produced, for example, when the core is sampled. In 1987 two variants of an exploratory drilling scenario were considered. A distinction was made between a routine analysis and a more detailed investigation of the core.

No scenarios aimed at the assessment of design options.

No specific what-if cases.

SFC1:

In the ONDRAF/NIRAS safety assessment methodology, scenarios include a reference scenario, based on the safety concept, several altered scenarios and human intrusion scenarios2.

A scenario is a set of high-level descriptions of possible evolutions of the disposal system, in a simplified, abstract form. These high-level descriptions share a common time-deployment of the safety functions.

In the **reference scenario**, safety functions are deployed such as described in the safety concept while for the altered-evolution scenarios, one or more safety functions are considered as partially or fully impaired. Thus, the reference scenario takes account of processes and events that are about certain to occur and assumes that (1) there are no unexpected or significant undetected features in the environment

	surrounding the disposal system (such as geological structures) that could significantly perturb its performance, and (2) intrusion into the repository or its immediate geological environs by humans does not occur within the period covered by safety assessment. This definition is in line with the common understanding of the reference scenario (Nagra, 2010) (NEA, 2012). On the relevant high-level descriptions of the possible evolutions of the disposal system within a scenario rest the so-called assessment cases. An assessment case is a specific realisation of how the disposal system might evolve and perform over time assuming 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 . In the reference case, the system is assumed to be implemented according to the specified design. The assumptions behind this case tend to be conservative. The development of the reference case is an iterative process, with the definition of successive working versions. The first working version is based on the existing knowledge from the previous Safety Case. In subsequent iterations, assumptions are refined making better use of acquired knowledge and understanding of the system. Working versions integrate the most recent RD&D results (Depaus and Capouet, 2012). Alternative cases within the reference scenario are defined to elucidate the impact of uncertainties on evolution, models and parameters or are 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, for those uncertainties that are potentially amenable to reduction or mitigation by future RD&D, to focus RD&D on the uncertainties to which safety and performance are most sensitive. Comparing the results of the evaluation of alternative cases with those of the reference case also provides an indication of the degree of conservatism introduced in the reference case and, hence, of the safety margins. In addition to cases of lower probability of occurrence than the reference case, alternative cases may also be considered for treating evolutions of the system with the same probability of occurrence as the reference case, such as climatic evolutions. No firm decision regarding what-if cases or stylised scenarios. Human Intrusion scenarios will be discussed with the regulator. Especially the way to handle “penalising scenarios”.
NWMO Implementer	Scenarios of interest are identified through consideration of the various Features, Events and Processes (FEPs) that could affect the repository system and its evolution. FEPs are categorised as either “external” or “internal”, depending on whether they are outside or inside the spatial and temporal boundaries of the repository system. Repository and contaminant factors can be considered as “internal" factors, whereas the external factors originate outside these boundaries. The significant FEPs are accounted for in the description of the Normal Evolution Scenario Internal FEPs are important aids in defining the expected evolution of the repository. They assist in determining which features and processes are important to include in the conceptual model and related computer codes. Internal FEPs are not usually scenario generating; however, they are considered with respect to Disruptive Scenarios. The External FEPs provide the system with boundary conditions and include influences originating outside the repository system that might cause change. Included in this group are decisions related to repository design, operation and

	closure since these are outside the temporal boundary of the post-closure behaviour of the repository system. If these External FEPs can significantly affect the evolution of the system and / or its safety functions of containment and isolation, they are considered scenario-generating FEPs in the sense that whether or not they occur (or the extent to which they occur) could define a particular future scenario that should be considered. Thus, the external FEPs are examined in a systematic method in order to identify potential FEPs that generate scenarios, e.g., seismicity, unidentified geological features, etc. ######################## There are two classes of scenarios, as identified in CNSC Guide 3-20, the Normal Evolution Scenario and Disruptive Scenarios. The Normal Evolution Scenario describes the expected evolution of the repository system. It is developed from consideration of the External FEPs and the Internal FEPs. External FEPs that are likely to occur (e.g., glaciation) are included in the Normal Evolution Scenario. This Scenario is used to guide both the development of the conceptual model for the safety assessment and the variations to this model considered in alternative calculation cases. Disruptive Event Scenarios postulate the occurrence of unlikely events leading to possible penetration of barriers and abnormal loss of containment. Since the long-term safety of the repository is based on the strength of the geosphere and engineered barriers (including the container and the shaft seals), scenarios focus on events in which these can be bypassed. **Normal Evolution Scenario** The Normal Evolution Scenario summarizes the main events in the evolution of the repository. Most of the processes identified are well understood. Key points are that the geosphere isolates the repository from the surface, that the groundwater around the repository level remains within its natural chemistry range and low oxygen state, and (in the longer term) that the load-bearing capacity of the containers is sufficient to withstand the effects of glaciation and earthquakes at repository depth. Recognizing that there are uncertainties associated with the future evolution of a repository, sensitivity analyses and bounding assessments are used to illustrate the impact of varying a number of important parameters and assumptions on the calculated impacts of the Normal Evolution Scenario. This approach is consistent with CNSC Guide G-320 on the use of different assessment strategies. Both deterministic and probabilistic safety assessments are carried out for the Normal Evolution Scenario. **Disruptive Event Scenarios** Disruptive Event Scenarios are an important part of the safety assessment since they explore alternative possible future evolutions of the repository system. Disruptive scenarios also include what-if scenarios that are not necessarily realistic (e.g., parameters are assigned values outside their realistic range) so that the robustness of barriers (buffer, geosphere, etc.) can be more clearly exhibited. In this way, the Disruptive Scenarios explore the robustness of the repository system. The critical group of interest for each Disruptive Scenario also needs to be defined since it may be different from the critical group in the Normal Evolution Scenario. The inadvertent human intrusion scenario is a Disruptive Scenario. CNSC Guide G-320 advises that scenarios assessing the risk from inadvertent intrusion should be case-specific and based on the nature of the used fuel and the design of the facility.

	Scenarios concerning inadvertent human intrusion may predict doses greater than the acceptance criterion, depending on the degree of uncertainty associated with the assessment, the conservatism in the dose limit, and the likelihood of the intrusion. The Inadvertent Human Intrusion Scenario considered by the NWMO assesses the impact of human intrusion sometime in the future. In this scenario, an exploration borehole is drilled through the geosphere and into the repository with the drill bit intersecting a used fuel container. This scenario is a special case since it bypasses all the barriers put in place; both the likelihood and the risk from the intrusion are reported. Disruptive Event Scenarios are evaluated separately rather than in combination since they have low probability and independent causes, and so the likelihood of simultaneous occurrence is even lower.
RAWRA Implementer	Normal evolution, altered evolution, human intrusion
POSIVA Oy Implementer	Figure 1. Scenario classification according to Guide YVL D.5 (draft 4, STUK 2011). As pointed in Figure 1, unlikely events or processes are included in disturbance scenarios for which “what-if” calculation cases are defined. For human intrusion, which is also a disturbance scenario, and for which several “what-if” cases are defined, a stylised approach is use in the analyses
ANDRA Implementer	”Scenarios” are simplified descriptions of the evolution of the repository. The terminology being used in the dossier 2005 is [15]: • a “Normal evolution scenario” (NES), which purpose is to provide a bounding value for all likely or probable future evolutions. • “Altered evolution scenarios” (AES): defines “altered situations” that encompass unlikely events (those events as recommended by the NSA guide) and are based on a breakdown of a safety function (as regards to results from QSA). • “ conventional “ or “ what if” scenario that may represent several situations in the form of stylised hypotheses. In that case, the altered scenario may not represent any physically possible situation. ######################## ”Scenarios” are simplified descriptions of the repository initial state and its evolution, based on the phenomenological analysis of the repository evolution [16]. • The system representation for the safety model thus developed is based on a “Normal evolution scenario” (NES), which purpose is to provide a bounding value for all likely or probable future evolutions. Events to take account are those induced by the disposal system (including the progressive degradation of engineered components), and by probable natural events (such as for example the climatic cycles). However, the NES does not aim to provide the best possible description, and according to ICRP 81 recommendations [17], it is not presented as a prediction of long term repository impact. Rather, its purpose is to provide a bounding value for all likely or probable future evolutions. Calculation results based on the NES are at the core of the performance assessment of the repository. • Andra also defines “altered situations” that encompass unlikely events (those events as recommended by the NSA guide [7]) and are based on a breakdown of a safety function. The AES represents these different situations in a “bounding” way, i.e. it provides a description that generally overestimates the

	different possible effects. In the example given from 2005 dossier, the AES would describe the loss of the function of the waste container by the total "disappearance" of the container after 200 years, i.e. earlier than the period for which it is dimensioned. AES allow better understanding of the role of the different components of the concept. For instance: • Seals limit the hydraulic influence of boreholes and can contribute in limiting the propagation of radionuclides in the underground structures in case of waste packages defects (control of the hydraulic transitory). What-if scenario: While one could assess the plausibility of each AES, it is a more delicate matter to assess the plausibility of a scenario that may represent several situations in the form of stylised hypotheses. In that case, the altered scenario may not represent any physically possible situation: in this case, it is defined as a "conventional" or "what if" scenario. As an example, a situation such as a whole series of defective containers resulting from a quality control error however used as the « what-if » basis for the "package failure" altered scenario evolution, which considers very early loss of the functionalities of the metal containers on a series of containers and for the entire inventory. This extreme "what-if" scenario finally covers all forms of uncertainty concerning the corrosion conditions. In 2005, various possible forms of human intrusion after closure of the repository were covered by the "borehole" altered evolution scenario. For this type of situation, Andra follows the NSA guide. It indicates that it is necessary, in a cautious approach, to suppose that memory of the existence of the repository can be lost beyond a time period of 500 years. As regards to the definition of the characteristics of the situations of human intrusion, Andra follows recommendation of the guide: the existence of the repository and its location is forgotten, the level of technology is the same that today.
GRS/BfS Research / Implementer	Note: The term class is actually used in the VSG project in connection with the categorization of scenarios in probability classes. Therefore, the term type of scenarios will be used in the following instead. Actually there are lots of terms and concepts used and defined in the report "scenario development: method and application" /10/. But only those which are essential for the further understanding will be explained in detail. It should be noted that already existing definitions in the Safety Requirements /6/ are adopted in the above mentioned report /10/. FEP: The potentially influencing factors on the disposal system will be named according to the English acronym FEP. The acronym FEP stands for Features, Events and Processes. Initial FEP: An initial FEP is described as a probable FEP with direct influence on the function of an initial barrier, e.g. host rock, seals and canisters. Scenario (according to /6/): A scenario refers to a post-decommissioning development of the disposal system and its safety-related properties, with a greater or lesser degree of probability, based on the current site conditions and on the basis of geo-scientific and other considerations. This development is determined by the starting situation as well as by future events and processes. Several developments may also be combined into one scenario. Scenario development:

	The scenario development is a systematically derivation and description of potential developments of the disposal system which are relevant for the reliable assessment of disposal safety. This will be done on the basis of a FEP catalogue. Reference scenario: The reference scenario describes as much as possible the entity of probable potential developments of the disposal system. It yields from predefined assumptions under consideration of initial FEP and those FEP which determine the mobilization of radionuclides from the waste and their transport. In this context the probable characteristic of the FEP are taken into account. In addition to that several alternative scenarios are developed which can describe probable and less probable developments. The basis for both types of scenarios is the FEP catalogue /12/, /13/. Alternative scenario: The alternative scenarios describe less probable developments or probable potential developments of the disposal system which are not covered by the reference scenario. Such potential developments can result from less probable FEP, less probable characteristics of probable FEP or from alternatives to specific assumptions as necessary frame conditions for the reference scenario. Both the "what-if" scenarios and "stylized" scenarios are not subject of the scenario development. But such types of scenarios are considered in separate analyses and work packages of the project VSG. The role of these types of scenarios will be described briefly in the following: What-if scenarios: What-if scenarios are used to demonstrate and test the behaviour and robustness of the disposal system or parts of the system /15/. This approach is called ultimate state analyses and was applied in the VSG project. Here, extreme limits and sometimes pretty unrealistic values for parameters are chosen to analyse how the disposal system reacts. For example, the heat entry as a result from the radioactive decay into the disposal system was varied in thermo-mechanical calculations up to really unrealistic data in order to study the reaction of the disposal system for extreme situations. These analyses shed light on the robustness of the disposal system. Stylised scenarios: According to /6/ it is required to analyse future human activities as a variety of stylised scenarios for unintended human intrusion (HI) into the disposal system (cf. issue 1. d. of the questionnaire). The aim of such analyses is the optimisation of the disposal system in order to reduce the potentials of HI and its radiological effects on the general public. Since human activities and the behaviour of societies cannot be predicted over the underlying demonstration period in safety analyses of the VSG project, it is not reasonable to combine stylised HI scenarios and scenarios from scenario development with the aim of optimisation. Due to their own nature, the stylised HI scenarios /14/ therefore have to be dealt with separately from the developments that have been identified by scenario development /10/. The analysis of stylised HI scenarios is based on the assumption of a probable development of the site and the disposal system.
JAEA / NUMO Implementer / Research	(moved from 3b) Scenario approach adopted in H12 report published in 19991) and reported at the NEA Scenario Workshop Held in Madrid in 1992) is shown in Fig.2. In this approach,

	FEPs had a basis to develop scenario. Safety functions was also considered but used mainly to check comprehensiveness of FEP combinations. The NEA peer review on H123) made comments on scenario that pointed out importance of "much emphasis on the description of calculation cases and in providing the supporting information" and "more discussion of rationale for discussion taken, as well as a discussion of the completeness of the scenario that have been identified". Fig.2 Procedure for scenario development in H12 Since 1999, based on the NEA peer review on H12 mentioned above, NUMO and JAEA have been focusing to improve transparency and traceability of scenario development procedure. The latest version of scenario development procedure is shown in Figs 3 and 4). […] See table 3.3 Specific features of this procedure are outlined below: […] In the discussion on a sub-surface disposal) mentioned in the response to question 1.d., the risk-informed safety regulations based on disaggregated dose/probability approach8) has been applied in which scenarios are classified into four categories depending on their probability: likely, less-likely very unlikely and human intrusion scenarios. […] […] […] Such categorized evolutions will then be classified into four classes of scenarios for safety assessment taking their probability/plausibility and impact into account. Calculation cases are derived for four classes of scenarios with defining models and data to be applied.
KAERI Research	
SKB Implementer	See description in question 3b.3 (table 3.3) […]. Key terms are safety functions, reference evolution, main scenario, less probable scenario, residual scenario. The two former terms are explained in the text above and the three latter are defined in SSM 2008:21 As noted above, this type of scenario is used to address i) scenarios where no plausible route to loss of a safety function under consideration has been identified and ii) human intrusion scenarios. Regarding human intrusion scenarios, scenarios treating inadvertent human intrusion are required in the safety assessment by SSM:s regulations, but they are not to be included in the risk summation. Advertent human intrusion does not have to be addressed in the safety assessment, see further the response to question 1d.
SSM Regulator	
RWMD/EA Implementer	[see question 1d1]
DoE NE & EM/CBFO Implementer	The words and concepts behind FEPS and scenarios have the same meaning in the US as elsewhere. For the DOE-NE generic disposal studies, only undisturbed scenarios have been examined to date. Disturbed scenarios (including human intrusion), which tend to require site- and design-specific information, will be examined in the future. In the case of WIPP, regulations at 40 CFR § 194.25 provide useful focus for scenarios in the future timeframe. It states that [performance assessments] shall assume that characteristics of the future remain what they are at the time the

	compliance application is prepared, provided that such characteristics are not related to hydrogeologic, geologic or climatic conditions. In other words, events and processes that are related to human activities (not the natural system) are assumed to remain the same into the future. EPA explains in their background information that it is not fruitful to try to predict what new technologies humans may or may not develop in the future, but rather assume that current technologies will prevail for the duration of the performance period. Geologic, hydrologic, and climatic trends are expected to be incorporated into the analysis. This is termed the "future state assumption." What-if scenarios are generally avoided. They may be useful in illustrating an upper bound but potentially create confusion with non-technical audiences. However, conservative scenarios, even ones that are physically not possible, may be usefully incorporated into a performance assessment to avoid the time, expense, and difficulty of proving a more nuanced effect of a process on a repository or portion thereof. That approaches a what-if scenario, but is not a standalone calculation to address a specific process, instead it is woven into the total system evaluation. The human-intrusion scenario is stylized and much of the FEP content is prescribed and limited by regulation (examples from the regulations were cited in the introductory part).

Table 19 Response to item 3b3: Steps of your methodology

Organization / Role	Steps of your methodology
FANC Regulator	See Ondraf/Niras' input
Ondraf/Niras Implementer	**SAFIR2** No input. **SFC1** Application of a systematic methodology for deriving scenarios has not been undertaken yet. However in Principle the scenarios will be derived in the following way: Alternative cases and altered scenarios will be derived from a systematic examination of the perturbing phenomena and associated uncertainties potentially affecting the validity of the Safety Statements, and consequently, by upward propagation of these uncertainties from one statement to another, up to the top-level statements representing the safety functions. Therefore, the safety statements tree providing a way to structure the information will be used to derive the scenarios instead of the FEPs list as in SAFIR 2 The International FEPs list will be used rather as completeness checks. In addition completeness checks can be performed with other methodologies (e.g., PROSA (ONDRAF/NIRAS, 2001), storyboards, etc.). The scenario derivation will thus remain a combination of top/down approaches.
NWMO Implementer	CNSC Guide G-320 advises a structured approach to assessing the long-term performance of a repository. The NWMO uses a systematic scenario identification process that acknowledges the timeframes of interest and that identifies features, events, and processes which could have an impact on the repository's safety features.

