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Review of Performance Confirmation Programs and Potential Roles in SSM's Current Review of SKB's License Application

Main Review Phase

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SSM perspektiv

Bakgrund

Strålsäkerhetsmyndigheten (SSM) granskar Svensk Kärnbränslehantering AB:s (SKB) ansökningar enligt lagen (1984:3) om kärnteknisk verksamhet om uppförande, innehav och drift av ett slutförvar för använt kärnbränsle och av en inkapslingsanläggning. Som en del i granskningen ger SSM konsulter uppdrag för att inhämta information och göra expertbedömningar i avgränsade frågor. I SSM:s Technical note-serie rapporteras resultaten från dessa konsultuppdrag.

Projektets syfte

Det övergripande syftet med projektet är att ta fram synpunkter på SKB:s säkerhetsanalys SR-Site för den långsiktiga strålsäkerheten hos det planerade slutförvaret i Forsmark. Det specifika syftet är att beskriva erfarenheterna med de detaljerade bestämmelserna som finns i Amerikas förenta stater om fortlöpande kontroll och bekräftelse av att ett slutförvar uppfyller de krav som antas i tillhörande tillståndsansökan. Med utgångspunkt i dessa erfarenheter har målsättningen varit att ge vägledning till SSM om vilken typ av information som kan förväntas i SKB:s tillståndsansökan. Vidare har målsättningen varit att få fram information som kan vara ett underlagsmaterial inför beslut om eventuella tillståndsvillkor i frågan om fortlöpande kontroll under konstruktions- och driftsfasen och bekräftelse av att förvaret lever upp till antagandena i tillståndsansökan.

Författarens sammanfattning

En tillståndsansökan för ett förvarskoncept för slutförvaring av kärnavfall baseras på omfattande platsbeskrivningar, monitering av bakgrundsvärden, utveckling av förvarsdesign och tekniska barriärer, data från tester av de tekniska barriärerna och integreringen av en rad modeller som representerar de processer som styr inneslutningen, radionuklidutsläpp samt flöden av radionuklider från förvaret till den tillgängliga miljön vid markytan. Denna information möjliggör en första bedömning av förvarskonceptet betydande säkerhetsaspekter. Den årtionde långa perioden innan förslutningen av förvaret som innefattar uppförande, drift och avfallsdeponering ger dock en möjlighetet att ytterligare bekräfta slutförvarets prestanda, effektivitet och förvarskonceptets tillförlitlighet. Ett sådant utökat program kan benämnas prestandabekräftelse (engelska ”performance confirmation”), vilket i denna rapport definieras som ett program av aktiviteter som genomförs under uppförande- och driftsfasen innan slutförvarets förslutning för att ytterligare testa och förstärka information, analyser och resultat från den initiala tillståndsansökan. Medan det i SSM:s föreskrifter inte uttryckligen krävs prestandabekräftelse, finns det dock i Strålsäkerhetsmyndighetens föreskrifter (SSMFS 2008:1) och allmänna råd om säkerhet i kärntekniska anläggningar 2 kap. 10 § krav på ett säkerhetsprogram som fortlöpande och på ett systematiskt sätt analyserar och bedömer säkerheten efter att en anläggning har tagits i drift. Programmet ska innefatta säkerhetsförbättrande åtgärder som föranleds av analyserna och bedömningarna. Detta ligger i linje med mål och syften med en prestandabekräftelse.

Denna Technical Note presenterar och diskuterar flera olika fördelar med ett planerat program för prestandabekräftelse som omfattar:

- Bekräftelse av att de verkliga undermarksförhållanden och förändringarna i dessa förhållanden under uppförande- och driftsfasen ligger inom de gränser som antogs i granskningen av tillståndsansökan.
- Kontroll och monitering av de naturliga och tekniska barriärersystemens olika delar för att undersöka om de har de förutsatta egenskaperna efter att avfallet har deponerats.
- En minskning av osäkerheter och förkastande av modellalternativ genom tillämpning av in situ tester på större skala eller med längre tider samt genom utvärdering av tillämpligheten av nya teknologier som utvecklas med tiden.
- En möjlig förstärkt samhällelig tilltro genom ett uthålligt och spårbart program som bekräftar att målen för slutförvarets prestanda eller säkerhetsfunktioner som har syftet att skydda människors hälsa är uppnådda.

Projektinformation
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Diarienummer ramavtal: SSM2011-3382
Diarienummer avrop: SSM2013-2036, SSM2014-895
Aktivitetsnummer: 3030012-4045, 3030012-4085

SSM perspective

Background

The Swedish Radiation Safety Authority (SSM) reviews the Swedish Nuclear Fuel Company's (SKB) applications under the Act on Nuclear Activities (SFS 1984:3) for the construction and operation of a repository for spent nuclear fuel and for an encapsulation facility. As part of the review, SSM commissions consultants to carry out work in order to obtain information and provide expert opinion on specific issues. The results from the consultants' tasks are reported in SSM's Technical Note series.

Objectives of the project

The general objective of the project is to provide review comments on SKB's postclosure safety analysis, SR-Site, for the proposed repository at Forsmark. The specific objective is to describe experience from the detailed U.S. regulations on measurements and tests (performance confirmation) under the construction and operating phase of a final repository to verify the assumptions underlying the license application. Based on these experiences the aim has been to offer SSM guidance of the type of information that could be expected from SKB's license application. Furthermore the aim has been to obtain information on performance confirmation that can be used as input to the decision on potential future license conditions.