	For scenario identification, a series of meetings are held. These include personnel from the different departments involved in the preparation of the safety assessment: geosciences, engineering and safety assessment. Based on the properties and characteristics of the repository site, repository design, and local biosphere the description of the Normal Evolution Scenario is developed from consideration of the External FEPs and the Internal FEPs and on a reasoned extrapolation of the hypothetical site and repository. It accounts for the expected degradation of the site and repository over time, and addresses the effects of anticipated events, such as glaciation, container breach, etc. A set of Disruptive Scenarios are identified by evaluating the potential for the External FEPs to compromise the safety of the repository system. Specifically, the repository system safety attributes and features are checked to see if they could be significantly compromised by any of the External FEPs. The potential for the Internal FEPs to compromise the long-term safety features is also considered. FEPs not capable on their own of modifying the repository system to an extent that results in a fundamentally different evolution to that considered in the Normal Evolution Scenario are not scenario generating; their effects can be evaluated through different calculation cases for the Normal Evolution Scenario rather than through the development of Disruptive Event Scenarios. Further confidence that a complete set of disruptive scenarios has been identified is then obtained by comparing with the scenarios considered in the post-closure safety assessments of deep repositories in other countries.
RAWRA Implementer	The first option, bottom-up is used with respect to the stage of repository development
POSIVA Oy Implementer	See above Posiva Oy's Q2 input. Scenarios are built for the repository environment and for the biosphere using similar methodology, but safety functions are only used for the repository environment and its components (see POSIVA 2012-08). Two examples are giving below concerning the methodology used to built scenarios for the repository environment and for the biosphere respectively: **The repository system** Posiva's methodology for scenario formulation relating to the repository system follows a top-down approach in first identifying the safety functions that are required of the repository system, then considering the effects of single FEPs or combinations of FEPs on those functions to check that the scenarios are comprehensive, and also to evaluate the effects of uncertainties within the expected lines of evolution. It is also based on the regulatory framework mentioned above and can be summarised as follows: ▪ The regulatory framework is taken into account; it is prescriptive in terminology and definitions. ▪ The safety functions for each of the repository system components are defined and a range of values for acceptable characteristics of those components (performance targets/target properties) is given whenever possible ▪ FEPs that could adversely affect one or more safety functions at a given time or place or under specific conditions within the repository are identified (i.e. FEPs that are scenario drivers within the evolution of the repository system in time and space; see POSIVA 2012-04). ▪ The effects of uncertainties in the expected evolution of the repository system are taken into account (see POSIVA 2012-04).

- Thus, lines of evolution that describe the evolution of the repository system and ultimately lead to canister breaching, form the basis for the definition of radionuclide release scenarios. Each line of evolution is then classified using STUK's scenario terminology (Figure 1).
- For each of the scenarios a set of calculation cases is defined to analyse the potential radiological impacts. The calculation cases take into account uncertainties in the assumptions and data through variations in the models and parameter values.

The biosphere

Formulation of scenarios for the biosphere must be consistent with the regulatory requirements, the methodology used in the formulation of scenarios for the repository system, and the current radiation protection systems for humans and the environment. Posiva's methodology for scenario formulation for the biosphere is somewhat different from that for the repository system, since the biosphere has no safety functions. Instead of identifying FEPs that could adversely affect one or more safety functions, the scenario formulation for the surface environment is based on identifying FEPs that may affect the evolution of the surface environment, fate of radionuclides in the surface environment and/or the potential radiation exposure of humans, plants and animals. The regulatory framework is also taken into account, mainly by coupling the scenario formulation to the dose constraints for humans (GD 736/2008 Section 4: "Disposal of nuclear waste shall be planned so that radiation impacts arising as a consequence of expected evolution scenarios will not exceed the constraints"), for which it is stated in YVL D.5 paragraph 307: "In applying the dose constraints, such environmental changes needs to be considered that arise from changes in the ground level in relation to sea. The climate type as well as the human habits, nutritional needs and metabolism can be assumed to remain unchanged[12]"). Thus, Posiva's methodology for formulating surface environment scenarios can be summarised as follows:

- Constraints on the scenarios arising from the regulatory framework are identified.
- The most important scenario drivers, i.e. key scenario drivers, with respect to the evolution of the surface environment, fate of radionuclides in the surface environment and/or the radiation exposure of humans, plants and animals are identified. This work also comprises identifying FEPs that are coupled to the key drivers, either in isolation or combined, and could induce changes in a timeline of evolution.
- One or several lines of evolution are defined that describe in timelines the surface environment evolution from which one or more scenarios are formulated. One credible line of evolution is identified and used to formulate the base scenario for the surface environment.

[12] Especially *human habits* is a very dynamic group of FEPs that likely change rapidly with time. Posiva interprets the term *unchanged* as: 'credible human habits for the time window when the dose constraints apply are how humans have behaved in the recent few years'. Furthermore, changes in how humans have behaved over the recent couple of decades are used to captures the uncertainties.

	- Variant scenarios are formulated, mainly by considering reasonable deviations from the lines of evolution underpinning the base scenario. Variant scenarios can include additional scenario drivers with a potentially significant effect on the fate of radionuclides in the surface environment and/or the radiation exposure of humans, plants and animals. - Disturbance scenarios are formulated, mainly by identifying unlikely FEPs or by considering unlikely deviations from the lines of evolution underpinning the base scenario. Disturbance scenarios can include additional scenario drivers with a potentially significant effect on the fate of radionuclides in the surface environment and/or the radiation exposure of humans, plants and animals. A set of biosphere calculation cases is defined to analyse the surface environment scenarios. These cases take into account uncertainties in assumptions and models, and the uncertainties and variability in parameter values applied in the models.
ANDRA Implementer	The development of scenarios for the feasibility assessment for the argillaceous site was built upon a number of key elements: • Basic input: the inventory of the waste and their characteristics and the geological site characteristics, • Safety functions and requirement management, • Technical solutions based on industrial experience, • Reversible management and monitoring, • Phenomenological Analysis of Repository Situations (PARS) and detailed, coupled process modelling, • Qualitative Safety Analyses (QSA), uncertainty management, and scenarios, • ALLIANCES simulation platform and calculation results. Andra's approach in Dossier 2005 Argile [15] could be qualified as a "top-down" approach for the definition of the scenarios, as the function analysis is an input data to decline scenarios. In the normal evolution scenario, the components fulfil the expected functions considering their evolution with time and probable events occurring. Although the repository does not undergo a unique evolution because uncertainties remain, a qualitative safety analysis (QSA/AQS) was conducted, in which there is a systematic analysis of uncertainties on FEPs and their effects on safety functions. This approach is in line with the 2008 NSA guide, which sets among the objectives of the post closure safety analysis, the identification and classification of uncertainties according to their consequences in the functioning of the repository, making sure that none is omitted. The QSA contribute to the evaluation of the robustness of the repository by exploring possible dysfunctions of the disposal system (degradation of performances, waste packages defects, cover failure, crosscut of the Callovo-Oxfordien…). In the QSA method, uncertainty is the subject of a systematic study that identifies: • which component is concerned by this uncertainty, with, if relevant, the effects caused by one component on another by means of a perturbation ; • which performance aspects of which safety function can become altered. A qualitative, but argued assessment, including the use of special calculations if relevant, is conducted on the risk of a significant reduction in the expected performances ; • if applicable, and if such information is useful, the time period involved.

	Thus, the methodology determines and assesses, component by component and with respect to the safety functions assigned to each, if the uncertainty (of any type) can affect the ability of a component to realise its functions. QSA then proposes management of uncertainties: • by design measures which reduce their effect; • by the definition of calculation cases in scenarios within the "normal evolution scenario" and its sensitivity analysis (by adjusting the level of conservatism for the parameters for example) within the altered evolution scenarios and their sensitivity analysis. As a first stage the objective is to identify whether the uncertainties can be managed by design measures or can correctly be covered by a calculation case in the NES, either in reference, or by a sensitivity studies. It must be confirmed that they would have little impact on the performance of the functions. As a second stage, if the analysis reveals that the occurrence of residual uncertainties is very unlikely and the effect likely to degrade the performance of a safety function, then the analysis may lead to the definition of altered evolution scenarios corresponding to highly unlikely events and to dysfunction of safety functions (the seals failure scenario, the package failure scenario, the bore-hole scenario and a severely degraded scenario which radically lower performances of safety functions). For example, if a safety function can be affected and the evolution of the repository could start to diverge from normal, with a possible impact on other components, this effect is then specifically identified. Other uncertainties can have a direct influence on the confidence that can be given to a safety function. For example, if the uncertainty about the permeability of the host formation is too large, this could question the performance of the function « prevent water circulation ». A systematic component-by-component analysis is used in particular to identify the shared causes of the loss of several functions: for example, an incorrect assessment of the long-term behaviour of a material can affect all the components that contain it, even though these could have different functions. The qualitative safety analysis provides an assessment of the degree of independence of safety functions, by identifying the possible uncertainties affecting several functions. The analysis includes a crossed-checked analysis of the uncertainties to list the possible common causes of degradation of the performances or identify effects of uncertainty accumulation. The appreciation is qualitative without becoming attached to the probability of a cause. Common causes may lead to grouping situations, when incompatible situations may lead to distinct situations within scenarios. A summary table is associated to the QSA methodology which allows a view on the type of uncertainty, the component(s) involved, the affected safety functions, a brief summary on management of uncertainties. The qualitative safety analysis is a method for verifying that all uncertainties in particular in FEPs and design options have been appropriately handled. It leads to the identification of a series of calculation cases and as a result, the derivation of scenarios. It also has the potential to inform design decisions. Once the NES and AES have been defined and their bounding characteristics verified by the QSA, they still have to be quantified through specific calculation cases. See answer to question 3, 5th bullet..
GRS/BfS Research / Implementer	In the frame of the project VSG a scenario development methodology was developed /10/. As already mentioned this methodology aims at deriving a reference scenario and a number of differing alternative scenarios. At large, the scenarios shall

	represent comprehensively the reasonable range of disposal system developments. The methodology allows straightforwardly the assignment of probability classes to the derived scenarios pursuant to the regulatory requirements /6/. The individual scenarios are characterized by FEP that may influence the future development of the disposal system, and their associated characteristics. The relevant information is given in a site-specific FEP catalogue /12/, /13/. The scenario development methodology is depicted schematically in Fig. 3.1 /11/. The scenario development commences at the following two starting points: • A number of so-called initial barriers are identified that constitute a subset of all barriers acting in the disposal system via diverse mode of operations and, partly, in different time frames. The initial barriers comprise the host rock (salt), the shaft seals, the drift seals, and the spent fuel canisters. Their common characteristic is that these barriers prevent the contact of solutions with the emplaced waste immediately upon closure of the repository system. FEP that could impair the functionality of the initial barriers provide the first starting point for scenario development. • In addition all possible system developments need to be considered which involve a release of radionuclides from the waste form even without any contact of solutions. Those FEP which are related to the mobilization of radionuclides and their transport constitute the second starting point for scenario development. Fig. 3.1: Scenario development methodology applied in the project VSG /11/ Derivation of the reference scenario: Taking specific assumptions into account, the reference scenario results by considering all probable FEP • that may impair the functionality of the initial barriers (initial FEP), and • that determine the mobilization of radionuclides from the waste and their subsequent transport, both in the gas phase and in the liquid phase. If appropriate information is available in the FEP catalogue /13/, the probable characteristics of these FEP or their representative characteristics are taken as a basis. Otherwise, the characteristics result from an analysis of the interaction with all relevant affecting FEP /10/. Specific assumptions concerning the reference scenario are an important element for the scenario development. They provide a means to deal in a transparent and traceable way with particular uncertainties, some of which may be minimized in the future while others may never be reduced at all. In particular, the latter pertains to the future climatic evolution. Therefore, a certain climatic evolution at the Gorleben site with a series of different types of ice ages (Weichsel-type, Saale-type, and Elster-type) was defined for the reference scenario. Other specific assumptions deal e.g. with situations, where no proof has been furnished yet with regard to producibility and functionality of engineered barriers or other technical components. Alternative specific assumptions constitute inter alia a starting point for deriving alternative scenarios. Derivation of alternative scenarios: The reference scenario comprises a set of probable developments of the disposal system that is as comprehensive as possible. Alternative scenarios are developments which differ in exactly one aspect from the reference scenario. Alternative scenarios are developed from the following starting points:

	• developments resulting from alternatives concerning the specific assumptions for the reference scenario, • developments resulting from less probable characteristics of the FEP that may impair the functionality of the initial barriers (initial FEP), • developments resulting from less probable characteristics of the FEP describing mobilization and transport of radionuclides, and • developments resulting from less probable FEP. If possible, information is directly taken from the FEP catalogue concerning less probable characteristics of FEP that may impair the functionality of the initial barriers or that describe mobilisation and transport of radionuclides, respectively, and less probable FEP. Otherwise, the characteristics can be determined by considering the interaction of all other relevant FEP in a similar way as for the reference scenario. It is possible that similar alternative developments result from the different starting points. In this case, various developments may be combined and abstracted into one representative alternative scenario that covers the different characteristics. The described methodology for scenario development can be characterised as a pure "bottom up" approach. The fundamental basis is a FEP catalogue /13/ from which the reference scenario and alternative scenarios are developed in consideration of the above mentioned steps.
JAEA / NUMO Implementer / Research	Fig 3 is a basic procedure to show what elements should be considered and how these elements should be combined to develop scenario(s). Main difference of this procedure from that developed in H12 is to highlight safety functions and treatment scenario uncertainty and likelihood of occurrence. Safety functions has been derived based on technical requirements defined in NUMO's 2010R5) and used as main blocks to develop scenarios. In this procedure, FEPs are used to check completeness of scenarios for SA. FEP list and relating information base, i.e. the state-of-the-art understandings about features, events and processes, are developed and used as scientific basis to check roles and evolutions of safety functions and system conditions. Compilation of FEPs and related information as a FEP database with documentation is undergoing. This scenario development procedure is a combination of top-down approach and bottom-up approach. Fig 4 shows scenario development procedure at working level. Fig 4 identifies practical works corresponding to each element in Fig 3 and also specifies outcome from each work. This procedure is still under development and to be checked for its applicability through some practical trial runs in near future. This procedure is developed with special attention to traceability and transparency of each work, discussions and decision made for scenario development, which contributes to increase of confidence in safety case. Fig.3 Modified procedure for scenario development (Basic procedure) (NB: SF=Safety Function) Fig.4 Modified procedure for scenario development (Detail work according to the basic procedure shown in Fig. 3) Specific features of this procedure are outlined below: The following tools are used to clearly identify outcomes of works shown in Fig 4:

	• Factor analysis chart: Description of relationships among "safety functions", "barrier performance (feature)" and "factors (events and processes)" in chart form, which identify features, events and processes that could influence the safety functions. • FEP Matrix: FEP arrangement in RES matrix form to be used completeness checking. • [see question 3b8]
KAERI Research	Step 1: identifies and classifies features, events, processes (EFPs) associated with long-term performance of the disposal concept. Step 2: screens the FEPs using criteria to determine FEPs that should be included in total safety performance assessment. Step 3: uses the retained FEPs to build scenarios Step 4: screens the scenarios using the same criteria applied to the FEPs to determine the scenarios that should be excluded from total safety performance assessment. Step 5: specifies the implementation of the scenarios in the computational modelling for the total safety performance assessment, and records the application of FEPs .
SKB Implementer	SKB's scenario approach is a combination of top-down and bottom-up. The use of safety functions to identify scenarios is a top-down approach, whereas both the reference evolution, lying the foundation for the main scenario and the scenario selection, and each scenario are systematically analysed by considering all initial state factors, processes and external conditions relevant for them. The latter is a bottom-up approach building on identification of relevant FEPs. (moved from 3b) The selection of scenarios in the SR-Site assessment is based on two key elements of the assessment methodology, that both precede the scenario selection: i) the definition of safety functions and ii) the analysis of a reference evolution. Since the method for scenarios selection cannot be understood without these elements, they are briefly described below. **Safety functions** A central element in the methodology of the SR-Site assessment is the definition of a set of *safety functions* that the repository system should ideally fulfil over time. Here, the overall safety functions containment and retardation are differentiated into a number of lower level functions for the canister, the buffer, the deposition tunnel backfill and the host rock. The evaluation of the safety functions over time is made possible by associating every safety function with a *safety function indicator*, i.e. a measurable or calculable property of the repository component in question. For several functions, it is also possible to associate a *safety function indicator criterion* such that if the safety function indicator fulfils the criterion, then the safety function in question is upheld. The ability of the canister to resist isostatic load is an example of a safety function. The associated indicator is the isostatic load on the canister and the criterion is the isostatic load that the canister has been demonstrated to sustain. **Reference evolution** A reference evolution of the repository system that follows from reference external conditions defined in a previous step of the assessment is defined and analysed prior to the selection of scenarios. The purpose is to gain an understanding of the overall evolution of the system and of uncertainties affecting the evolution, for the scenario

	selection and scenario analyses that follow in subsequent steps. The evolution is an important basis for the later definition of a main scenario. Focus is on the containment capacity of the system. Two cases of the reference evolution are analysed. A base case in which the external conditions during the first 120,000 year glacial cycle are assumed to be similar to those experienced during the most recent cycle, the Weichselian. Thereafter, seven repetitions of that cycle are assumed to cover the entire 1,000,000 year assessment period. A global warming variant in which the future climate and hence external conditions are assumed to be substantially influenced by human-induced greenhouse gas emissions during the first 120,000 year glacial cycle. **Selection of scenarios** A key feature in managing uncertainties in the future evolution of the repository system is the reduction of the number of possible evolutions to analyse by selecting a set of representative scenarios. The selection focuses on addressing the safety relevant aspects of the evolution expressed at a high level by the safety functions 'containment' and 'retardation' which are further detailed as lower level safety functions and characterised by reference to safety function indicators. *1. Definition of the main scenario* A main scenario is defined, based on the reference evolution and in accordance with SSMFS 2008:21 (see response to question 2d). The main scenario is split into two variants, based on the two variants of the reference evolution, (the Weichselian base case and the global warming variant). *2. Selection of additional scenarios based on potential loss of safety functions* A main factor governing scenario selection is the concern that the safety functions relating to containment should be upheld. Therefore, these safety functions are used to structure the selection of additional scenarios. This is the main approach for addressing the issue of less probable scenarios, in SSMFS 2008:21 (see response to question 2d). There are three canister safety functions related to containment: to provide a corrosion barrier, to withstand isostatic load and to withstand shear load. Three distinct canister failure modes, due to corrosion, isostatic pressure and shear movement, respectively, can thus be derived from the safety functions. Therefore, three scenarios, one for each canister failure mode, are generated. Three 'failed' states of the buffer; advective, frozen and transformed, are also considered as scenarios. The canister scenarios are systematically combined with the buffer scenarios. For each selected scenario, uncertainties related to initial state factors, processes and external conditions that are not covered in the main scenario are considered. In e.g. the case of canister failure due to isostatic overpressure, inadequacies in the manufacturing of the load-bearing canister insert, higher than reference buffer swelling pressures and extreme ice sheets yielding high groundwater pressures are considered. An assessment of whether each scenario is to be considered as "less probable" or "residual" is made. In the former case, the likelihood of the scenario is normally pessimistically set to one, whereas the assessed limited likelihoods of its characteristic FEPs, e.g. large earthquakes, are taken into account in the risk calculation associated with the scenario. These scenarios also cover many of the residual scenarios required by SSM's Regulations and General Guidance to analyse the significance of barriers and barrier functions. To obtain a deeper understanding of barrier functions, a number of residual scenarios are defined illustrating, from the point-of-view of radionuclide transport, hypothetical situations where one or several barriers are assumed to be initially lost.

	3. Scenarios related to future human actions A set of scenarios related to future human actions is also defined and analysed. Human intrusion scenarios resulting in a degradation of system performance are to be considered as “less probable scenarios” according to SSMFS 2008:21, but not included in the risk summation according to the General Guidance to SSMFS 2008:37. SSM requires residual scenarios to illustrate damage to humans intruding into the repository and cases to illustrate the consequences of an unclosed repository that is not monitored. *4. Other residual scenarios, etc.* Any other scenarios that are, for any reason, considered necessary in order to obtain an adequate set of scenarios are also to be defined. These could include scenarios directly identified in the FEP analysis but not according to the criteria above. No such issues have been identified in SR-Site. *5. Combination of scenarios* For the scenario selection to be comprehensive, combinations of the scenarios must be considered. This is done when all the scenarios have been selected and analysed. Related to the issue of combination of scenarios is that of different event sequences. The sequence in which different events or aspects of the evolution occur may be important for the evolution of the repository. This is explicitly addressed within each scenario. Summary In summary, the scenario methodology is an investigation of all routes to the three identified canister failure modes aiming at ruling them out or at quantifying them, considering all conceivable evolutions of the system. The safety functions of the repository components and the understanding of the development of the repository system emerging from the analysis of the reference evolution form the basis for exhaustive evaluations of such routes. For a more comprehensive description see section 3.5.8 and chapter 11 of (SKB, 2011). Table 11-1 in section 11.3 of (SKB, 2011) lists the scenarios selected in SR-Site.
SSM Regulator	See SKB.
RWMD/EA Implementer	Scenario development is not a major part of NDA’s current generic work programme. However, we are developing a ‘safety narrative’ that traces the arguments for safety back to the relevant FEPs, using the safety functions of isolation and containment. The aim is to provide a clear, generic description of the basis for safety, that can then be applied to specific disposal concept examples. It is probably fair to say that we primarily adopt a ‘top-down’ approach to safety case development, but this is complemented by a ‘bottom-up’ check against relevant FEPs and consideration of ‘what if?’ scenarios. Our modelling approach tends to be predominantly probabilistic, with explicit representation of relevant uncertainties, typically as an expert elicited PDF for uncertain parameter values.
DoE NE & EM/CBFO Implementer	Combination approach: Identify scenarios, compare/audit the scenarios against FEP lists for completeness (i.e., to check if there are any included FEPs that might define, augment, or alter a scenario), screen the scenarios for applicability, screen them for regulatory exclusions, the comprehensively catalogue and describe them. Next weave the scenarios into, and incorporate them into the models for evaluating, the two large scale scenarios that are credible: undisturbed performance, and disturbed repository performance.

	This approach reflects regulatory requirements to address undisturbed performance for some performance measures (groundwater protection, for example, involving the calculation of drinking-water doses), and both undisturbed and disturbed performance for other performance measures (cumulative releases and individual protection: dose). (moved from 3) Within DOE-NE UFD, FEP identification, FEP screening, and scenario development have been performed only in a generic (i.e., non-site-specific) sense. A preliminary iteration that identified a generic list of 208 FEPs has been completed (Freeze et al. 2010; 2011). FEP identification derived from the NEA FEP list and from a FEP list developed to support the Yucca Mountain Project (YMP). The generic UFD FEPs are broadly defined, so as to be applicable to a range of disposal concepts including mined geologic disposal of UNF and HLW in granite/crystalline rock, clay/argillite, and domal and bedded salt, and deep borehole disposal in crystalline rock. The UFD FEP list is used to define the broad scope of potential disposal phenomena that need to be considered in (1) developing a conceptual model of generic system components/features, (2) identifying generic PA model components, (3) identifying scenarios, and (4) systematically managing/mapping/identifying R&D priorities across the various disposal alternatives. The UFD FEPs are organized in a hierarchical structure based on, and very similar to, the NEA structure as shown in the graphic below. For YMP, a key function of the FEP list was to support the demonstration of comprehensive of the PA model (and post-closure aspects of license application). Having a FEP list that was systematically organized and traceable back to the NEA FEP list provided confidence in the comprehensiveness and completeness of the YMP FEP list. The same strategy is expected to be used for UFD, and a comparable strategy was used in support of WIPP. Preliminary FEP screening and scenario development for the generic UFD disposal concepts is documented in Generic Deep Geologic Disposal Safety Case (Freeze et al. 2013b). Due to the generic nature of the work, the preliminary FEP screening was based on a number of design assumptions and was not intended to represent a formal FEP screening. Rather, the preliminary screening was intended to provide initial guidance into research and development needs. Similarly, formal scenario development cannot be done generically. Instead, for each of the four disposal concepts (granite, clay, salt, and deep borehole), general discussions of the expected initial state of a repository system, and the likely evolution to a final state under undisturbed conditions, were provided (Freeze et al. 2013b, Section 4.2.3.2). Based on these discussions, simple undisturbed scenarios were postulated. The simple undisturbed scenarios in some cases included the effects of defective EBS components. Because the WIPP is an operating facility, any changes to the PA baseline must be approved by the EPA. Because the FEP list for the WIPP is a cornerstone of WIPP PA, it falls within this regulated baseline, and must therefore be maintained using a formalized process. Since the WIPP must be recertified every five years, the FEP baseline is re-evaluated at this frequency, plus at times between when new information or operational changes warrant it, to assure that each PA conducted in support of recertification is conducted using the most recent FEPs.

	The following document describes the WIPP FEPs approach and status: http://www.wipp.energy.gov/library/cra/2009_cra/CRA/Appendix_SCR/Appendix_SCR.htm This document provides a very short summary of the FEPs process by referring to WIPPs use of the FEPs database created by SKB (Sweden), which was then added to and modified to become applicable to WIPP. The SKB work in turn used work by others, including the NEA, to assure its comprehensiveness for the type of repository and the type of location envisioned. The document then describes the continuing work on FEPs and provides an updated FEPs list for the next iteration of the PA accompanying the Compliance Recertification Analysis (CRA) submitted in 2009. These updates are described as follows: The reassessment of FEPs results in a new FEPs baseline for CRA-2009. ... 235 WIPP FEPs have not changed since the CRA-2004. However, 35 FEPs required updates to their FEP descriptions and/or screening arguments, 10 FEPs have been split into 20 similar but more descriptive FEPs, and 1 FEP has had its screening decision changed. The single screening decision change does not result in a new FEP incorporated into PA calculations; the FEP continues to be screened out of PA. Thus the CRA-2009 evaluates 245 WIPP FEPs.

Table 20 Response to item 3b4: uses of international guidance documents and databases, e.g. NEA's FEP database

Organization / Role	Response to item 3b4: Indicate the uses of international guidance documents and databases, e.g. NEA's FEP database
FANC Regulator	See Ondraf/Niras' input
Ondraf/Niras Implementer	**SAFIR2** Nuclear Energy Agency, Confidence in the long-term safety of deep geological repositories. Its development and communication. NEA/OECD, Paris, 1999. Nuclear Energy Agency, Systematic approaches to scenario development. Nuclear Energy Agency, Paris, 1992. International Atomic Energy Agency, Programme on improvement of safety assessment methodologies for near surface waste disposal facilities (ISAM). (Nagra, 2010) NAGRA, Scenario Development methodologies: Applications at Japanese and European implementers, Project Report NPB 10-02, Outcomes of NUMO's Scenario Development Methodology Workshop at Baden, Switzerland, 2-3 December 2009, 2010 (NEA, 2012) NEA, Methods for Safety Assessment of Geological Disposal Facilities for Radioactive Waste, Outcomes of the NEA MeSA initiative, NEA Report No. 6923, OECD/NEA, 2012 Depaus et Capouet; Treatment of the uncertainty of the safety parameters in SFC1, Ondraf/Niras note 2011-0207, 2011 **SFC1** No input.
NWMO Implementer	Before 2013, the NWMO FEPs database followed the organization of the international FEPs database developed by the OECD Nuclear Energy Agency. Currently, the NWMO FEPs database follows the organization recommended to the NEA by Little (2012, private communication). The FEPs are organized under the following seven categories:

	• Assessment basis - defines the scope of the assessment; • External factors - describe factors outside the repository system; • Waste package factors - describe features (properties) and processes associated with the waste package, including its contents; • Repository factors - describe features (properties) and processes associated with the repository and the excavation damage zones; • Geosphere factors - describe features (properties) and processes associated with the geosphere environment in which the repository is located; • Biosphere factors - describe features (properties) and processes associated with the biosphere, including human behaviour and exposure factors; and • Contaminant factors - describe the features (properties) of the contaminants in the waste packages.
RAWRA Implementer	N/A
POSIVA Oy Implementer	The NEA's FEPs database is at the bottom of the FEP screening process
ANDRA Implementer	As regards the 2005 Dossier safety demonstration, NEA's FEPs database has not been used as an entry point, but as a comparison with the QSA. To consolidate a comprehensive qualitative safety analysis, the Agency relied on the « features, events and processes » databases available internationally, in particular the FEP 2000 database of the OECD/NEA [18] and FEPCAT [19]. The FEPs databases list « features, events and processes » that are in principle important for safety analysis, which is a different approach from that of qualitative safety analysis which studies the uncertainties relating to these same features, processes and events. The qualitative safety analysis emphasizes the uncertainties, component-by-component and by function approach; a FEP can therefore appear in several parties of the qualitative safety analysis. Establishing a link between each FEP and each part of the analysis requires going into detail of the qualitative safety analysis arguments, but did prove possible in practice, and useful for verifying and clarifying the qualitative safety analysis. Furthermore, the FEPs are intended to cover all of the phenomenology that could be found in different safety analyses, conducted in different geological contexts, and some require being adapted to become applicable to the Dossier 2005. This adaptation could be done without major difficulties, only a few FEPs concerning phenomena that could not occur in the particular context of the Meuse / Haute-Marne site could be identified in the databases, and were not included in the qualitative analysis. The comparison between the FEPs databases and Andra's own analyses was an important exercise for the qualitative safety analysis, and provided supplementary information on several aspects, to finally end with consistency between the approaches. It proved to be very useful to safety engineers in ensuring that no fundamental characteristic of the components and no phenomenological process likely to have an influence on the repository had been forgotten. Apart from this aim of completeness, the comparison facilitated dialogue between engineers contributing to the safety analysis and engineers contributing to the development of scientific documents.
GRS/BfS Research / Implementer	The regulatory basis for the scenario development constitute as already mentioned the Safety Requirements /6/. These requirements were elaborated in consideration of international standards like the Safety Series from the IAEA and guides and

	recommendations from the OECD/NEA. Therefore, international guidance documents were indirectly considered in the scenario development. In order to verify whether any relevant aspect has been accounted for, the FEP catalogue /13/ was checked using the generic NEA FEP database. Actually, it was one of the tasks to assign each site specific FEP of the VSG project to the FEP of the generic NEA FEP database (cf. /12/ Appendix A). In the case that FEP of the NEA FEP database includes no assigned FEP from the FEP catalogue a respective justification was given.
JAEA / NUMO Implementer / Research	Specific features of this procedure are outlined below: • […] • In the discussion on the scenario development procedure, international discussion of safety case (e.g. [9]) has been referred, especially in the viewpoint of increase in traceability and transparency. And NEA's FEP database (e.g. [10]) has been used to check comprehensiveness of our project FEPs. • […]
KAERI Research	International database on FEPs for geologic disposal of radioactive waste has been referred, when our FEPs have been developed.
SKB Implementer	NEA's FEP database was used when developing a FEP catalogue for the SR-Site assessment. See further chapter 3 of (SKB, 2011).
SSM Regulator	See SKB.
RWMD/EA Implementer	See above.
DoE NE & EM/CBFO Implementer	The DOE-NE UFD FEP list was developed from the YMP FEP list, which was in turn developed from the 1999 NEA FEP list. Initial development of the YMP FEP list considered all of the ~1650 individual NEA FEPs. This involved generalizing NEA FEPs for applicability YMP (e.g., specific YMP design features, oxidizing condition, unsaturated tuff geology) and eliminating redundant FEPs (many FEPs were identified by each of the participating NEA programs). The generalized NEA FEPs were then augmented by YMP-specific considerations (e.g., from YMP literature and expert elicitation). The result was a list of 374 YMP FEPs. Given the historical genesis of the YMP FEP list from the NEA FEP list, initial development of the UFD FEP list did not go all the way back to the NEA FEP list. Rather, it derived from the YMP FEP list. The 374 YMP FEPs (applicable to the specific YMP design and setting) were further generalized to be broadly applicable to the UFD disposal alternatives under consideration. This produced the preliminary list of 208 UFD FEPs. The reduced number of FEPs (374 to 208 simply reflects the broadening/ generalizing of the list – both lists broadly capture the same overall scope – just at a slightly different level of detail). Examples of FEPs broadly applicable to all disposal alternatives include; "Flow through host rock" and "Waste form degradation". In the future, the UFD FEP list will be audited against the updated NEA FEP list, for completeness. In addition, as the UFD program matures, it is likely that the level of detail of the FEPs is likely to increase, such that phenomena specific to certain design alternatives will need to be captured in the FEP list. The WIPP FEP list predated the NEA list. However, it was also a product of taking FEP lists developed for other repository programs, the SKB (Swedish) FEP list in particular (which is also in the NEA FEP list) and combining and refining them in a way that considered the site-specific disposal concept and unique regulatory

	framework at WIPP. Now that WIPP is an operating facility, changes to the current list are carried out via the formalized periodic review/update process that accompanies the five-year recertification process cycle, and incorporates changes during that five-year period to support proposed repository changes or to evaluate new information..

Table 21 Response to item 3b5: Approach to go from scenarios to safety models and/or calculation cases

Organization / Role	Response to item 3b5: Approach to go from scenarios to safety models and/or calculation cases
FANC Regulator	See Ondraf/Niras' input
Ondraf/Niras Implementer	**SAFIR2** The conceptual model used for the normal evolution scenario is essentially the same for the altered scenarios. FEP impacts are represented by an alternative choice of parameters (dissolution rates, Clay thickness,…). Alternative values for BCFs or darcy flow are output from biosphere or hydrogeological models. **SFC1** No input.
NWMO Implementer	The NWMO uses a conservative approach when developing computer codes and models, such that any assumptions and simplifications of processes to make them more amenable for inclusion in computer models does not result in under-estimation of the potential risks or impacts. The NWMO uses a systematic process to ensure that the set of data used for developing the assessment model is accurate and representative. Until a site for the repository has been selected, generic or default data are used in place of site-specific data. Through review of the FEPs, a conceptual model is developed; models developed by other organizations are also considered. For Disruptive Scenarios, the conceptual model is generally a modification of the conceptual model used in the Normal Evolution Scenario since usually there is one particular feature (or process or event) that distinguishes the Disruptive Scenario from the Normal Evolution Scenario.
RAWRA Implementer	Robust approach was used – near field evaluations were based on container life time data and instant partial release of critical radionuclides, with combination of four potential far field (host structure) descriptions
POSIVA Oy Implementer	The scenarios are defined first to illustrate simplistically different possibilities for how the repository system may evolve and perform over time in terms of situations leading to radionuclide releases. Then calculation cases are defined for each of the repository system scenarios following STUK's scenario (Figure 1) hierarchy taking into account uncertainties in the models and parameter values used to represent radionuclide release, retention and transport. In the base scenario, a reference case is defined to which the results of other calculation cases can be compared. The calculation cases for the repository system scenarios are thus classified into three main classes: • A reference case, which is one model representation of the base scenario. Models and data for the reference case are, in most instances, selected to be either realistic or moderately cautious.