Summary by the author

The initial license application of a repository concept for disposal of radioactive waste is based on extensive site characterization, baseline monitoring, development of disposal designs and engineered barriers, test data on engineered barriers, and the integration of a series of models representing processes controlling the containment, release and migration of radionuclides from the repository to the accessible surface environment. This information allows an initial assessment of safety-significant feature of the repository concept to be made. The multi-decade, pre-closure period of repository construction, operations, and waste emplacement, however, presents an extended, additional opportunity to seek and obtain further confirmation of the performance, effectiveness, and reliability of the repository concept. Such an extended program can be called "performance confirmation", defined here as a program of activities to be conducted during the pre-closure construction and operational period to further test and augment the information, analyses and results of the initial construction license application (CLA). While there is no specific mention or requirement for 'performance confirmation' in Swedish regulations, SSMFS 2008:1 Chapter 2, Section 10 states requirements on a safety program that calls for a continuous systematic assessment of the facility's safety and to safety improvement measures, which closely aligns with the motivation and goals of performance confirmation.

This Technical Note presents and discusses several advantages to a planned 'performance confirmation' program, including:

- Establishing that the actual subsurface conditions encountered and changes in these conditions during construction and waste emplacement operations are within the limits assumed in the CLA review,
- Testing and monitoring whether the natural and engineered systems and barrier components have the targeted properties as intended following waste emplacement,
- Reducing uncertainties and eliminating alternatives in models through application of in situ, larger-scale, or longer-term testing, as well as evaluating the applicability of emerging new technologies,
- Enhancing public confidence through a sustained and traceable program to confirm that performance objectives/ safety functions designed to protect public health and safety are satisfied.

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Contents

1. Introduction

Examining and establishing confidence that a deep geological repository will safely and successfully isolate spent nuclear fuel (SNF) for the regulatory compliance period is challenging because of the long time frames and the associated uncertainties that are involved. The overall evaluation of repository post-closure safety is founded on two fundamental and independent aspects: (1) a robust repository disposal concept involving multiple barriers, and (2) a thorough modelling of the repository system of barriers, based on multiple lines of evidence, that incorporates appropriate methods, credible models, and traceable data. With respect to safety-assessment modelling, evaluating performance for a first-of-a-kind facility like a repository involves models used to estimate system behavior over an extended compliance period for which direct observation and verification of this performance is not possible.

The initial license application for a repository is based on extensive site characterization, baseline monitoring, development of disposal concepts, testing of engineered components, and the integration of a series of models representing processes controlling the containment, release and migration of radionuclides from the repository to the accessible surface environment. License applications contain a large amount of necessary information to allow an initial assessment of safety. The multi-decade, pre-closure period of repository construction, operations, and waste emplacement, however, presents an extended, additional opportunity to seek and obtain further confirmation of the performance, effectiveness, and reliability of the repository concept, which can be called "performance confirmation".

A specific requirement for 'performance confirmation' is not explicitly mentioned in Swedish regulations as the concept is defined the regulations by the US Nuclear Regulatory Commission (Subpart F of 10 CFR Part 63) for the disposal of spent nuclear fuel. There are, however, SSM requirements that point to similar objectives as implied in the USNRC description of a 'performance confirmation' program. For instance, SSMFS 2008:1 Chapter 2, Section 10 (SSM 2008a)states requirements on a safety program that calls for a continuous systematic assessment of the facility's safety and to safety improvement measures. In Section 4 of SSMFS 2008:21 (SSM 2008b), there are requirements on reporting deficiencies of the repository's barrier functions detected during construction and operation. The general advice relating to Section 4 (SSM 2008b) points to the SSMFS 2008:1(SSM, 2008a) requirements for the licensee to keep continuously informed of the conditions of importance to the assessment of repository safety. For instance, if the properties or performance of a barrier is detected or suspected of becoming degraded, it is recommended that SSM be notified.

In brief, Swedish regulations are more generalized than the very lengthy and specific 'performance confirmation' requirements in USNRC's 10 CR Part 63 Subpart F on "performance confirmation'. The clear point of connection to the USNRC 'performance confirmation' concept, however, is that there is a recognized expectation for the SKB licensee in Sweden to conduct a sustained program of monitoring, testing and updating of uncertainties associated with initial assumptions, data, models and design features of its disposal concept throughout the extended construction and operational period. Thus, there is scope within the requirements of the Nuclear Activities Act and the Radiation Protection Act for SSM to consider the

advantages and attributes of activities to confirm performance as an option within possible licensing conditions.

While there is not a specific requirement for or definition of 'performance confirmation' in SSM regulations, this term with be used throughout this Technical Note as a shorthand expression for a program of activities to be conducted during the pre-closure construction and operational period to further test and augment the information, analyses and results of the initial construction license application (CLA). The objectives of such a pre-closure performance confirmation program could include

- Establishing that the actual subsurface conditions encountered and changes in these conditions during construction and waste emplacement operations are within the limits assumed in the CLA review,
- Testing and monitoring whether the natural and engineered systems and barrier components have the targeted properties and safety function as intended following waste emplacement,
- Reducing uncertainties and eliminating alternatives in models through application of *in situ*, larger-scale, or longer-term testing, as well as application of emerging new technologies,
- Enhancing public confidence through a sustained and traceable testing program to confirm that performance objectives/ safety functions designed to protect public health and safety are satisfied.

There may also be opportunities for a performance confirmation program to guide and assist in further optimization of the design, handling and operational safety of a repository constructed over a multi-decade period.

Chapter 2 of this report presents as an illustration the well-developed concept of performance confirmation as instituted in the regulations of the US Nuclear Regulatory Commission (USNRC). To further this illustration of the range of activities that might be considered within a Swedish performance confirmation program, Chapter 3 summarizes some of the performance confirmation activities as planned by the US Department of Energy (USDOE) in response to the USNRC regulations[1]. Chapter 4 summarizes key aspects of a performance confirmation program that might aid SSM in Sweden. To aid readers interested in pursuing further details, Appendices are also included of sections from USNRC 10 CFR Part 63, Subpart F, describing performance confirmation program regulations and its use in resolving safety-related questions.

[1] This review of USDOE's *Performance Confirmation Plan* is presented solely as an example, to provide insights into the conceptual thinking and approach to organize such confirmatory test activities. Because of the differences between the engineered and natural barriers of the repository concepts in Sweden and the US, some aspects of the US performance confirmation program would not be directly applicable to the situation in Sweden.

2. US Nuclear Regulatory Commission (USNRC)

Regulatory requirements for a formal performance confirmation program are specified in the USNRC's 10 Code of Federal Regulations (CFR) Part 63, Subpart F (abstracted in Appendix A). Guidance for the program is also provided in the *Yucca Mountain Review Plan, Final Report*, (USNRC, 2003, NUREG-1804) (abstracted in Appendix B). According to the USNRC, a performance confirmation program essentially begins during site characterization, and the formulation of a continuing performance confirmation program presumes a regulatory finding by the USNRC to authorize a construction license application. The performance confirmation program would be conducted until permanent closure of the repository (10 CFR 63.131(b)). The scope of the program would consist of tests, monitoring activities, and analyses to evaluate the adequacy of assumptions, data, and analyses that supported the findings that permitted construction of the repository and subsequent emplacement of wastes (10 CFR 63.102(m)).

The purpose and objectives of this *Performance Confirmation Plan*, as quoted in regulation 10 CFR 63.102(m), is that:

> *[A] performance confirmation program be conducted to evaluate the adequacy of assumptions, data, and analyses that led to the findings that permitted construction of the repository and subsequent emplacement of the wastes. Key geotechnical and design parameters, including any interactions between natural and engineered systems and components, will be monitored throughout site characterization, construction, emplacement, and operation to identify any significant changes in the conditions assumed in the license application that may affect compliance with the performance objectives specified at 63.113(b) and (c).*

In brief, USNRC regulation require that the performance confirmation program must:

- Confirm that subsurface conditions, geotechnical and design parameters are as anticipated and that changes to these parameters are within limits assumed in the License Application.
- Confirm that the waste-retrieval option is preserved.
- Evaluate information used to assess whether natural and engineered barriers function as intended.
- Evaluate effectiveness of design features intended to perform a post-closure function during repository operation and development.
- Monitor the condition of an as-emplaced waste package (but not necessarily all packages).

The USNRC envisions the repository system as composed of natural and engineered barriers that have been characterized and designed to work together to prevent or reduce the movement of water or radionuclides, or prevent the release or substantially reduce the release rate of radionuclides. Specifically, the USNRC requires that the applicant for a repository permit show how at least one engineered barrier and at least one natural barrier contribute to overall isolation in safety

assessments. The features and structures, systems, or components of the repository system that form repository barriers include any feature or structure, system, or component that contributes to the performance of the repository and is considered to be important to waste isolation.

3. US Department of Energy (USDOE)

To better illustrate how a performance confirmation program might be organized and conducted, the performance confirmation activity described by the USDOE in the construction license application (USDOE, 2008). submitted for a high-level waste repository at Yucca Mountain, Nevada to the USNRC is summarized here. At this time, there has been no formal review and acceptance by the USNRC of the performance confirmation plan as designed by the USDOE to support its CLA. Nonetheless, USDOE (2008) and its many supporting reports contain useful information as to how a repository program envisioned planning, conducting and reporting a performance confirmation program during the pre-closure period of operations. This section abstracts key points from the proposed USDOE program.

The USDOE (2008) argues that the robustness of the engineered and natural systems of their Yucca Mountain repository concept reduced the possibility that uncertainties associated with any one parameter could result in conditions that would lead to exceeding the USNRC's post-closure performance objectives, or result in conditions that would preclude retrieval of the waste. By examining the confidence and accuracy in understanding subsystem components, as well as the overall system sensitivity to particular processes, the USDOE planned to direct their performance confirmation program at confirming design and model parameters, and as a consequence, the bases for their estimates of long-term performance. The USDOE also wanted to confirm and demonstrate that repository conditions would not preclude the retrievability option. A formal *Performance Confirmation Plan* was developed by the USDOE (2008) to meet these objectives.

3.1. Continued Site Characterization as Part of Performance Confirmation

Both the USDOE and the USNRC views performance confirmation as already begun during the characterization of the Yucca Mountain site. Thus, the USDOE *Performance Confirmation Plan* would continue such observations during repository construction and through operational emplacement of waste, only concluding when repository would be closed.