	• Sensitivity cases represent alternative models and/or data to those of the reference case, but remain within the scope of the base scenario and/or variant scenarios. • What-if cases are model representations of disturbance scenarios. Models and data for these what-if cases are selected to represent unlikely events and processes. • Complementary cases using models and data that are not necessarily consistent with the base, variant and disturbance scenarios are also defined to enhance system understanding.
ANDRA Implementer	Scenarios are inextricably linked with a safety calculation model that is used to evaluate the quantified impact. Once the scenario is described, the models and parameters are set. The NES is made up of a series of calculation cases, as follows: • A « reference calculation » that sets out Andra's current knowledge of the repository's foreseeable evolution, in an approach that considers both the fruits of scientific research and the safety strategy. The purpose of this calculation is to assess factors that would increase the impact of creating a repository. To this end, it includes a series of parameters and models, choosing those based on the best available scientific knowledge, and incorporating a degree of conservatism that varies according to the uncertainties, being less conservative where the parameters or models have been validated in detail, and more conservative where substantial questions remain outstanding ; • A series of single- or multi-parameter sensitivity analyses that set out to rank the parameters and models by determining the ones that, if they were to vary, would have the greatest consequences for the overall assessment. The NES and its sensitivity studies form a non-dissociable whole. Models may depend on parameters fitting and adjustment. Such adjustments are based on available experimental data; in numerical terms, this data may not be sufficiently representative to allow a mean and standard deviation to be calculated, which leaves a degree of freedom in the choice of the model's parameters; In some cases, chaining the selected models together to form the overall calculation model can result in an exaggeratedly complex representation of the repository that causes prejudice to the good understanding of the fundamental mechanisms. For all these reasons, certain choices must be made in order to position the « safety model », which forms the basis of the scenario assessment, in relation to the available conceptual models. They must be made in such a way that they do not result in the repository's impact being underestimated. For those reasons, in 2005, a standard terminology for qualifying the models and parameters proposed by scientists have been defined to ensure that the « safety » choices are made on a standardised basis common to the science and safety engineers. Depending on the knowledge acquired for each phenomenon or material, four different types of models might be available at a given stage of the project development: • A so called "modèle phénoménologique", or "best estimate model", is either, the model that is based on the most comprehensive understanding of the

	phenomenon to be modelled, and whose ability to account for direct or indirect measurements has been confirmed, or in comparison with the other available models it might be the one offering the best match between the reality that it is supposed to represent and the numerical results that it generates in the impact calculation. • A so called "modèle conservatif", or "conservative model", addresses a case in which it is possible to demonstrate that its use tends to overestimate the repository's impact, compared with the results that would be obtained by taking into consideration all the relevant phenomena in the chosen parameter variation range. For example, selecting a transport model that ignores chemical retention could, in situations where retention has a potentially significant effect, be deemed "conservative". • A so called "modèle pénalisant", or "pessimistic model", designates a model that is not based on phenomenological understanding, however empirical, but that definitely overestimates the repository's impact. For example, making an assumption that waste packages immediately release radionuclides is, except in special cases, a pessimistic choice. • Finally, an "alternative" model stands for a model that can't be classified according to this three items list but offers a different perspective. Examples might include models that don't have an unequivocal effect on the impact, or models that appear more comprehensive than the selected reference model but have been less thoroughly validated. A parallel classification is defined as regards parameter values: • A "phenomenological" value is considered to offer the best match between the model's results and the measured results. This choice must be supported by detailed arguments which may include a representative number of measurements, a physical reasoning that demonstrates that the chosen value is the most representative based on reliable data, or a judgment by recognised experts unambiguously designating it as the most appropriate value for the study context. • The "conservative" value is chosen among those generated by the studies and measurements which give a calculated impact in a range of high values, all other parameters being equal. "Conservative" values cannot be defined if the variations in impact are not monotonic with changes in the parameter. • A "pessimistic" value is one that is not based on a state of phenomenological understanding, but is chosen by convention as definitely yielding an impact greater than the impact that would be calculated using possible values. Such values can represent physical limits. A pessimistic value can also be equal to the conservative value plus (or minus, where applicable) an appropriate safety factor that places it significantly beyond the range of measured values. A value cannot be described as "pessimistic" if the variation in impact in response to a variation in a parameter cannot be characterised. • In order to explore the possible parameter variation ranges, one or more so-called "alternative" values can be suggested as a means of investigating the effect of contrasting values.
GRS/BfS Research / Implementer	[...] Finally the developed scenarios have to be considered in quantitative safety analyses. This requires the implementation of the scenarios in pursuant models and/or calculation cases. In most cases, it is not possible to implement the

	scenarios directly in computer programs for the numerical calculation. There are different reasons for that, e.g. individual natural phenomena cannot be transformed in models due to the complexity of the underlying physical processes or simply because the appropriate software and/ or data are not available. This implies the abstraction of scenarios in models with the need to make assumptions and simplifications or the identification of covering calculation cases with less complexity. At the end of the VSG project it was realized that a systematic approach or formalized procedure to transform scenarios in calculation cases would be more than helpful. In this context, the mentioned aspect was adopted to the list of future R&D work as one of the outcomes of the project (not published yet)
JAEA / NUMO Implementer / Research	See answers of Q3b-1.
KAERI Research	The draft guideline of "General Standard on Deep Geological Disposal Facility for HLW" stipulates as follows: (Safety goal) Deep geological system shall be designed to satisfy constraints in post-closure safety assessment. • Total annual risk for the representative person resulting from radiation exposure should not exceed 10^{-6}/yr for the major scenarios concerning natural phenomena and human intrusions. • Expected radiation exposure to the representative person for each scenario should not exceed 10 mSv/yr In accordance with draft guidelines, post-closure safe assessment code has been developed to implement probabilistic risk assessment resulting from normal and five abnormal scenarios, and deterministic radiation exposure calculation for each scenario.
SKB Implementer	The general evolution for each identified scenario is analysed quantitatively using models established in several Process reports for the safety assessment, see further chapter 7 of (SKB, 2011). Data for the model calculations are compiled according to an established procedure, as reported in a Data report, see further chapter 9 of (SKB, 2011). The analysis of the general evolution may result in the formulation of several calculation cases for radionuclide transport and dose in order to fully quantify the span of possible radiological consequences associated with the scenario as reported in chapter 13 of (SKB, 2011).
SSM Regulator	See SKB.
RWMD/EA Implementer	See above.
DoE NE & EM/CBFO Implementer	Scenarios embed processes, therefore process-level models are developed to determine the interactions between repository features and events and the processes determined to be operative. This is not a linear process, it is an iterative process that in fact identifies new FEPS as models mature and include ancillary data and information to make them applicable to the complex systems being evaluated. Safety assessment models incorporate some process-level models directly, but also rely on process abstractions where the computational burden of fully coupled process-level models is not feasible. That said, DOE-NE UFD is currently evaluating the efficacy of high-performance-computing (HPC)-based safety assessment models that can explicitly accommodate more processes and couplings, as necessary and technically defensible..

Table 22Response to item 3b6: Use of deterministic / probabilistic approach, or a combination of both.

Organization / Role	Response to item 3b6: Use of deterministic / probabilistic approach, or a combination of both.
FANC Regulator	See Ondraf/Niras' input
Ondraf/Niras Implementer	**SAFIR2** Next to the deterministic approach, stochastic methods of calculation were also applied in SAFIR2. In this approach the uncertainty in each model parameter is described by means of a statistical distribution of possible parameter values. Multiple simulations are then carried out in which the parameter values are selected from the parameter distribution functions (PDFs). Stochastic calculations based on 'Latin Hypercube Sampling' technique. These calculations were used to perform sensitivity analysis on radionuclide solubility limits, radionuclide migration parameters for Boom Clay, Groundwater velocity, Biosphere conversion factors (in order to assess conceptual model uncertainties among which climate uncertainties) **SFC1** No firm decision: It should be a combination of both, however we don't intend to use probabilistic density functions..or at least in some particular cases.
NWMO Implementer	Recognizing that the geosphere characteristics at a candidate site and the design of the repository may be different from the assumed reference conditions, both deterministic and probabilistic simulations are performed. A number of deterministic sensitivity cases are examined to illustrate the function of the various engineered and natural barriers. In the deterministic simulations, parameters are varied about a Reference Case of the Normal Evolution Scenario. Many of the modelling parameters are uncertain or have a natural degree of variability and as such are more generally characterized by a range or distribution of values. Probabilistic simulations define a fixed geosphere and then vary all such parameters simultaneously, providing information on the overall range or uncertainty in the results. Random sampling is used to vary input parameters for which probability distribution functions are available.
RAWRA Implementer	Probabilistic evaluation was used for description of container degradation, the other parts of the system (hydrogeology, biosphere) were evaluated using deterministic approach
POSIVA Oy Implementer	A combination of both, deterministic and probabilistic approach for the analysis of the calculation cases within the scenarios is used. The analyses include deterministic analyses of complementary calculation cases, scoping calculations, and also Monte Carlo simulations and probabilistic sensitivity analysis. The aim of these analyses is to develop a better understanding of the modelled system or subsystems
ANDRA Implementer	The normal evolution scenario is defined as a set of evolutions that appear probable enough to be treated as normal, rather than as a single linear scenario. Therefore, in addition to the deterministic elements, it also comprises some events defined with a high occurrence probability. For instance, the welding of the caps of the canisters is a very accurately monitored process, but it has been considered that a certain percentage of faulty quality checks would be unavoidable. Then, considering the present nuclear industry standards, a deterministic assumption of one canister's default per each waste type was considered within the NES.

	As regards the modelling and computation of the scenarios, the approach is also mainly deterministic. Usually, computation cases are carried out with a given set of fixed parameters. Comparisons are made by changing only one parameter at a time, or in any case a limited number (See details about the models and parameters in previous question). By testing the influence of a set of determined parameters on the performances of the repository system, the results of the NES and AES calculations enabled to identify the most influential elements and to deduce the lessons learnt on the role of the components with regard to the main safety functions. In addition to this main deterministic approach, a preliminary probabilistic study has also been carried out taking into account the simultaneous variation of several parameters. It consists as an example in a sensitivity analysis exercise conducted for the iodine and selenium from some vitrified waste packages. The purpose was to back up the lessons learnt with the deterministic studies and assess the effects of joint variations of several parameters according to probability density functions adopted for each one. At this stage, it is intended as a methodological exercise; the calculation is limited to indicators such as the molar flow rates out of the Callovo-Oxfordian and access structures. The parameters which have been associated with probability density functions are: permeability, vertical hydraulic gradient, porosity accessible to diffusion, diffusion coefficients ant the Selenium solubility limit. From this type of calculation, it is possible to deduce information on the uncertainty of the result by situating the position of the various deterministic calculations on an overall distribution curve. It is however difficult to draw direct lessons from this type of assessment as it depends on the probably distribution laws that were adopted. Consequently, the objective adopted by Andra at the stage of this initial methodological exercise is first and foremost to identify the parameters which, due to their uncertainty, have the greatest influence on the uncertainty of the result. This does not mean proceeding with a probabilistic treatment of the impact of the repository. In accordance with the safety rule, the safety approach remains deterministic. The calculation is limited to the indicators as such the molar flow rate out of the Callovo-Oxfordian and access structures and the distribution of radiological impact is not assessed [Andra 2005g]. In the future developments, this kind of approach is likely to be renewed to reinforce the global confidence in the safety analysis by showing the possible span and variability of the results, but it is not foreseen that it could replace or even overpass the deterministic approach which will keep being the backbone of the analysis.
GRS/BfS Research / Implementer	The calculations concerning integrity analyses /15/ and consequence analyses (not published yet) were performed on a deterministic basis.
JAEA / NUMO Implementer / Research	Specific features of this procedure are outlined below: ▪ […] ▪ This approach would also be referred to in the future discussion on categorization of scenarios for geological disposal taking into account different features between sub-surface and geological disposal. On-going study on scenario development for geological disposal system has therefore been aiming to incorporate the disaggregated dose/probability approach into scenario classification. ▪ […] ▪ Systematic analysis applying the scenario development procedure shown in Figs 3 and 4 could result in categorization of potential future evolutions of a

	disposal system considering probability/plausibility and impact on safety functions under specified conditions, which are discussed through factor analysis and argumentation modelling. ▪ […]
KAERI Research	We use deterministic approach, when we develop scenarios.
SKB Implementer	A combination of deterministic and probabilistic approaches was used. In particular for the radionuclide transport and dose calculations, a probabilistic approach was taken to quantify output uncertainty.
SSM Regulator	See SKB.
RWMD/EA Implementer	See above.
DoE NE & EM/CBFO Implementer	Given probabilistic performance measures in US regulations, calculations are exclusively probabilistic.

Table 23 Response to item 3b7: Consideration for temporal sequences in scenario (time cut-off, climate evolution, other events or processes.

Organisation / Role	**Response to item 3b7: Consideration for temporal sequences in scenario (time cut-off, climate evolution, other events or processes.**
FANC Regulator	See Ondraf/Niras' input
Ondraf/Niras Implementer	**SFC1** No firm decision: we are in the stage to perform sentivity analysis. There is no yet decision on the way to structure and define our scenarios.
NWMO Implementer	As indicated above, glaciation is considered as part of the Normal Evolution Scenario. Consequently for the Normal Evolution Scenario, the groundwater flow field is time dependent since it is affected by the advance and retreat of glaciers. Although glaciation is likely to cause major changes in the surface and near-surface environment, the repository itself is intentionally isolated by its depth from these changes. For the hypothetical repository site, paleohydrogeologic simulations are used to determine whether glacial meltwaters may reach the repository level and whether this glacial recharge is expected to be oxygenated or to influence redox conditions at the repository horizon. These characteristics are used in the scenario identification and development. For Disruptive Scenarios, it is generally assumed for conservatism that the events or processes causing the disruption (e.g., seismicity, failure of shaft seals, inadvertent human intrusion ,etc.) occurs at the time of repository closure. Moreover, for Disruptive Scenarios, the impact of glaciation is generally neglected since these scenarios are treated in a more stylistic fashion. Consequently, for Disruptive Scenarios, the groundwater flow field is time independent. Safety assessments for repositories within crystalline host formations focus on the evolution of the repository over a post-closure period of one million years. It will be during this period that the differences between the natural environment and an engineered repository for used fuel are noticeable. Beyond one million years, the repository will be a relatively passive feature of the geosphere, in quasi-equilibrium with the surrounding rock. The total amount of radioactivity in the waste will have diminished to that of a naturally occurring uranium ore body. The dominant

	processes will be regional perturbations to the geosphere that in turn affect the repository.
RAWRA Implementer	N/A
POSIVA Oy Implementer	Climate evolution: The climatic evolution gives the time windows for which various climate-driven processes in the disposal system may operate. Processes internal to the disposal system (whether or not driven by external events and associated changes in external conditions) are also taken into account. The lines of evolution that comprise the expected climatic evolution and frame the disposal system evolution are as follows: • The climatic evolution takes into account a temperate period (i.e. boreal climate) similar to the current one. Thereafter, present-era human effects are assumed to have subsided and a return to glacial-interglacial cycling is expected; this is represented by assuming a repetition of the Weichselian glacial-interglacial cycle (which lasted about 120,000 years). It is acknowledged that this is a very simplistic assumption, since in the last million years none of the glacial cycles has been a repetition of any other. There could be shorter or longer permafrost periods and less or greater ice cover. However very pessimistic, if not unrealistic, climate conditions would need to be assumed for permafrost to reach repository depth. • The evolution of the geosphere and biosphere includes the hydrogeological evolution (groundwater and surface water; coupled to thermal and mechanical evolution in the context of groundwater evolution); the evolution of surface water gives the boundary conditions for the hydrogeological evolution of groundwater • The evolution of the EBS (i.e. canister, buffer, backfill, plugs at the mouth of the deposition tunnels and closure components) is coupled to climatic and geosphere evolution for the same time windows. The evolution of the intact canister is coupled to buffer and backfill evolution (and consequently to climatic and geosphere evolution). The development of the biosphere is considered, following regulatory requirements, up to 10,000 years after disposal of the first canister
ANDRA Implementer	Considering the overall approach, the development of scenarios relies upon a thorough knowledge and understanding of processes and phenomena likely to evolve in the disposal system and its environment. The agency adopted an approach which relies upon the identification of FEPs, their analyses and their conceptualization by fractioning the disposal system in time and space sequences or situations. These situations or key-time sequences represent the basis for derivation of uncertainties and their analyses (qualitative and quantitative analyses), and the background for definition and assessment of scenarios (reference or altered evolutions): • Which processes or effects can affect the evolution of the disposal system? • How a particular FEPs or uncertainties can affect the evolution of the disposal system? • Which processes or effects of FEPs can affect the safety functions? They consider:

	• the study of the initial state and the repository induced (chemical (C), thermal (T); hydraulic (H); mechanical (M); gas formation (G), radiation (R)) processes with time • the study of the evolution of the major disposal systems components and their THMCR interactions, • the study of external events including climate changes (such as glaciations) and human induced phenomena (anthropic effects), They also consider the prediction/modelling of potential evolutions of the site and the disposal system including influences of any disturbances (natural or human induced). The Phenomenological Analysis of Repository Situations (PARS) methodology is an illustration of this approach to structure THMCR and gas processes. To analyse the evolution of the disposal system, Andra adopted segmentation into "situations" of the repository evolution in time and space. This work is based on a breakdown of the disposal system into situations, with each of these situations corresponding to a space and time interval within which a few major phenomena dominate the evolution of the components. In this evolution, each state of the disposal system depends on the former state (Figure 2). The peculiarity of the Dossier 2005 Argile is that it is based on the observations and the results from experiments carried out on a real site (on the Meuse / Haute-Marne site where the underground research laboratory is located). The methodological approach to define the timeframes of those situations relied upon spatial fractioning according to the main disposal system components. This analysis is based on a detailed description of the aforementioned components. It identifies the major processes and determines the uncertainties associated with them. TH(G)MCR phenomena are recorded in this context. These different phenomena have their own time characteristics (constants), which determine the successive, distinctive states of the disposal system, including transitory state. It is possible therefore to define a "typical sequence" of situations
GRS/BfS Research / Implementer	As mentioned above, the limitation in time for safety analyses and safety assessments including scenario development corresponds to the demonstration period of one million years (cf. response to the issue 1. d. of the questionnaire). It was also aforementioned, that a certain climatic evolution at the Gorleben site with a series of different types of ice ages (Weichsel-type, Saale-type, and Elster-type) was defined for the reference scenario. The defined climate evolution covers the underlying demonstration period of one million years /10/. Furthermore the temporal evolution of events and processes were considered in the scenario development. It should be pointed out that the majority of FEP have no temporal limitations. Only some processes and events show a temporal dependency which can be classified as follows /10/: • Decreasing evolution, e.g. radioactive decay and heat production • Increasing evolution, e.g. degradation of spent fuel canisters and hydraulic permeability of drift seals and shaft seals • Becoming active to a later point in time in the post closure phase, e.g. permafrost and glacial channel formation
JAEA / NUMO Implementer / Research	Specific features of this procedure are outlined below: ▪ […]

	Discussion mentioned above on exertion and evolution of safety functions under the effects of factors defines system conditions and their evolution which allow describing temporal sequence in scenarios. A storyboard is used as a visible format to describe such temporal sequence. As mentioned in the response to question 1.d., discussion on safety regulation so far has not suggested time cut-off for the safety assessment yet and required that assessment calculation should be conducted to the time when peak dose appears. ▪ […]
KAERI Research	Not answered.
SKB Implementer	The temporal evolution of the system is analysed in the reference evolution. Here, four time frames are considered: 1. The excavation/operational period. 2. The first 1,000 years after repository closure and the initial period of temperate domain from the reference glacial cycle. 3. The remaining part of the glacial cycle. 4. Subsequent glacial cycles up to one million years after repository closure. Each scenario has the reference evolution as a starting point and hence implicitly considers the same temporal sequences. Relevant aspects of the climate evolution are thus addressed in each scenario, and the time cut-off of one million years after closure, derived from the general guidance to SSM's regulation SSMFS 2008:37, applies to all scenarios.
SSM Regulator	See SKB.
RWMD/EA Implementer	See above.
DoE NE & EM/CBFO Implementer	This topic was covered in the introductory section where the text of various US regulations was cited: 10,000 years for screening FEPs/scenarios, with some additional guidance regarding processes required to be evaluated beyond 10,000 years. A stylized biosphere and stylized human intrusion cases, and a stylized future climate beyond 10,000 years are examples discussed in the introductory material.

Table 24 Response to item 3b8: Indicate the use of formal tools (e.g. software-based tools)

Organisation / Role	**Response to item 3b8: Indicate the use of formal tools (e.g. software-based tools)**
FANC Regulator	See Ondraf/Niras' input
Ondraf/Niras Implementer	**SAFIR2** PORFLOW **SFC1** Usually the software tools used for SA analysis are Comsol and Porflow
NWMO Implementer	The NWMO currently does not use formal tools in scenario identification and development
RAWRA Implementer	Software based tools.
POSIVA Oy Implementer	For the repository system verification measures, including benchmarking exercises that address specific functions of GoldSim and MARFA, have been carried out during the development of these codes. In addition, benchmarking exercises have

	been carried out in which results generated by these codes were compared with those generated by REPCOM and FTRANS, which are the codes that were used in previous Posiva safety analyses and have been shown to handle the main features, events and processes of concern (e.g. Smith et al. 2007, Nykyri et al. 2008). Section 14.2.4. The exercises use test cases that are representative of the types of calculations for which GoldSim and MARFA are used in Posiva Safety Case TURVA-2012, and so contribute to validation as well as verification. For the biosphere the delineation of basic biosphere objects changes with time throughout the simulation results and this is done by the UNTAMO data extraction tools (Posiva 2007). The selection of the number and location of wells (in biosphere objects) is based on the delineation of the soil types provided by the UNTAMO toolbox. The key data sets used in dose calculation are the dose coefficients. The dose coefficients for inhalation are based on the values recommended by (ICRP 1996) for adults. In (ICRP 1996), three values are given, one for each class of absorption in the lungs: F (fast), M (moderate) and S (slow). The class resulting in the highest exposure was chosen for each radionuclide. The dose coefficients used for external radiation are due to radionuclides uniformly distributed to an infinite depth in soil. The (effective) dose coefficients are based on Table III.3 in (EPA 1993), extracted using the software Radiological Toolbox (version 2.0.0, August 2006); developed for the U.S. Nuclear Regulatory Commission (http://www.nrc.gov/about-nrc/regulatory/research/radiological-toolbox.html) For the dose estimates for plants and animals (other biota) simplification is required from the long-term releases from the proposed Olkiluoto repository. Such simplifications are implicit within available assessment approaches and tools, including the ERICA (ERICA 2007) and the ICRP Reference Animals and Plants (ICRP 2008) approaches
ANDRA Implementer	The feasibility assessment for the argillaceous site was built upon a number of key elements: • Basic input: the inventory model of the waste and the geological site, • Safety functions and requirement management, • Technical solutions based on industrial experience, • Reversible management and monitoring, • Phenomenological Analysis of Repository Situations (PARS) and detailed, coupled process modelling, • Qualitative Safety Assessment (QSA), uncertainty management, and scenarios, • ALLIANCES simulation platform and calculation results. The following tools have been carried out in the framework of the Dossier 2005. They support the task of scenario development: • the functional analysis (FA) [15] to determine the safety functions and associated requirements – what do we want? -; • the Phenomenological Analysis of Repository Situations (PARS) [16] providing a good scientific understanding based on scientific studies from surface and underground laboratory – what do we get? -;

	• the qualitative safety analysis (QSA) [15] managing uncertainties and the quantitative assessment [safety and performance indicators] including sensitivity analysis –. What is the impact of a given uncertainty (or set of uncertainty factors) on the robustness of the system? – And eventually: does the concept meet the safety/acceptability criteria? Simulation tools have been developed for the evaluation of the impact and/or performance of functions. • The overall safety model, based on the NES and AES, is composed of a number of hydraulic and chemical analyses and transfer models. One or several dedicated simulation codes were chosen for each of these models – for example, Castem, Porflow or Traces for hydraulic simulation; Castem, MT3D, Traces, Chess, or PhreeqC for chemical transport simulation; LHS, Kalif, Pastis to sample and analyse sensitivity simulations. • All individual codes are linked together on a simulation platform called ALLIANCE, to build an overall safety calculation best suited for the considered scenario. ALLIANCE was co-developed with the CEA (Atomic Energy Commission) to provide a modular structure for simulation development, and to ensure proper treatment and transfer of parameters and values between individual codes.
GRS/BfS Research / Implementer	The use of formal tools refers only to the elaboration of the FEP catalogue /12/, /13/. In this regard templates were provided for the characterisation of the FEP. The templates include a structured mask with different input fields, e.g. FEP-number, NEA-number, title, date, brief description, direct dependencies and implication /12/. This guarantees a structured and consistent form of the FEP description. The handling and management of the FEP data is supported by a computer aided database program. This program enables the search, selection and identification of data to a specific FEP, a group of FEP or the FEP database at large. Another feature is the consistency check regarding the included information of FEP interactions. This facilitated the work in particular in the development phase of the FEP catalogue /12/.
JAEA / NUMO Implementer / Research	[…] Specific features of this procedure are outlined below: The following tools are used to clearly identify outcomes of works shown in Fig 4: • [see 3b3] • Argumentation model (e.g. [6]): A tool of developing structured chains of arguments on support and adverse claims with their evidence, which enhance the reasoning of likelihood of occurrence of a range of possible system states and their evolutions identified through the factor analysis. • Correlation diagram of safety functions: Description of integrated information on exertion and evolution of safety functions reflecting the results of identification/extraction of the key factors based on factors analysis chart(s) and the argumentation model(s). • Storyboard[5)]: Graphical table, which is used as a tool to visually summarize the results of scenario development (i.e. safety functions and their evolutions

	with relevant processes and conditions in different timeframes). Storyboard can be used as a portal to access relating detail information. – [...] Applying advanced IT and KM technologies/tools, the scenario development procedure and tools are being integrated in an electrical platform (e.g. portal site of web page). This platform includes a function of recording all relevant work with associated discussions and decisions made for scenario development, which contribute to increase in traceability and in particular to externalization of knowledge and evidence in expert judgement.
KAERI Research	None.
SKB Implementer	An SKB FEP database was developed using a commercially available database tool, see further chapter 3 of (SKB, 2011) and references therein. A so called FEP chart was developed to keep track of all major FEPs of relevance for the safety case, see section 8.5 of (SKB, 2011). The chart was primarily used as a check list when analysing the selected scenarios. Two assessment model flow charts, AMFs, were developed to describe how the processes of relevance for long-term evolution are modelled in the safety assessment, see further section 7.5 of (SKB, 2011).
SSM Regulator	See SKB.
RWMD/EA Implementer	We are also developing our generic modelling tools; this includes our approach to data elicitation and the development of a register of uncertainties.
DoE NE & EM/CBFO Implementer	Databases are the only tools being used in either of the US programs contributing to this response.

Table 25 Response to item 3b9: Indicate the use of formal expert elicitation processes.

Organization / Role	**11. Response to item 3b9: Indicate the use of formal expert elicitation processes.**
FANC Regulator	See Ondraf/Niras' input
Ondraf/Niras Implementer	**SAFIR2** The management of uncertainties and expert elicitation processes were not formalised as such in SAFIR 2 (as also remarked by the International Peer Review Team) **SFC1** For SFC1, we have tried to formalise the expert elicitation process to derive the safety parameters from the assessment basis. The safety parameters are used in safety assessment calculation. The tools are the following: • The safety parameter values and their associated uncertainties are derived within the framework of "interaction meetings ": Topic experts present their knowledge and through discussion the safety assessors derive the safety parameters. An independent technical secretary takes note of the argumentation given at the meeting supporting the choice of the values. Operating this way allow to derive safety parameters that are endorsed by both the safety assessors and the topic experts. The technical secretary ensure consistency and coherence.

	• We have also formalised the way the safety parameter uncertainty is characterised: Indeed, the experts are required to give two different intervals of parameters values taking into account the current hypotheses of the reference scenario (Depaus & Capouet, 2011):
	  - the **expert range (ER)** : the range within which experts expect the parameter value to lie. This range is also referred to as the realistic[13] or likely range
	  - the **source range (SR)**: the range outside of which the experts do not expect the parameter value to lie. This range is also referred to as the support range.
	In order to derive the expert range on the basis of this broad information, the expert has to select the knowledge that he/she considers as the most representative of the process under concern, in the conditions of the reference scenario (e.g. most reliable or representative data, larger consensus among one reasoning line).
	The broader nature of the source range can be multiple and may allow including "informations" that are believed to be less representative of the process or situation under study but cannot be excluded at this program stage. This piece of information can be of different types:
	• It can be under the form of data that seem less reliable or representative of the assumed **conditions** (e.g. different site or host) but cannot be excluded for good at this program stage.
	• The uncertainty included in the source range might be also a result of an uncertainty on the exact nature of a process (or set of processes) occurring at more elementary phenomenological level

NWMO Implementer	The NWMO currently only uses internal expert elicitation processes in scenario identification and development. The NWMO`s scenario identification methodology will be reviewed by the CNSC as part of the review of the 4CS and 5CS pre-project reports.
RAWRA Implementer	N/A.
POSIVA Oy Implementer	Formal expert elicitation process has been used for the selection of solubility limits, and sorption and diffusion values. It helped to identify the main sources of uncertainty and determine whether different views may have to be propagated through the safety assessment. The expert elicitation process was been initiated, recruited, documented and managed by the Posiva's Quality Co-ordinator
ANDRA Implementer	Formal internal reviews are implemented and recorded in order to get experts' views and make decision (see 4.a). In that framework externalisation of expert judgment may be integrated (see 4.c). Such reviews were organized for the dossier 2005 concerning the choice of the scenarios to be quantified and related choices of models and parameters of the safety calculation. Expert elicitation process is also formalised in the way models and parameters values are presented for internal review process. Depending on the knowledge acquired for each phenomenon or material, scientists experts present the range of variability of parameters values and qualify those one using a standard terminology

[13] Such as deemed by the experts

	("phenomenological or best estimate value…see 3b item 5). If a set of data is proposed resulting from expert judgement, it should be recorded at that step. This approach ensures that the « safety » choices are made on a standardised basis common to the science and safety engineers. Safety models and safety data sets associated to a scenario are then formalised in a technical document submitted to the formal internal review by experts before final approval. This technical document is jointly produced by the experts and safety engineers. Safety models and parameters values presented in the Dossier 2005 result from this process.
GRS/BfS Research / Implementer	Following to the project VSG an international review of the outcome was originally envisaged. Due to the current German political discussion and the implementation of the new site selection act for a repository of high-level radioactive waste (StandAG, July 2013) there are no chances for further work like an international review. But project-related internal reviews were performed by external experts. The results of the internal reviews were presented and discussed on several workshops during the project. Furthermore, an internal systematic review process of the project reports were developed and applied
JAEA / NUMO Implementer / Research	See answers of Q3b-1.
KAERI Research	We have carried out expert elicitation process once, and have planned to perform experts' elicitation process to include additional FEPs related with radioactive wastes from pyroprocessing.
SKB Implementer	Formal expert elicitation was not used in SR-Site. See further sections 2.8.5 and 13.10.2 of (SKB, 2011).
SSM Regulator	See SKB.
RWMD/EA Implementer	See above.
DoE NE & EM/CBFO Implementer	Peer reviews of process models and of performance-assessment models by necessity addressed the completeness of the FEPs addressed in these models. No external elicitations were performed just to determine the completeness of the FEPs list, although several external reviews of models led to changing and adding FEPs.

Table 26 Response to item 3b10: How is the propagation of uncertainties managed?

Organisation / Role	**Response to item 3b10: How is the propagation of uncertainties managed?**
FAN**C** Regulator	See Ondraf/Niras' input
Ondraf/Niras Implementer	**SAFIR2** Not answered. **SFC1** No firm decision since we are not yet in the process to derive scenarios: However we think to use the safety statement tree that is used as knowledge management system to structure the uncertainties according to the safety functions
NWMO Implementer	Uncertainty in the future evolution of the site is addressed by assessing a range of scenarios that describe the potential evolution of the system. The scenario identification process ensures that key uncertainties are identified and scenarios are defined to explore their consequences.

	It is unrealistic to predict human habits and behaviour over the time scale of relevance to the repository system. Major changes to the surface and near-surface environment are likely to occur as a result of natural changes such as ice sheet advance / retreat or as a result of future human actions. Also, societal and technological changes are inherently unpredictable over such timescales. To estimate potential future impacts, a stylized representation of the biosphere and human receptors is used to allow illustrative estimates to be made. It is assumed that future humans are generally similar to present day humans, and will adopt behaviours that would be consistent with current or past human practice. People are assumed to live on the repository site in the future in a manner that maximizes their potential dose from exposure to releases from the repository. Since assumptions concerning the biosphere (e.g., climate), human lifestyles (e.g., critical group characteristics) and water flows in the near-surface environment become increasingly uncertain with time, two complementary long-term indicators are also used to supplement the dose rate indicator using system characteristics that are much less sensitive to such assumptions. The types of complementary indicators used in this report are radionuclide concentrations in the biosphere and radionuclide transport to the biosphere. Indicators of the first type avoid assumptions about biosphere pathways but make assumptions about flow rates in surface water bodies (i.e., dilution rates). Indicators of the second type avoid assumptions about surface water flows. Concentration type indicators are more useful on medium timeframes (about 10,000 to 100,000 years), while transport type indicators are more useful for very long timeframes (> 100,000 years) when there is more uncertainty about surface conditions. The specific complementary indicators used in this study are radiotoxicity concentration in a water body and radiotoxicity transport from the geosphere. Radiotoxicity concentration is the sum over all radionuclides of the activity concentrations in the water body multiplied by the corresponding radionuclide ingestion dose coefficient. The radiotoxicity transport from the geosphere is similarly defined. Many of the modelling parameters are uncertain or have a natural degree of variability and as such are more generally characterized by a range or distribution of values. Probabilistic simulations define a fixed geosphere and then vary all such parameters simultaneously, providing information on the overall range or uncertainty in the results. Random sampling is used to vary input parameters for which probability distribution functions are available.
RAWRA Implementer	N/A.
POSIVA Oy Implementer	In Posiva (2012-04) uncertainties in the initial state of the barriers and/or in the evolution of the repository system that could lead to radionuclide releases are identified. These deviations from the desired initial state or expected evolution are propagated to Formulation of Radionuclide Release Scenarios (POSIVA 2012-08), which defines the scenarios and the calculation cases for both the repository system and the surface environment (biosphere). The aim of Formulation of Radionuclide Release Scenarios is to systematically define a set of scenarios that encompass the important combinations of initial conditions, expected evolution and disruptive events. The impact of specific model and parameter uncertainties or combination of uncertainties is analysed using sensitivity calculation cases within the scenarios defined.
ANDRA Implementer	QSA examines uncertainties due to perturbations by adjacent component or those who can act on him at distance. Thus, uncertainties concerning the nature and the

	extension of the disturbances (Thermal Hydraulic (Gas) Mechanical Chemical Radiological and Bacteriological) are transcribed. They are the uncertainties bound to the internal interactions processes within the repository.
	During QSA, a particular attention is brought on the possible existence of propagation of uncertainties (for example, a possible uncertainty on the intrinsic thermicity of some waste or the evolution of the temperature in the repository can impact on the performances of a remote component).
	QSA methodology is then applied and proposes management of uncertainties according to the same approach, i.e.:
	• by design measures which reduce their effect;
	• by the definition of calculation cases in scenarios;
	  - within the “normal evolution scenario” and its sensitivity analysis (by adjusting the level of conservatism for the parameters for example);
	  - within the altered evolution scenarios and their sensitivity analysis.