Many of the specific performance confirmation tests envisioned by UDOE (2008) are not directly relevant to the proposed SKB license because of differences in hydrology (unsaturated vs. saturated), disposal concept and engineered barriers, site properties, etc. Broadly, the proposed USDOE (2008) performance confirmation activities included the study of impacts arising from excavation and heating from radiogenic decay of emplaced waste packages on:

- site hydrology, including surface water,
- site hydrochemistry,
- seismicity,
- rock mechanics,
- re-entry of water into the engineered barrier system (EBS),
- SNF testing at relevant repository conditions,

- sealing of access tunnels and shafts,
- chemical corrosion of canisters,
- release and migration behavior of radionuclides.

Also of concern for the USDOE performance confirmation program was documentation of feasibility for the construction and stability of underground openings, safe transport and handling of highly radioactive waste packages, refinement of worker-safety procedures, and quality assurance of the presumed initial properties (‘initial state’) of as-emplaced barriers of the EBS.

3.2. Staged Approach to Managing Performance Confirmation

USDOE (2008) recognized the need to manage, improve and optimize its performance confirmation program over the multi-decade construction and operational period. This included the need to develop management criteria regarding:

- is the proposed activity necessary and/or sufficient for regulatory compliance as based on the identified safety-significant factors in the license application,
- are new findings, revised design features, and perhaps new (initially unrecognized) issues continually factored in performance confirmation planning,
- how does the activity contribute to confirming the expected performance/ safety functions of specific barriers,
- can closely related activities possibly be combined,
- is the proposed activity ‘confirmatory’, or ‘model refinement’, or ‘supplemental data’, or ‘development/ optimization’ in nature,
- do the proposed activities/ tests recognize and *a priori* set appropriate ranges in the accuracy and precision in parameters and conditions (including rates of changes in parameters) by which ‘confirmation’ is to be verified,
- are the proposed activities/ tests designed in a manner to be able to confirm or reject the validity between or among alternative, competing models for a specific safety-significant process,
- how will practical issues such as instrument calibration and re-calibration over extended time periods be conducted, how with the possibility of ‘false-positive’ measurement results be minimized, how will durability of measurement devices be developed for severe environmental (e.g., high radiation field, high temperature, salinity, etc.) conditions,
- are compensating effects from other barriers factored into tests on simplified, single barrier tests,
- are new developments in testing methods, materials, measurement techniques, and modifications from the initial repository design concept

continually followed and evaluated to guide improvement in existing or planned performance confirmation tests,
- collection and record keeping of all performance confirmation information to supplement the evaluation for final closure of the repository.

Finally, USDOE (2008) recognized that its performance confirmation program would require continued consultation, oversight and monitoring by the USNRC. This would allow the nuclear safety authority to (1) propose revisions to current and planned activities, and (2) possibly require new and revised performance evaluations by the licensee, based on information derived from the performance confirmation activities

To assure a complete and integrated organization to performance confirmation, a staged approach was proposed by the USDOE. Eight stages were identified:

1. Select performance confirmation parameters and test methods.
2. Predict performance and establish a baseline.
3. Establish bounds and tolerances for key parameters.
4. Establish test completion criteria and variance guidelines.
5. Plan activities, and construct and install the performance confirmation program.
6. Monitor, test, and collect data.
7. Analyze and evaluate data.
8. Recommend *corrective action* in the case of variance.

These eight stages of performance confirmation rely on the selection of parameters based on their importance to performance. The phased nature of repository construction and waste emplacement would allow progressive development of performance confirmation tests and methods. Monitoring and test methodologies for activities continuing from site characterization were acknowledged as more fully developed, while additional confirmatory tests associated with the construction and operational period activities were more at the conceptual stage of planning. The USDOE advocated that there would be a continuing series of updates and future revisions of their initial *Performance Confirmation Plan* in order to flexibly adapt to new information. For the purposes of this introductory report and in the context of relevance to SSM's current review of SKB license application, emphasis is placed on the first stage, selection of performance confirmation parameters and test methods, based on USDOE's reports supporting its construction license application (CLA).

3.3. Risk-Based Approach for Preliminary Confirmation Activities

USDOE's approach to selecting parameters for their performance confirmation program was risk-informed, performance-based, focusing on parameters and processes that were found to be important to evaluating assumptions, data and analyses used in the licensing process. Generally, parameters that are important to either system performance or barrier safety-functions, and have a relatively high degree of uncertainty, would be considered a prime activity to include in the performance confirmation program.

It was also jointly recognized by both the USNRC (Appendix B) and the USDOE that, even after the initial regulatory authorization to proceed to initial construction phase, there might be certain difficult-to-resolve, safety-related issues remaining. Such issues might, for example, require confirmatory testing in underground service conditions, or over large-scale, or over longer time periods to enhance confidence.

The USDOE approach used for selecting the initial set of activities for evaluating the post-closure performance of the repository was based on addressing three risk-based questions traditionally used in the US:

- "What can go wrong?"
- "How likely is it?"
- "What are the consequences?"