GRS/BfS Research / Implementer	There is no specific requirement or procedure how the propagation of uncertainties can or should be managed. Irrespective of this fact the uncertainties in general are considered both in the scenario development and in safety analyses. In the context of scenario development the uncertainties are considered actually by developing alternative scenarios where the majority will be less probable due to the consideration of less probable FEP and probable FEP (initial FEP and FEP describing mobilization and transport of radionuclides) with less probable characteristics. The deviating considerations of the underlying assumptions for the reference scenario are also an aspect for alternative scenarios (cf. also the response to the issue “Steps of your methodology”). When it comes to quantitative analyses then it should be pointed out that for probable scenarios uncertainty analyses and sensitivity analyses were performed /15/
JAEA / NUMO Implementer / Research	Specific features of this procedure are outlined below: […] Probabilities of occurrence of processes and/or events are not explicitly assigned in this procedure, but likelihood of occurrence is subjectively judged. This judgement is made for each branch which is identified in the form of factors analysis chart taking possible affects of factors on safety functions into account. Such analysis can also be useful to manage uncertainties associated with the effects on safety functions and conditional propagation of these effects in time and space. […]
KAERI Research	▪ Not answered.
SKB Implementer	This is an issue for the entire assessment methodology, not just the scenario approach. The following can be said in brief: In terms of uncertainties, the analyses in the reference evolution aim at reducing the number of uncertainties requiring further consideration and at identifying and quantifying uncertainties that need to be propagated to subsequent parts of the assessment. To obtain a systematic handling of uncertainties in the reference evolution, each sub-analysis is concluded with a reporting of uncertainties in the results. The need for propagation of any uncertainties to subsequent parts of the safety assessment is also reported. After completion of the analysis of the reference evolution, an account of the identified uncertainties is given in table format for subsequent use in the selection of scenarios and calculation cases for

	consequence analysis of the scenarios. See further section 10.7 of (SKB, 2011). A main purpose of the selection and analysis of a number of scenarios based on the potential loss of safety functions is to evaluate the effect of uncertainties not covered in the reference evolution. In each of these scenarios, the handling of relevant aspects in the reference evolution is revisited and the handling of relevant system, conceptual and data uncertainties is extended or modified, as appropriate. This is reported in chapter 12 of (SKB, 2011). The analysis of the general evolution of each scenario may result in the formulation of several calculation cases covering uncertainties in the scenario evolution. The uncertainties associated with each such calculations case are mainly quantified probabilistically. This is reported in chapter 13 of (SKB, 2011).
SSM Regulator	See SKB.
RWMD/EA Implementer	See above.
DoE NE & EM/CBFO Implementer	Uncertainties are reflected through varying and sampling data ranges that may describe several likely processes. They are evaluated probabilistically to provide statistical descriptions of outcomes such as the mean, the 95th %-iles, and in one instance the likelihood of the mean outcome.

Annexe 3: *Discuss why the current scenario definition and analysis approach is appropriate for this project at present?*

Table 27 Question 4: Discuss why the current scenario definition and analysis approach is appropriate for this project at present? Global answer to question 4.

Organisation / role	**Question 4 Discuss why the current scenario definition and analysis approach is appropriate for this project at present? Global answers to question 4**
RAWRA	The steps considered are not yet applied
Posiva Oy Implementer	The current scenario definition is part of the safety case, which is reported in a well-structured portfolio (Figure 2). The performance of the repository system (Performance Assessment, Posiva 2012-04) evaluates the fulfilment of performance targets and target properties, which underline the safety functions of the repository system components (e.g. canister, buffer, …) and highlight uncertainties, which are propagated to the scenario definition (Formulation of Scenarios, Posiva 2012-08) and their impact analysed in the assessment of scenarios for the repository system (Posiva 2012-09) and the biosphere assessment (Posiva 2012-10). The strategy for scenario formulation can be summarized as: Firstly, the Finnish regulatory guidelines in Guide YVL D.5, which are in accordance with the IAEA Safety Standard Series No. GSR Part 4 (IAEA 2009), SSG-14 (IAEA 2011) and SSG-23 (IAEA 2012), have been followed. A comprehensive set of safety functions for the repository system components has been identified and reported in Design Basis and assessed in Performance Assessment under the framework of the expected or normal evolution of the repository system. This assessment is done taking into account all evolution-related FEPs (see Features, Events and Processes) along with groundwater flow (advection) and water-rock interactions (groundwater chemistry). In the expected evolution, no canister failure occurs during the first 10,000 years after emplacement and not even within the first 100,000 years. Performance Assessment highlights the uncertainties in the initial state of the components of the repository system and specifically of the canister, and the uncertainties in the evolution of the repository system with respect to containment and retention of radionuclides. These uncertainties are propagated to the Formulation of Radionuclide Release Scenarios and dealt with by selecting individual FEPs or combination of FEPs to form scenarios that ultimately lead to canister failure over a timescale of one million years. Whenever radionuclide releases occur within the time window of the first ten thousand years after canister(s) emplacement, the results of the calculation cases within the repository release scenarios are fed to the surface environment scenarios. The formulation of these follows the Finnish regulatory guidelines in as much as that the characteristics of the Olkiluoto site and uncertainties in its development (throughout the analysis of a comprehensive set of surface environment FEPs) are taken into account ***Figure 1-2.*** *TURVA-2012 safety case portfolio including report names (coloured boxes) and brief descriptions of the contents (white boxes). Disposal system = repository system + surface environment.*

GRS/BfS Research / Implementer	The scenario development which was established and applied in the VSG project was able to identify a reference scenario and several alternative scenarios with less probability. Therefore, it was able to fulfill the implicit recommendations by the Safety Requirements /6/ to distinguish between probable and less probable developments of the repository system in the post closure phase. In that sense the scenario development method was found to be appropriate for the purpose. By using initial barriers, the scenario development method is directly oriented along the lines of the safety concept. This results in a high confidence on the comprehensiveness of the method. However, an actual proof of the completeness of the scenario development might not be achievable. The final report for the scenario development /10/ suggests applying diverse methods for the scenario development to check whether the obtained scenarios are reproducible. This is considered as future action. The VSG ended on the 31st of March 2013, only four months prior the preparation of the answers to this questionnaire. No official review of the scenario development has been performed from the regulatory body during that time. A statement of the German Nuclear Waste Management Commission (ESK) on the post-closure safety case for the Morsleben repository for radioactive waste /17/, proposes to apply the newly established scenario development also to the ERAM repository. This proposition was supported by the Federal Ministry of Environment (BMU). These two statements both can be considered as assent to the scenario development method. The idea of an international review of the VSG by the NEA was unfortunately dropped, but an internal national review of the scenario development during the VSG project met general approval of the method with some critical remarks. These remarks mainly touched two points: The first one is the choice of the so-called initial barriers and the influence of the choice on the derived scenarios. The second one is the assignment of a scenario probability class which is derived from the probability of the underlying FEP and its quantitative characteristic, which requires knowledge on the statistical dependence of the FEP. The latter issue was also under dispute in the ESK in the context to express the Safety Requirements /6/ on scenarios in concrete terms /16/. Both issues are considered as remaining open questions and are on the agenda of future research.
RWMD/EA Implementer	As already noted, due to the generic stage of the UK programme, we do not really have an active programme of work for scenario definition. When we consider a specific site, we will review our previous approach (documented in Nirex Report S/98/009 and its supporting references) and apply this to the specific site. This will also include a review of our FEP database (currently contained within a Master Directed Diagram (MDD) – [Nirex Science Report S/98/010, 1998]. The approach documented in the 1998 series of Nirex reports was favourably reviewed by an NEA International Review Team [*Nirex Methodology for Scenario and Conceptual Model Development: An International Review*, OECD-NEA, June 1999.

Table 28 Question 4a. Describe the process used to determine if your project's contributors internally agree that the set of scenarios carried out in the safety analysis is sufficiently complete / comprehensive for the purpose at hand

Organisation / role	**Question 4a Describe the process used to determine if your project's contributors internally agree that the set of scenarios carried out in the safety analysis is sufficiently complete / comprehensive for the purpose at hand**
FANC Regulator	No input
Ondraf/Niras Implementer	No input.
NWMO Implementer	Formal procedures govern the performance of safety assessments. These procedures define specific contributors to assessment planning; they also prescribe a technical review of the assessment that includes confirmation of the initial assumptions used to guide scenario development. For scenario identification, a series of meetings are held. These include personnel from the different departments involved in the preparation of the safety assessment: Geosciences, Engineering, and Repository Safety. Discussion begins around an initial set of proposed scenarios and considers how they would be defined; discussion may also include some speculation on the consequences predicted within each scenario and how models might characterise scenarios appropriately. Further confidence that a complete set of Disruptive Scenarios has been identified is obtained by comparing the scenarios considered in the postclosure safety assessments of other repository programs. Although there may be some scenarios identified by others that are not considered by the NWMO, the reason for this is examined to ensure its omission is correct.
RAWRA Implementer	Steps not yet applied.
Posiva Oy Implementer	Discussion on the final set of scenario took place in several meetings and workshops, where the project's contributors could add comments on the completeness/comprehensiveness of the scenarios that were being defined.
ANDRA Implementer	For Andra, the quality and reliability of a safety assessment depends on the quality and reliability of this assessment basis. According to NEA [11, 12, 20], a discussion of the assessment basis in any detailed presentation of the safety case should include evidence and arguments to support the quality and reliability of its components. It was pointed out that the confidence in the safety analyses was not simply based on the intrinsic quality of the supplied data. • The "transparency", that is the clarity and the comprehensibility, with a concern of writing adaptation to the various aimed readers; • The "traceability", allowing to go back at the origin of any assertion, given data or hypothesis, by a clear presentation and by the use of reference; • The "openness", that is the presentation and the discussion of the uncertainties, the open questions, or of any element which can question the safety of the repository; • The organization of internal and external reviews by the peers. A good control of the utilisation of these data and of the methods employed, and the existence of independent reviews of the results offer major guarantees for any person who has to analyse or use the dossier's data.

	According to the principles defined in the ISO 9001 standard, Andra has defined processes regrouping activities, which contribute to the same finality and are oriented toward a customer's satisfaction. Certain procedures are general within Andra (they are for example, general procedure of management of documents, conduction of internal reviews, and management of interfaces between units). Accordingly, at each key step of the establishing of the safety case (in particular, QSA, scenarios, calculation cases, safety models for quantification of scenarios and related data sets), internal reviews are implemented and recorded in order to get experts' views and make decisions. These measures are a part of the control of the repository safety, as far as they send back to appropriate choices, to assure that the safety analyses took into account all the relevant input data, but also that these data and the results of analyses are managed within a system which insures the traceability of choices and results. The different milestones of the project are thus the object of formal internal review, organized according to the procedure: organization of a group of review to examine a set of documents and to ask questions in prerequisite to the meeting, the instruction of the questions by a group of in review (consisting of engineers having contributed to the elaboration of documents), the discussion in session and elaboration of a proposal of decision, submitted to the managers (decision-making board). Such reviews were organized for the dossier 2005 concerning the choice of the scenarios to be quantified and related choices of models and parameters of the safety calculation. Similar reviews are planned for the 2015 authorisation case. Accordingly, QSA, scenarios, calculation cases, parameters and models will be submitted to internal review. Furthermore, the review team will include international experts.
GRS/BfS Research / Implementer	Not answered.
JAEA / NUMO Implementer / Research	At this time, we judge appropriateness based on the agreement among a range of experts from different organizations through discussion on the developed approach. But this approach has not yet fully applied in the process for scenario development. Appropriateness will be further checked through such comprehensive application. The approach is developed with special attention in particular to increase in traceability and transparency of scenario development process. Communication with wider stakeholders on scenarios would be useful to test the appropriateness in this regard.
KAERI Research	We have confirmed our method to develop scenarios by elicitation process done by expert in various field in relation to deep geological disposal.
SKB Implementer	Each member of the project is engaged in the aspects of scenario definition analysis that concerns his/her area of expertise, and hereby contributes to the completeness discussion for part of the system analysis. The entire set of scenarios is discussed at project meetings involving experts of all areas of expertise. Also, the safety assessment report, including the scenario selection, was reviewed by an international panel of experts several times in the development of the safety case.
SSM Regulator	See SKB.
RWMD/EA Implementer	.
DoE NE & EM/CBFO Implementer	In both the WIPP and Yucca Mountain cases there were structured internal meetings between the data providers (experimentalists) and data user (process and performance assessment modelers) with constructive feedback leading to

	some modelling adjustments and, more importantly, experimentalists agreeing to the use of their data in assessing system performance. For DOE-NE UFD, scenario development is still in a preliminary stage.

Table 29 Question 4b-1 Provide details of acceptance in terms of regulatory compliance feedback, outcomes of external reviews

Organization / role	**Question 4b-1 Provide details of acceptance in terms of regulatory compliance feedback, outcomes of external reviews**
FANC Regulator	No input
Ondraf/Niras Implementer	No input.
NWMO Implementer	A special project arrangement10 has been agreed to by the NWMO and the CNSC that includes a CNSC review of the design concepts for APM. NWMO's request for a regulatory review of pre-project reports is consistent with CNSC Guide G-320, which states, "It is up to the applicant to determine an appropriate methodology for achieving the long term safety of radioactive waste based on their specific circumstances; however, applicants are encouraged to consult with CNSC staff throughout the pre-licensing period on the acceptability of their chosen methodology." The CNSC informally reviewed an APM post-closure safety assessment in 2010. In their report, the CNSC confirmed that, at a high level, the assessment followed the guiding principles of CNSC Guide G-320. With respect to scenario definition, the CNSC advised that subsequent case studies should address glaciations, seismicity, possible deterioration of seal material, and gas generation and migration; also, the role played by institutional control should be explicitly discussed. In December 2012, the NWMO submitted a safety assessment11 to the CNSC to illustrate that the assessment approach is consistent with the CNSC Guide G-320. Chapter 6 ofthis report describes the scenario identification methodology. Review by the CNSC is ongoing.
RAWRA Implementer	Not answered.
Posiva Oy Implementer	External reviews provided useful feedback to improve the final versions of the reports. Acceptance in terms of regulatory compliance feedback is an undergoing process, where hearing and meetings are being used. The huge amount of information makes challenges in transparency, but memos and hearings are used to easily and transparently communicate the basis of the safety case.
ANDRA Implementer	See answer to question 2a. According to the regulation, Andra's is subject to various external councils and nuclear safety authority: • Established by law, a National Commission (Commission Nationale d'Evaluation, CNE) • A local committee of information (Comité Local d'Information, CLIS) • The Nuclear Safety Authority (NSA),

	• The scientific council (CS) of Andra • International OECD/NEA Peer review. The remarks and the recommendations stemming from these diverse authorities, covering the spectre of the activities of the project (engineering, scientific data, safety) are taken into account to contribute to the permanent improvement of the project..
GRS/BfS Research / Implementer	Not answered.
JAEA / NUMO Implementer / Research	At present stage, there have been no concrete and formal regulatory requirements on the definition and consideration of scenarios for geological disposal yet. In the repository development program of NUMO, NUMO intend to carry out the safety assessment step by step along with the national disposal program in Japan, and would have peer-review from various stakeholders and experts, in general means. Experts shall include the foreign geological disposal implementers. The review comments should be incorporated into development of plans and measures to be applied to the next phase.
KAERI Research	▪ .
SKB Implementer	The SR-Site assessment is currently under review by the Swedish regulator SSM. An earlier version of the scenario approach has been reviewed by the Swedish regulator, see response to question 2a. SKB's safety case has also been reviewed by an international review team under the auspices of the NEA (NEA, 2012). Regarding the scenario approach, the following was concluded: "Scenario selection is sound, and based on safety functions in a traceable way, which is on par with the international state-of-the-art. Along with these scenarios, SKB's presentation of stylised scenarios that represent the loss of the individual barriers, in order to evaluate their contribution to safety and the robustness of the concept, is seen as a good practice to build confidence in the safety case. It is important, however, that such stylized scenarios be used cautiously and with full understanding of their limitations." (NEA, 2012, excerpt from section 2.2.2)..
SSM Regulator	See SKB.
RWMD/EA Implementer	▪ .
DoE NE & EM/CBFO Implementer	In the case of WIPP, the initial regulatory compliance certification in 1999, and the two re-certifications in 2006 and 2010, show that the FEPs approach and the substance behind it passed regulatory scrutiny. The U.S. Nuclear Regulatory Commission's Technical Evaluation Report (2011; NUREG-2107) on the content of the DOE 2008 license application, revision, and support information indicated that the treatment of FEPs was appropriate. The report also indicated that there was an appropriate technical basis in support of model abstractions and that the abstractions were reasonable for use in the long-term performance assessments.