In this manner, the USDOE performance confirmation program was linked to the performance assessment (PA) supporting its CLA. This PA, and the USNRC's review of this PA (never completed), was to provide the basis to identify the reasonableness and completeness of the initially proposed *Performance Confirmation Plan*, and that the *Performance Confirmation Plan* would be revised periodically based on new data and/or revised analyses. Performance confirmation monitoring in the *Performance Confirmation Plan* would be implemented to focus on areas important to evaluating information supporting assessments of repository performance relative to underground *service conditions* (that is, the environmental conditions prevailing at the repository horizon). Other parts of the *Performance Confirmation Plan* focused on further examination and testing of uncertainties in the performance assessments that contributed to higher potential risk. This risk-informed portion of performance confirmation, therefore, relied on the results, review and interpretation of the performance assessment presented in the CLA to select key parameters and processes for inclusion in the performance confirmation program.

In contrast, a proposal to measure a parameter to which neither system performance nor barrier capability (safety function) was sensitive, or for which there was already high confidence in the current representation of that parameter, would be assigned a much lower ranking with respect to inclusion in the performance confirmation program. For example, investigating solubilities of very short-lived radionuclides might have a much lower importance (utility ranking) because decay occurs so quickly that the radionuclides would not even incrementally impact safety. This *risk-importance ranking approach* was advocated to allow directing finite human and financial resources to those areas that would be most important for protecting public safety.

Lastly, it must be cautioned that the relative risk-importance of many safety-relevant processes and parameters of barriers can be masked by the performance of other barriers. Extended containment by canisters, for example, can conceal appreciation that additional processes and parameters such as radioelement solubility and retardation, strongly affected long-term, regulatory release-compliance once canisters failed.

3.4. Selection Criteria

Using the cumulative set of performance assessments results in support of the USDOE's CLA, the following criteria were used to identify and evaluate processes and parameters (and associated uncertainties) affecting overall repository safety, hence, of potential importance for inclusion in a performance confirmation program:

- How important is the parameter to barrier capability (i.e., safety function) and system performance?
- What is the level of confidence in the current knowledge about the parameter?
- How accurately can information be obtained by a particular test activity?

The first criterion relates to the sensitivity of the total system performance and barrier capability to a performance confirmation parameter. Many such sensitivity analyses are provided by SKB in SKB (2011, Chapter 13) for their proposed KBS-3 concept. The second criterion relates to confidence in the current representation of the safety-significant parameter or process being measured or modeled. The less confidence in a particular parameter/process, the more important it should be included in performance confirmation. The last criterion recognizes that it is not always possible to take direct measurements of a parameter, or that the difficulty in measuring a particular parameter is prohibitive so the accuracy and ease with which information can be collected should be considered. The cost of measuring the parameter was also identified as an applicable but lesser criterion, certainly valid in developing tests that might provide confirmation of more than one key process/parameter.

A *decision analysis process* is advocated by the USDOE (2008) to identify key, risk-important natural-system and engineered-system parameters. According to the USDOE, a decision analysis approach offers three key benefits in evaluating candidate activities;

- logically account for multiple objectives for the performance confirmation program,
- incorporate information from project personnel with different areas of expertise relevant to the selection of activities, and
- provided a traceable and defensible logic for the performance confirmation activity selection.

USDOE's approach advocates that both *objective* technical/safety judgments and *subjective* value judgments might be a necessary part of decision-making, and that different experts would likely be responsible for the judgments in each area.

3.5. Organization of Performance Confirmation Activities

In USDOE (2008), each performance confirmation activity would be organized and identified according to these subheadings:

- **Activity Description** (list the major parameters that may be measured or tested, the barrier safety-function that the activity investigates, when testing and monitoring is to begin, and other programs that may support interpretations of the tests),
- **Purpose** (short statement of the purpose of the test activity),
- **Selection Justification** (cite both technical and regulatory justifications),
- **Current Understanding** (summarize is known about the parameters/ processes covered by this activity, including baseline information),
- **Anticipated Methodology** (identify the planned test and measurement methods, discuss typical data evaluation (e.g., uncertainties, 'drift' in measurement over extended time or spatial scales, and how the results of this activity will be factored into updated safety evaluation).

The activities would be planned using technical work plans and products known as *performance confirmation test plans*, to be developed subsequent to receiving authorization of the CLA. The performance confirmation test plans would be implemented using appropriate quality assurance protocols. Schedules for implementation would be described in the individual activity descriptions.

The USDOE made some essential distinctions in planning and implementation. Its planning process for performance confirmation activities would be adapted to be directly applicable to its own understanding of the safety-significant features of its disposal concept and strategy, and include consultation with the U.S. Nuclear Regulatory Commission. In this planning, special emphasis would be given to instrumentation selection, maintenance, reliability, and calibration considering many of these tests will be in locations not easily accessible or conducted over long periods of time. Each activity would be evaluated to assess relevance to:

- worker safety,
- waste isolation impacts due to test construction, performance confirmation activities or both,
- potential interactions between independent activities, and
- potential interactions between repository construction activities and performance confirmation activities.

Performance confirmation test plans would be the primary planning document for each test activity, being implemented by subordinate implementing and work control documents.

In summary, USDOE (2008) stressed its *Performance Confirmation Plan* was a planning document. Each of the *activities* would use a number of criteria, including safety-significance, current level of knowledge/uncertainty, and feasibility of implementation. As a planning document, its *Performance Confirmation Plan* would be expected to be regularly updated and adapted on the basis of information collected, possibly new issues emerging, and possibly new methods and measurement techniques becoming available.

4. Summary

"Performance Confirmation" is defined here as a program of activities to be conducted during the pre-closure construction and operational period to further test and augment the information, analyses and results of the initial construction license application (CLA). While there is no specific mention or requirement for 'performance confirmation' in Swedish regulations, SSMFS 2008:1 Chapter 2, Section 10 (SSM, 2008a) states requirements on a safety program that calls for a continuous systematic assessment of the facility's safety and to safety improvement measures, which closely aligns with the motivation and goals of performance confirmation.

The objectives of such a pre-closure performance confirmation program could include

- Establishing that the actual subsurface conditions encountered and changes in these conditions during construction and waste emplacement operations are within the limits assumed in the CLA review,
- Testing and monitoring whether the natural and engineered systems and barrier components have the targeted properties and safety function as intended following waste emplacement,
- Reducing uncertainties and eliminating alternatives in models through application of *in situ*, larger-scale, or longer-term testing, as well as application of emerging new technologies,
- Enhancing public confidence through a sustained and traceable testing program to confirm that performance objectives/ safety functions designed to protect public health and safety are satisfied.

Specific features of a potential performance confirmation program are illustrated by examples from both the US NRC regulator and the USDOE repository implementing organization for SNF at the Yucca Mountain site.

Both the USNRC and the USDOE recognized the advantages of a performance confirmation period in addressing difficult-to-resolve, safety-relevant topics. The multi-decade pre-closure period involving sub-surface excavation, construction, fabrication of engineered barriers, handling, waste emplacement and other operational activities offers opportunities to further support initial licensing decisions, for example through application of *in situ* tests, larger-scale tests, or longer-term tests. As outlined in this Technical Note, the features of USDOE's proposed Performance Confirmation Plan offers insight into how such a program could be organized, conducted, and adapted over the multi-decade pre-closure period. Such a performance confirmation program would also allow for evaluation of emerging new technologies, measurement methods and materials, facilitating optimization of design and operational activities during this same extended period.

Because of detailed differences in applicable regulations, site, hydrological conditions, and engineered barrier system, it would be necessary for SSM and SKB together to select, revise and possible re-interpret how a performance confirmation-

type program might be instituted and applied. The focus of this Technical Note is on basic principles and methods as illustrated in the case for SNF disposal in the US.

To guide SSM in its consideration of how a performance confirmation program might contribute to, or be part of, licensing conditions, several observations are noted:

- A significant part of any pre-closure performance confirmation program includes continuation of previous site characterization and materials testing that were the basis for the initial CLA.
- Management of limited human, schedule and financial resources within any performance confirmation program will require focusing on processes and parameters that are important to either system performance or barrier safety-functions, and have a relatively high degree of uncertainty. Selection of processes and parameters for a performance confirmation program should, therefore, be risk-informed and performance-based for expected and credible alternative evolutionary scenarios.
- After identification of key, risk-important and difficult-to-resolve issues, three broad selection criteria could be applied to each:
    - How important is the parameter to barrier capability (i.e., safety function) and system performance?
    - What is the level of confidence in the current knowledge about the parameter?
    - How accurately can information be obtained by a particular test activity?
- A performance confirmation program needs iterative updating, to guide, modify and incorporate implications from evolving technologies, as well as program advancements in confirming repository performance and safety. .

5. References

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Appendix A: USNRC 10 CFR Part 63, Subpart F: Performance Confirmation Program

§ 63.131 General requirements.

(a) The performance confirmation program must provide data that indicate, where practicable, whether:

(1) Actual subsurface conditions encountered and changes in those conditions during construction and waste emplacement operations are within the limits assumed in the licensing review; and

(2) Natural and engineered systems and components required for repository operation, and that are designed or assumed to operate as barriers after permanent closure, are functioning as intended and anticipated.

(b) The program must have been started during site characterization, and it will continue until permanent closure.

(c) The program must include in situ monitoring, laboratory and field testing, and in situ experiments, as may be appropriate to provide the data required by paragraph (a) of this section.

(d) The program must be implemented so that:

(1) It does not adversely affect the ability of the geologic and engineered elements of the geologic repository to meet the performance objectives.

(2) It provides baseline information and analysis of that information on those parameters and natural processes pertaining to the geologic setting that may be changed by site characterization, construction, and operational activities.

(3) It monitors and analyzes changes from the baseline condition of parameters that could affect the performance of a geologic repository.

§ 63.132 Confirmation of geotechnical and design parameters.

(a) During repository construction and operation, a continuing program of surveillance, measurement, testing, and geologic mapping must be conducted to ensure that geotechnical and design parameters are confirmed and to ensure that appropriate action is taken to inform the Commission of design changes needed to accommodate actual field conditions encountered.

(b) Subsurface conditions must be monitored and evaluated against design assumptions.

(c) Specific geotechnical and design parameters to be measured or observed, including any interactions between natural and engineered systems and components, must be identified in the performance confirmation plan.

(d) These measurements and observations must be compared with the original design bases and assumptions. If significant differences exist between the measurements and observations and the original design bases and assumptions, the need for modifications to the design or in construction methods must be determined and these differences, their significance to repository performance, and the recommended changes reported to the Commission.