Table 30 Question 4b-2 Provide details of experience base for judging the current approach provides transparency in communicating the basis of the safety case

Organization / role	Question 4b-2 Provide details of experience base for judging the current approach provides transparency in communicating the basis of the safety case
FANC Regulator	No input
Ondraf/Niras Implementer	No input.
NWMO Implementer	NWMO maintains confidence in its approach to safety assessment in part through regular reporting, publishing results of NWMO research on the NWMO website and in peer-reviewed journals, presenting at conferences, pursuing collaborative research with universities and joint projects with international organizations.
RAWRA Implementer	Not answered.
Posiva Oy Implementer	Not answered
ANDRA Implementer	See Q4b-1.
GRS/BfS Research / Implementer	Not answered.
JAEA / NUMO Implementer / Research	As mentioned in the response to question 4.a., the current scenario development approach has not been applied in providing a safety case. The approach has been developed however with special attention to increase of transparency and traceability in scenario development procedure, which is expected to facilitate communication among experts of a range of disciplines who are involved in making a safety case and also with different stakeholders on safety case.
KAERI Research	Not answered.
SKB Implementer	So far, the experience of communicating the scenario approach in SR-Site to both professional audiences and to the general public has been positive.
SSM Regulator	See SKB.
RWMD/EA Implementer	.
DoE NE & EM/CBFO Implementer	There is room for improvement in the manner in which the basis for the WIPP safety case can be communicated to non-technical audiences. The DOE-NE UFD effort is taking a closer look at international guidance on safety cases and may develop communication techniques that may be useful for WIPP.

Table 31Question 4c Describe the externalization of expert judgements used through scenario development (To elicit FEPs? To review scenario development?)

Organisation / role	Question 4c Describe the externalization of expert judgements used through scenario development (To elicit FEPs? To review scenario development?)
FANC Regulator	▪ See Ondraf/Niras' input
Ondraf/Niras Implementer	**SAFIR2** ▪ No input.

	SFC1 -To date, we are not yet in the process to derive the scenarios. However we are working on the derivation of the reference case of the reference scenario. A workshop was organised in October 2011 during one week with all topic experts where the safety assessors presented the global picture of the reference case they had derived on basis of the knowledge provided by the topic experts in the "interaction meetings" (see above). This workshop allowed to foster discussions between topic experts to identify possible interactions between processes, and discussions on the overall modelling at the scale of the repository. It was also a good opportunity to identify uncertainties to take into account in other scenarios or assessment cases. This workshop was a way to check that the reference case was qualified, that is "fit for purpose". -We will also use the international FEP list to check if the scenarios are complete. -No discussions with the regulators were concretely initiated except on the "penalising scenarios" as defined by the regulators because these categories of scenarios seems more particular than the other usual categories of scenarios
NWMO Implementer	The NWMO continues to participate in the international radioactive waste management program of the Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency, including the Integration Group for the Safety Case (IGSC) Methods for Safety Assessment (MeSA) Project.
RAWRA Implementer	Not answered.
Posiva Oy Implementer	No externalization of expert judgements was used at this stage of the safety case.
GRS/BfS Research / Implementer	Not answered.
ANDRA Implementer	Such reviews are planned for the choice of the scenarios to be quantified, for the choices of models and parameters. The review team will include international experts. As mentioned in answer to question 4.a, formal reviews are being organized to examine a set of documents and to ask questions in prerequisite to the meeting. QSA, scenarios, calculation cases, parameters and models will be submitted to those reviews. The review team will include international experts, as regards to international practices.
JAEA / NUMO Implementer / Research	Translation of work procedure shown in Figs 3 and 4 to an electrical platform with a template for recording and structuring not only results but also processes/decisions in each work (see also the response to question 3.b.) is expected to support externalization of tacit knowledge used for expert judgments.
KAERI Research	We have carried out expert elicitation process once, and have planned to perform experts' elicitation process to include additional FEPs related with radioactive wastes from pyroprocessing.
SKB Implementer	We don't understand this question. As mentioned in the response to question 3b, formal expert elicitation was not used in SR-Site. As mentioned in the response to question 4a, the safety assessment report, including the scenario selection, was reviewed by an international panel of experts several times in the development of the safety case.
SSM Regulator	▪ See SKB.

RWMD/EA Implementer	▪ .
DoE NE & EM/CBFO Implementer	As previously discussed, both in the WIPP and Yucca Mountain regulatory compliance demonstration development process, peer reviews were used to evaluate models, which included evaluating their incorporated FEPs. In addition, where data and other information was sparse, such as in the case of creating a seismic hazard and volcanic hazard model for the Yucca Mountain repository, formal expert elicitation was used to define the model used.

Table 32 : Question 4 Addendum: Additional ideas about desirable features of the revised database?

Organisation / role	Question 4 Addendum: Additional ideas about desirable features of the revised database?
FANC Regulator	▪ No input
Ondraf/Niras Implementer	▪ No.
NWMO Implementer	Suggest the NEA FEP to include a detailed description of the FEP. This is important since it can be used to ensure that the FEP screening analysis is complete. Considers it useful if the NEA gives direction in the preparation of the FEP screening analysis. The NWMO FEPs database, in some instances, includes minor processes (relative to the main topic of the FEP) and it is not clear whether or not the FEP screening analysis needs to address all the minor points. As recommended by Little (2012, private communications) a contaminant factor category is added which describes the features / properties of the contaminants in the waste packages. The NWMO FEPs database includes the category "Assessment Basis", which defined the scope of the assessment. If this category is not included in future NEA FEP, should it be removed from the NWMO FEP dbase?
Posiva Oy Implementer	▪ Biosphere related FEPs used in recent safety cases (e.g. Posiva 2012-07) are recommended to be added to the revised database.
ANDRA Implementer	▪ No input.
GRS/BfS Research / Implementer	▪ Not answered.
JAEA / NUMO Implementer / Research	▪ Not answered.
KAERI Research	▪ Not answered.
SKB Implementer	▪ No.
SSM Regulator	▪ See SKB.
RWMD/EA Implementer	As already noted, due to the generic stage of the UK programme, we do not really have an active programme of work for scenario definition. When we consider a specific site, we will review our previous approach (documented in Nirex Report S/98/009 and its supporting references) and apply this to the specific site. This will also include a review of our FEP database (currently contained within a Master Directed Diagram (MDD) – [Nirex Science Report S/98/010, 1998].

	The approach documented in the 1998 series of Nirex reports was favourably reviewed by an NEA International Review Team [Nirex Methodology for Scenario and Conceptual Model Development: An International Review, OECD-NEA, June 1999]. **Addendum from EA:** Q1: We note the attached response from the UK developer, kindly provided by Lucy Bailey (RWMD). We agree with this response to Q1, but note against the penultimate paragraph ("There is no explicit requirement in the GRA to estimate quantitative probabilities for scenarios; however, as the quantitative regulatory guidance level is a risk criterion, there is an implicit requirement to assess the probability of unlikely events and scenarios in order to assess their risk") that this needs to be approached carefully because there may be only limited, or no, basis for assigning such probabilities. Q2, 3, 4: We consider that for the UK these questions are best answered by the developer.
DoE NE & EM/CBFO Implementer	The development/compilation of NEA FEP list and database was a ground-breaking effort that provides an invaluable foundation for developing future FEP lists for radioactive waste disposal projects and an on-going resource for auditing existing and future FEP lists. The value of the NEA FEP list to U.S. HLW waste disposal and management efforts was (1) to provide a systematic structure to organizing FEPs, (2) as a source of FEPs that aided in the development of new lists, and (3) as an auditable list to provide confidence in the comprehensive of the new lists. The project specific content (i.e., screening rationales) in the NEA database was of less use because the screening rationales are by nature specific to a design and setting. However, there is still some relevant generic information that can be gleaned from the project-specific content. The NEA FEP list and database in its current form will continue to provide this value to the development of future FEP lists. The structure is mature and has been "tested" against FEP lists from multiple programs. It is therefore unlikely to change significantly in the future in response to any new FEP development. The FEP lists are also reasonably mature. While new FEPs may continue to be identified on specific new programs, these new FEPs are invariably sub-FEPs (i.e., further levels of detail of existing FEPs) rather than truly new, never-before-thought-of FEPs. For these reasons the NEA FEP list and database in its current form will remain a valuable resource to the international FEP community (and to the UFD Campaign and the continuing WIPP repository effort). There is value in maintaining a single point of contact "repository" for FEP lists. Significant value would come from the IGSC continuing to maintain a FEP website. The website would contain a link to the current International FEP list and database, with the associated FEP lists from the participating programs. As new FEP lists are produced by various programs, references and/or links to those new lists could be maintained on the IGSC FEP website. There would be no need to electronically import the new lists into the database, just having the reference list would help steer FEP developers and screeners to the additional information. One limitation of the NEA FEP database in its current form is its "one-dimensional" nature. FEPs are listed one-dimensionally in numerical order by FEP number. While the hierarchical nature of the FEP number provides an indication of the scope of the FEP, it can be difficult to find all related FEPs within the database. For example, FEPs associated with the chemical environment of a waste container

	might reside in 2.1.03 or in 2.1.09. To support the UFD FEPs a two-dimensional FEP matrix approach was developed to better “organize” the FEPs (Freeze et al. 2013a). In recognition of the fact that most FEPs describe a process or event acting upon or within a feature, the FEP matrix consists of “rows” corresponding to repository features (engineered and natural) and “columns” corresponding process and event categories (e.g., Hydrologic, Mechanical, Climatic, Seismic, etc.). By mapping all of the FEPs (which can retain their hierarchical NEA-based number) to a matrix cell (i.e., the intersection of a feature and a process/event) related FEPs are most readily grouped together. For example, looking across the “Backfill” feature row, one would find all FEPs related to the backfill. Looking down the “Transport” column, one would find all FEP s related to transport. And looking in the Backfill-Transport cell, one would find all FEPs relevant to transport in and through the backfill. This is the point of view of two organizations that have developed mature FEPs lists and maintain them in a controlled manner. Other programs that may not have achieved this level of maturity may well benefit from a more accessible structured database, especially if it utilizes an open-source platform.

Annex 4: Sample Questionnaire

Scenario Development in Safety Cases State of the Art

Questionnaire

(June 2013)

Introduction

The Scenario Development and Practices workshop held in Madrid in 1999 [NEA 2001] made an assessment of developments in scenario methodologies and applications in safety assessments. Since, different NEA projects, in particular INTESC and the safety case symposium held in Paris in 2007 [NEA 2008 b], but also the European project PAMINA underlined the evolution of national approaches for scenario development. They have been described in various NEA publications (Cf. §5), the most recent one being the MeSA project (2010).

According to those publications, scenarios are still a fundamental basis for achieving and demonstrating post-closure safety and the development of scenarios constitutes a key element of the management of uncertainties.

The 1999 workshop in Madrid concluded that one noticeable progress was the application in practice of methods for FEP analysis. National and International FEP Databases have been developed and are regularly updated. At that time, the use of emerging concept such as the use of safety functions concept were introduced but not discussed in detail for the derivation of scenarios.

The outcomes from the different NEA and European projects now indicate wider use and application practices of safety function concept, their categorization, their use in derivation of scenarios, and the evaluation of their performance using some indicators. They introduce new bases for scenario development but also enhance the overall safety analysis. They also underline that the derivation of scenarios is not a strictly *Top-down* or *Bottom-up* approach but rather a combination of both.

It is proposed to make a new assessment of the state of art in order to review national developments since 1999 in terms of scenario development and feedback from application practices in safety cases. This initiative is in continuity with the previous NEA and European projects and aims in this respect at targeting some specific key concerns related to scenario development.

In order to draw the national developments realised since 1999 and the experience acquired in using those approaches in safety cases, it is proposed to hold a new workshop in 2014.

The following questionnaire is submitted to prepare the discussions of this future workshop. This questionnaire is in the continuity of the one performed for the previous workshop in Madrid and the one realised through the topic 3 of MeSA project and, in that respect, addresses some key concerns raised during those projects.

It is to note that this questionnaire will be complementary to some other NEA projects, particularly the project dedicated to updating the NEA FEP Database. Uses of NEA FEP Database have been reported in many safety assessments, either to derive scenario, or to check that proposed national/specific FEP list was sufficiently complete. Due to their link to scenario development they will be part of the discussions during the workshop.

Background of the Questionnaire

Background

Work related to the scenario development topic can be found in NEA documentation [NEA 1992, 2001, 2002, 2003, 2004, 2006, 2008a and 2008b, MeSA project 2010] which includes brochures, symposium and workshop proceedings as well as the documentation of a Topical Session held during the Annual Meeting of the Integration Group for the Safety Case (IGSC-8). It also includes the European project PAMINA (Performance Assessment Methodologies in Application to Guide the Development of the Safety Case, [PAMINA 2006-2009]). The Scenario Development workshop held in Madrid [NEA 2001] reviewed developments in scenario methodologies and applications in safety assessments since 1992. In this document, it is admitted that scenario development constitutes the overall framework for the discussion of the possible evolutions of the disposal system and the calculation cases examined in the safety assessment and their results, as well as failures or degradation of the system, attributed to unknown or less known mechanisms [NEA, 2001].

It was acknowledged in NEA 2001 that large differences in the application of scenario development existed. Since then, new methods for scenario development have emerged. New concepts such as the use of safety functions, their categorization, and the evaluation of their performance using some indicators introduce new bases for scenario development but also enhance the overall safety analysis. In the framework of the MeSA project [NEA, 2010] it was outlined that straight forward *Top-down* or *Bottom-up* approach probably never existed, and consider a combination of both. In many projects, the approach relies on a comprehensive list of relevant and specific features, events and processes (FEP). They are supported by detailed description and organization of the FEP. In that respect, new approaches in structuring the scientific knowledge in time and space have emerged (for example: Phenomenological Analysis of Repository Situations PARS, storyboards).

Key Concerns

The topics in the questions have been defined in line with two previous NEA projects:

1 The NEA 2001: Scenario Development Methods and Practice. An Evaluation Based on the NEA Workshop on Scenario Development, Madrid, Mai 1999, Spain. OECD/NEA, Paris, France.

2 The NEA MeSA project: System description and scenarios (2010), Klaus-Jürgen RÖHLIG, et al. The group performed a survey on scenario development, use of FEPs and safety functions.

Among the outcomes from the NEA MeSA project [NEA, 2010], it was concluded that the role of the safety function to derive scenarios requires further development. It was also outlined that the quality of scenario development may depend on expert judgment, e.g. judgments of PA specialists and technical subject specialists.

Based on the outcomes from NEA 2001, and MeSA project, it is proposed to discuss further in the framework the workshop the following issues:

3 The derivation of scenarios using safety functions.

4 The categorisation of scenarios (including human intrusion). It also refers to the classification of base scenario and alternative scenarios; in particular with regard to probability (or plausibility) within various time frame (and associated uncertainties). In that respect, the regulatory aspects could be further developed.

5 The analysis of relationships between developed scenario and calculation cases.

6 The analysis of similarities and differences of development methodologies.

7 The analysis of similarities and differences of developed scenarios which take into account same/similar processes and/or events (e.g. timing and probability of occurrence, evaluation period, impact on system performance).

8 The externalisation of expert judgements used through scenario development (e.g. definition of importance and/or occurrence of processes and events, use of external knowledge (safety cases, international FEP's database, expert panels for the completeness checking in scenarios).

Aims of the Exercise

The questionnaire, contained in the present document, is designed to elicit background information for a future workshop, in order to:

9 Review the current status and on-going discussions on the handling of issues related to the scenario development approach.

10 To provide a clear overview of the progress that has been made since 1999.

11 To provide a clear overview of the feedback and lessons learned from application practices for scenario development in safety cases.

12 To provide a state of art report to support discussions within the framework of a workshop.

13 To identify areas in which further co-operation at the international level is desirable.

Guidance on Providing Responses

Questions are organised around a number of subject areas in parts 1 through 4 of the questionnaire, namely:

1. General/Context/Regulatory requirement/Regulatory requirement.

2. Summaries of changes since NEA Scenario workshop held in Madrid.
3. Detail regarding Scenario approach currently in use by project.
4. Discussion on the current scenario definition and analysis approach/Expert Judgement.

The questionnaire focuses mainly on post-closure safety.

Please identify the most recent work and safety reports produced at your organisation relevant in the context of scenario development and use. In general, it is preferable if the sources of material for responses are published documents. It is emphasised that the responses or opinions provided should nevertheless represent the view of the organisation and not the individual answering the question. Respondents may therefore choose to subject their response to a review within their organisation.

Part of some previous questionnaires (ex: NEA INTESC and MeSA projects, and EC PAMINA project) can be used as source material.

PRIOR TO FILLING OUT THIS QUESTIONNAIRE PLEASE CAREFULLY READ THE INTRODUCTORY MATERIALS TO UNDERSTAND ITS CONTEXT AND PURPOSE

1. **General/Context/Regulatory requirement:**

   a. Name of organisation:____

   b. Select role of organization: implementer, licensing authority, decision maker, regulatory TSO, research organization, others (please specify) ______________

   c. Stage of the national program and disposal concept

   [Suggested length several paragraphs, max 1 page; if a project overview document exists, please reference here, and provide the internet link if one is available.]

   d. Legal and/or regulatory requirements on the definition and consideration of scenarios in safety evaluations

   This section should describe the role of current national laws and regulations in defining scenarios.