(e) *In situ* monitoring of the thermo-mechanical response of the underground facility must be conducted until permanent closure, to ensure that the performance of the geologic and engineering features is within design limits.

§ 63.133 Design testing.

(a) During the early or developmental stages of construction, a program for testing of engineered systems and components used in the design, such as, for example, borehole and shaft seals, backfill, and drip shields, as well as the thermal interaction effects of the waste packages, backfill, drip shields, rock, and unsaturated zone and saturated zone water, must be conducted.

(b) The testing must be initiated as early as practicable.

(c) If backfill is included in the repository design, a test must be conducted to evaluate the effectiveness of backfill placement and compaction procedures against design requirements before permanent backfill placement is begun.

(d) Tests must be conducted to evaluate the effectiveness of borehole, shaft, and ramp seals before full-scale operation proceeds to seal boreholes, shafts, and ramps.

§ 63.134 Monitoring and testing waste packages.

(a) A program must be established at the geologic repository operations area for monitoring the condition of the waste packages. Waste packages chosen for the program must be representative of those to be emplaced in the underground facility.

(b) Consistent with safe operation at the geologic repository operations area, the environment of the waste packages selected for the waste package monitoring program must be representative of the environment in which the wastes are to be emplaced.

(c) The waste-package monitoring program must include laboratory experiments that focus on the internal condition of the waste packages. To the extent practical, the environment experienced by the emplaced waste packages within the underground facility during the waste-package monitoring program must be duplicated in the laboratory experiments.

(d) The waste package monitoring program must continue as long as practical up to the time of permanent closure.

Appendix B: Yucca Mountain Review Plan (YMRP) by the USNRC's High-Level Waste Branch and Environmental and Performance Assessment Branch

The USNRC staff developed a Yucca Mountain Review Plan to aid in their preparation to receive and review the CLA from the US Department of Energy. The portion provided below focuses on the potential approaches to resolve safety questions arising from the initial CLA. Implementation and sustained review of a performance confirmation program by the USDOE was one of the key aspects of resolving safety questions. This material is provided as a guide to overall regulatory perspective and context to resolution of difficult safety issues, as envisioned by the USNRC technical staff. The "*research and development program*" referred to is the performance confirmation plan that would be provided by the USDOE as part of their CLA, or as necessarily modified in response to specific safety-related questions on their submitted CLA.

2.3 Research and Development Program to Resolve Safety Questions Review Responsibilities

2.3.1 Areas of Review
This section reviews the research and development program for resolving safety questions related to structures, systems, and components important to safety and engineered or natural barriers important to waste isolation. Reviewers will evaluate the information, required by 10 CFR 63.21(c)(16). The program is required to identify, describe, and discuss those safety features or components for which further technical information is required, to confirm the adequacy of design, and engineered or natural barriers. The staff will evaluate the following parts of the research and development program to resolve safety questions, using the review methods and acceptance criteria in Sections 2.3.2 and 2.3.3:

(1) Identification and description of safety questions;

(2) Identification and description of the research and development programs that will be conducted to resolve any safety questions for structures, systems, and components important to safety and the engineered and natural barriers important to waste isolation;

(3) A schedule for completion of the program, as related to the projected startup date of repository operation; and

(4) The design alternatives or operational restrictions available, if the results of the program do not demonstrate acceptable resolution of the safety question problem(s).

2.3.2 Review Methods
Review Method 1: Identification and Description of Safety Questions
Verify that the license application identifies safety questions. If there are deficiencies, examine the rationale for them to verify that it is adequate.

Review Method 2: Identification and Detailed Description of the Research and Development Programs to Resolve Any Safety Questions for Structures, Systems, and Components Important to Safety and the Engineered and Natural Barriers Important to Waste Isolation

Verify that for each safety question identified, a detailed research and development program has been established.

Verify there is a description of the specific technical information that must be obtained to demonstrate acceptable resolution of the safety question. The description of the program should be of sufficient detail to show how the information will be obtained.

Verify that criteria described in the research and development program to resolve safety questions Review Plan for Safety Analysis Report incorporate appropriate scientific or engineering techniques to address the scope of the issues.

Examine the specific programs to verify that appropriate analyses, experiments, data collection, field tests, or other techniques have been identified, and that the timing and sequence of these activities have been specified.

Review Method 3: Schedule for Completion of the Program as Related to the Projected Startup Date of Repository Operation, and Commitment to Include Resolved Questions in Amendments to the License Application

Verify schedules for resolution of safety questions specify a date by which the issues should be resolved. Schedules should include intermediate dates or events at which decisions relating to the issue resolution program implementation will be made, if appropriate. The program and schedule should be detailed enough to show the interface with the repository design, construction activities, schedule proposed for receipt and emplacement of wastes, and any other related activities. In conducting this verification, consider the accessibility of underground locations, conditions that are likely to exist at the geologic repository operations area, and other interferences that might exist during construction.

Evaluate the research and development program for compatibility with other site activities and any schedule proposed for receipt and emplacement of wastes. The schedule must be compatible with:

(i) other site activities and schedules, including the performance confirmation program (10 CFR Part 63, Subpart F);
(ii) repository design; and
(iii) site characteristics. It should also satisfy the requirements of any license conditions, established under 10 CFR 63.32 and 63.42.

Verify a commitment in the license application to include resolved questions in amendments to the license application.