   [Suggested length several paragraphs,; give references and include internet links if available.]

   In the description, please address the following issues:

   - *Any prescriptive requirements regarding FEP, scenarios, or approaches for scenario development and/or classification?*
   - *Any specifications on how compliance with requirements could be demonstrated? (including consideration of non human biota)*
   - *Any requirements on providing convincing arguments that relevant physical phenomena have been considered in an appropriately comprehensive manner*
   - *Any guidance to limit arbitrary speculations (ex: future human behaviour?)*
   - *Any guidance on the role and/or use of the safety functions concept?*
   - *Any requirements to estimate quantitative probabilities for scenarios?*
   - *Any requirements on Time cut-off to account for in scenario development?*

2. SUMMARIES of changes since the 1999 NEA Scenario Workshop held in Madrid

a. In one or several paragraphs, please summarize the changes made in defining scenarios, describe the reasons for changes and discuss how they affect the definition or the use of scenarios, give references and internet links if available.

In the summary of changes, please indicate if changes are made in response to which of the following categories [Note: for each category, provide reference to the most recently published safety case or other relevant documents]:

- **Changes in law, regulations or guidance regarding geological disposal since 1999** *[describe the salient changes and discuss how they affect the definition or the use of scenarios]*
- **External and/or regulatory reviews in any in-progress or planned reconsideration of scenario definition or use** *[Describe any salient suggestions from independent, external and/or regulatory reviews of the safety case or safety assessment and discuss how they affected the definition or the use of scenarios]***.**
- **A new approach to building a safety case including safety assessment methodologies** *[discuss the changes in the way the safety case is being built. If those changes involve defining 'safety functions' and building scenarios based on their potential failure modes, provide references to this new approach if it exists in published materials, otherwise just discuss the approach and how it affects the definition, use and explanation of scenarios.]*
- **New potentially safety-relevant information or a knowledge refinement** *[discuss and provide references to the new information if it exists in published materials, otherwise just discuss the nature of the new information and how scenarios are or may be changed by its consideration.]*
- **International practices** *[specify which one]*
- **A combination of one or more of the foregoing reasons for a change in how scenarios are developed or used** *[describe the combination of reasons and discuss how they affected the definition or the use of scenarios]*
- **If no changes have been made in defining the scenarios, please explain briefly why no changes since 1999.**

3. DETAIL Regarding Scenario Approach Currently in Use by Project

If there exists a document describing scenario-development and scenario use in the safety analysis and it is readily available on the internet or can be attached, use of it as a reference.]

a. What are the objectives and scope of scenario development in recent PA?

Indicate also if scenarios used for other issues (than strictly safety assessment) like comparison between design options, sites, etc.

b. Describe the approach in detail to defining scenarios

Address the following in your description:

- **Terminology and associated definition.**
- **Classes of scenarios and the role of these classes in your assessment. Indicate also:**
  - The role of "what-if" and/or "stylised" scenarios in the current approach (If they are used, please, indicate their objectives).
  - The place of human intrusion scenarios
- **Steps of your methodology.**
  - **Bottom up**, i.e. FEPS-combinations-based – *[Discuss the use of FEP compilations / databases and / or process reports, or other means to compile scientific knowledge on which system description and scenario derivation are based]: building blocks for scenarios or check list.*
  - **Top down**, i.e. "safety-function" based - *[discuss the derivation of top-level and lower-level functions and their use, e.g. when defining scenarios, calculation cases or evaluating compliance],* or
  - **A combination approach**. *Describe*
- **Indicate the uses of international guidance documents and databases such as the NEA's FEPs database.**
- **Approach to go from scenarios to safety models and/or calculation cases.**
- **Use of deterministic / probabilistic approach, or a combination of both.**
- **Consideration for temporal sequences in scenario (time cut-off, climate evolution, other events or processes).**
- **Indicate the use of formal tools (e.g. software-based tools).**
- **Indicate the use of formal expert elicitation processes.**
- **How is the propagation of uncertainties managed?**

4. Discuss why the current scenario definition and analysis approach is appropriate for this project at present.

    a. Describe the process used to determine if your project's contributors internally agree that the set of scenarios carried into the safety analysis is sufficiently complete / comprehensive for the purpose at hand.

    b. Provide details of the following:

        - *Acceptance in terms of regulatory compliance feedback and/or outcomes of external reviews;*

        - *Experience base for judging the current approach provides transparency in communicating the basis of the safety case;*

    c. Describe the externalisation of expert judgements used through scenario development (To elicit FEPs? To review scenario development?).

Addendum: Presently, a revision of the NEA FEP database is carried out by IGSC. The objective and scope is described in the proposal [NEA 2012a, b]. After having replied to the above questions, did any additional ideas about desirable features of the revised database come up?

References

NEA (1992). Systematic approaches to scenario development. Report of the NEA Working Group on the Identification and Selection of Scenarios for Performance Assessment. OECD Publications, Paris, France.

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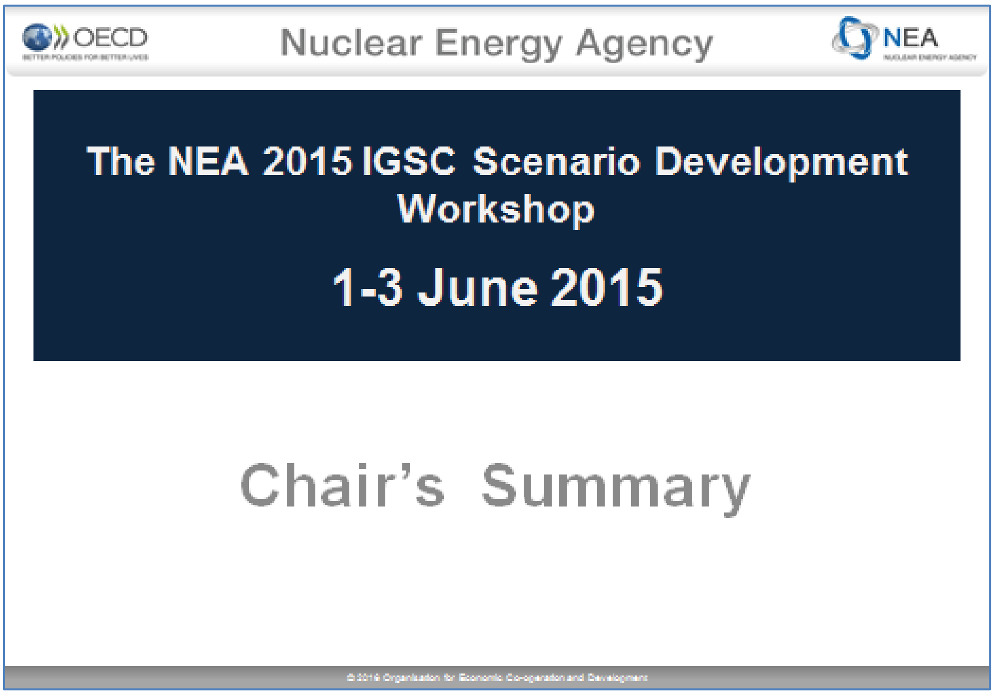
NEA (2010). System description and scenarios. MeSA, Klaus-Jürgen Röhlig, et al.

PAMINA, http://www.ip-pamina.eu/

NEA (2012a). Updating the NEA International FEP List – Identification and Review of Recent Project-specific FEP Lists.

NEA (2012b). Updating the NEA International FEP List – Proposed Revisions to the NEA International FEP List.

Appendix F. Results of working group discussions



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Perspectives on regulatory requirements

- Regulatory requirements are set out formally in documents, but important guidance can also come from interactions/dialogue and review
  - important to consider both aspects
  - dialogue is an ongoing process
  - the less prescriptive the regulatory documents, the greater the demands/emphasis on dialogue
- All regulations prescribe general principles/objectives for scenario development
  - transparency of process, traceability of decisions, comprehensiveness, etc.
  - requirements are often developed to address gaps identified in review/dialogue
- Regulatory expectations regarding the application of these principles likely to increase as a programme progresses
  - methods need to be developed and applied to ensure principles are adhered to

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Perspectives on regulatory requirements [2]

- Many implementer & regulators see advantages to less prescriptive approach in regulatory documents:
  - broadly applicable irrespective of details of site, design or programme stage
  - regulatory documents may still need periodic updates based on lessons learnt from previous stages or advances in international practice/standards, but not too often (transparency and flexibility)
  - puts responsible for developing the safety case primarily on the implementer
  - maintains independence of the regulator in reviewing the safety case
- Dialogue can promote common understanding on more detailed aspects of scenario development or at least confirmation that the implementer's approach is in line with expectations
  - dialogue is a step-wise process
  - aspects covered by dialogue will increase as programmes progress
  - both the implementer and regulator need independent expertise to review scenarios

 3

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Perspectives on regulatory requirements [3]

- Some regulatory documents also include more specific requirements or guidance on some aspects
  - FEPs to be included/excluded (or at least probability cut-off), aspects of methodology (probabilistic vs. deterministic), treatment of human intrusion
  - However, it is not usually the case that the methods/tools to reach the objectives are prescribed
- No pressing demands from implementers for more (or less) prescriptive requirements/guidance in their own national regulations
  - Even though the degree to which guidance is prescriptive varies greatly
  - Implies guidance reflects country-specific boundary conditions, context, culture etc.

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Objectives in scenario development

- Integral part of the safety case, but, in addition, …
- Seen as key part of the overall management of uncertainties, and provides guidance to/help steer R&D and design development
  - uncertainties need to be avoided, reduced (by R&D), mitigated by design?
- Detailed objectives, as well as the FEPs included in scenarios, may vary as programme matures
  - Derivation of siting criteria/site selection
  - Design optimisation
  - ….
- Key issue is whether all uncertainties have been identified and accounted for (in scenarios or otherwise)

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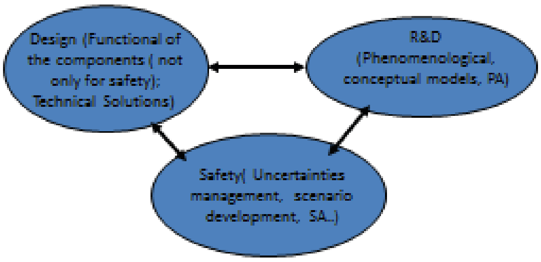
Role in integration

- Scenario development needs, but can also help promote, safety/pheno/design interdisciplinary communication "integration tool"
  - Importance to maintain traceability of decisions, e.g. design change
  - Integration in management systems?



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Scenario classification

- Base/reference/normal evolution scenario ("realistic", likely)
- Other, generally lower probability scenarios, sometimes subdivided into e.g. less likely and very unlikely
- What/-if? scenarios to test robustness, account for "unknown unknowns"
  - These may yield high consequences
  - Need to be carefully explained/communicated
- Human intrusion scenarios generally classified and treated separately

- Comprehensiveness of scenario coverage and clear documentation more important than harmonisation of terminology/definitions

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Evolution of approaches

- Scenario development methodologies significantly revised over the past decade in many programmes
- Approaches more thoroughly documented
- Emphasis on transparency and traceability of decisions

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Evolution of approaches [2]

- Provide more visible links between the three pillars of safety assessment, design/engineering and science ("pheno")
  - necessary when comparing potential design solutions (components, layouts)
  - also when planning R&D programme

- Some convergence apparent in main steps adopted by national programmes [next slide]
  - in spite of differences in terminology/definitions/detailed tools

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Broad steps in scenario development

- Start by developing integrated phenomenological view of system evolution and related uncertainties ("conceptual model" or reference evolution)
- Combination of top-down (safety-driven) and bottom-up (FEP/phenol-driven) elements
- Key roles of both safety functions and FEPs (and FEP screening)
- Scenarios developed by establishing which FEPs/uncertainties may compromise the safety functions fulfilled by components
- How to develop biosphere scenarios (no biosphere safety functions)?
- Need for further consideration of combination/complex scenarios?

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Tools for implementing the broad steps

- NEA FEP lists
- Storyboards
- QSA
- Safety statements/ safety features
- Phenomenological analysis
- Conceptual models
- Safety function indicator criteria, performance targets
- Sensitivity cases
- Safety/R&D/design meetings
- Use of expert judgement (necessary, but does not replace data collection)
- Peer review

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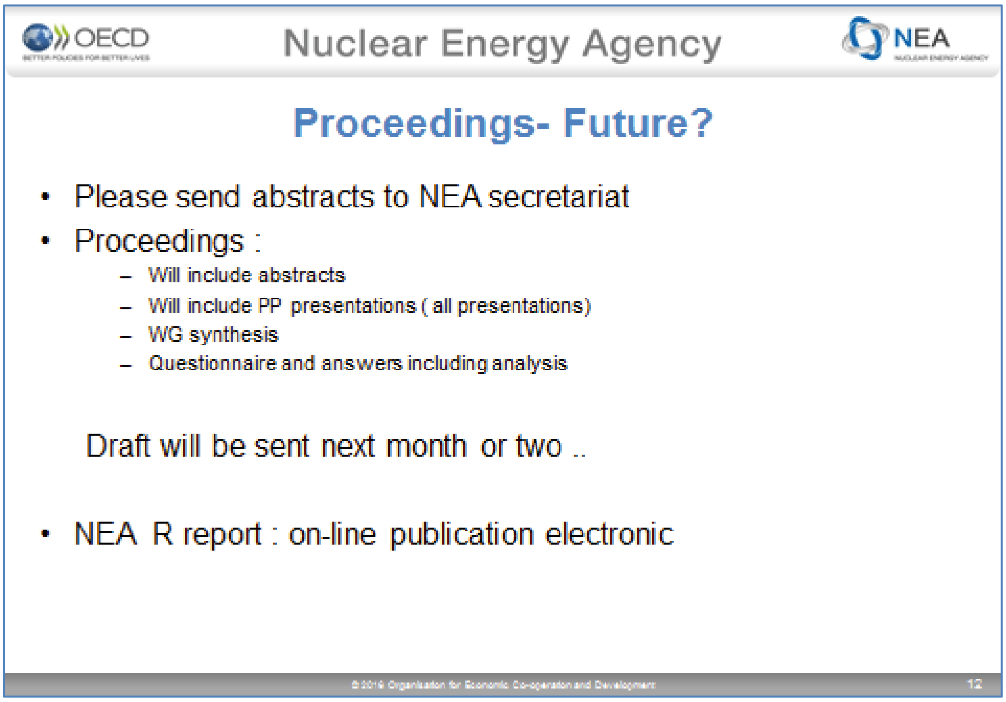
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Proceedings- Future?
• Please send abstracts to NEA secretariat
• Proceedings :
– Will include abstracts
– Will include PP presentations (all presentations)
– WG synthesis
– Questionnaire and answers including analysis
Draft will be sent next month or two ..
• NEA R report : on-line publication electronic
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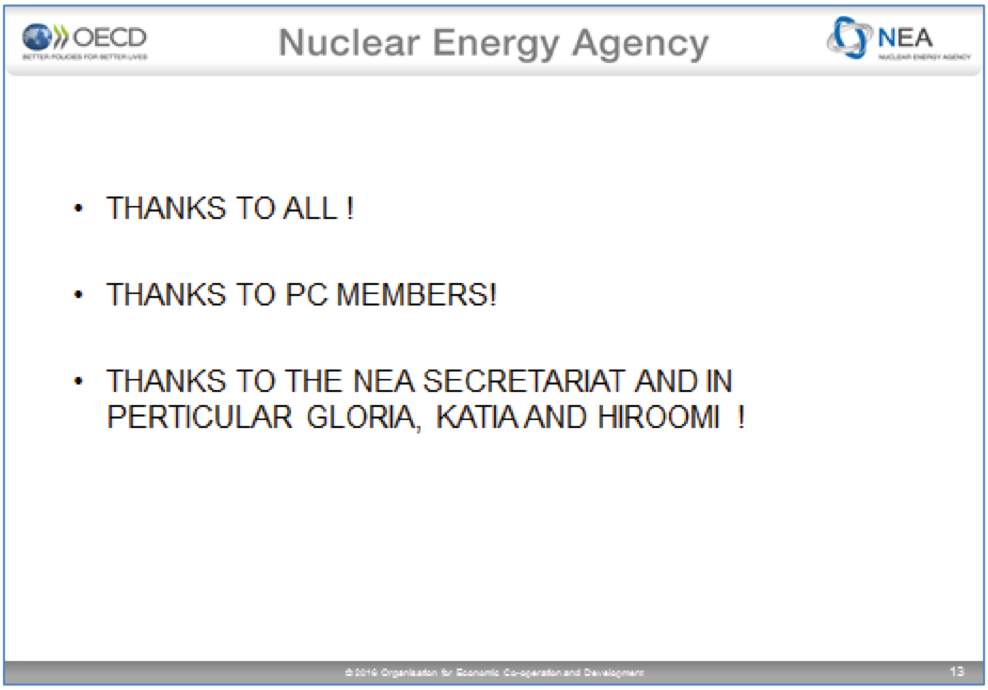
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• THANKS TO ALL !
• THANKS TO PC MEMBERS!
• THANKS TO THE NEA SECRETARIAT AND IN PERTICULAR GLORIA, KATIA AND HIROOMI !
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