Review Method 4: Design Alternatives or Operational Restrictions Available in the Event That the Results of the Program Do Not Demonstrate Acceptable Resolution of the Problem

Verify there is an alternative plan to demonstrate acceptable resolution of the safety questions.

Design alternatives or operational restrictions should be discussed in the alternative plan.

Confirm there is a discussion of any programs that will be conducted during operation to demonstrate the acceptability of contemplated future changes in design or operation.

2.3.3 Acceptance Criteria
The following acceptance criteria meet the requirements of 10 CFR 63.21(c)(16).

Acceptance Criterion 1: The Identification and Descriptions of Safety Questions Are Adequate.

Acceptance Criterion 2: The U.S. Department of Energy Adequately Identifies, and
Describes in Detail, a Research and Development Program That Will Be Conducted to Resolve Any Safety Questions, in a Reasonable Time Period, for Structures, Systems, and Components Important to Safety, and the Engineered and Natural Barriers Important to Waste isolation. Review Plan for Safety Analysis Report

Acceptance Criterion 3: The U.S. Department of Energy Provides a Reasonable Schedule for the Completion of the Program, as Related to the Projected Startup Date of Repository Operation, and the Date When Items Are Expected to Be Resolved. The
U.S. Department of Energy Makes a Commitment to Include Resolved Questions in Requested Amendments to the License Application, as Appropriate.

Acceptance Criterion 4: The U.S. Department of Energy Provides the Design Alternatives or Operational Restrictions Available, If the Results of the Program Do Not Demonstrate Acceptable Resolution of the Problem.

2.3.4 Evaluation Findings
If the license application provides sufficient information and the regulatory acceptance criteria in Section 2.3.3 are appropriately satisfied, the staff concludes that this portion of the staff evaluation is acceptable. The reviewer writes material suitable for inclusion in the safety evaluation report prepared for the entire application. The report includes a summary statement of what was reviewed and why the reviewer finds the submittal acceptable. The staff can document the review as follows.

• U.S. Nuclear Regulatory Commission staff has reviewed the Safety Analysis Report and other information submitted in support of the license application, and has found, with reasonable assurance, that the requirements of 10 CFR 63.21(c)(16) are satisfied.
• Requirements for identification and description of safety questions related to structures, systems, and components and the engineered and natural barriers have been met.

• The U.S. Department of Energy has provided a detailed description of the programs designed to resolve safety questions, including a schedule indicating when these questions would be resolved.

• The design alternatives or operational restrictions available, if the results of the program do not demonstrate acceptable resolution of the problem, have been provided.

• Repository construction can proceed, considering the scope of the safety questions and the programs and schedules for their resolution.

2.4 Performance Confirmation Program Review Responsibilities

2.4.1 Areas of Review

Subpart F of 10 CFR Part 63 provides the requirements for the performance confirmation program. The staff defines performance confirmation as the program of tests, experiments, and analyses that are conducted to evaluate the adequacy of the information used to demonstrate compliance with the performance objectives in Subpart E (refer to 10 CFR 63.2).

The need for a performance confirmation program is unique to high-level radioactive waste disposal. This reflects the uncertainties in estimating geologic repository performance over thousands of years. At permanent closure, 10 CFR 63.51(a)(1) requires the U.S. Department of Energy to present an update of the post-closure performance assessment. The updated assessment includes any performance confirmation data collected and relevant to post-closure performance.

The U.S. Nuclear Regulatory Commission will then decide whether the U.S. Department of Energy comprehensive program of testing, monitoring, and confirmation suggests the repository will work as planned. Unless the U.S. Department of Energy designs the repository to preserve the option to retrieve the waste before permanent closure, an action reserved to the U.S. Nuclear Regulatory Commission could be foreclosed, and an unsafe condition could be transmitted to future generations. Therefore, the broad reference to the performance objectives under Subpart E in the performance confirmation definition reflects the need to consider retrievability when monitoring subsurface conditions, and that preserving the retrieval option is a pre-closure performance requirement. The general requirements for the performance confirmation program do not require testing and monitoring to confirm pre-closure performance in other contexts (that is, testing and monitoring structures, systems, and components important to safety). The general requirements at 10 CFR 63.131 focus on subsurface conditions, as well as the natural and engineered systems and components required for repository operation and that are designed or assumed to operate as barriers after permanent closure. The bases for the acceptance criteria are the requirements for performance confirmation, in 10 CFR Part 63, that are performance-based. Where suitable, the acceptance criteria are also risk informed, because performance confirmation focuses on those parameters and natural and engineered barriers important to waste isolation.

The staff will confirm that the submittal complies with the requirements for tests, specified by 10 CFR 63.74(b) and 10 CFR Part 63, Subpart F, "Performance Confirmation Program."

The staff will evaluate the information that is relevant to the performance confirmation program and is in the Safety Analysis Report, as required by 10 CFR 63.21(c)(17).

The staff will evaluate the following parts of the performance confirmation program, using the review methods and acceptance criteria in Sections 2.4.2 and 2.4.3:
(1) General requirements for the performance confirmation program, including:

(a) Objectives of the performance confirmation program to acquire data by identified
in situ monitoring, laboratory, and field testing, and *in situ* experiments, to indicate whether: (i) actual subsurface conditions (i.e., specific geotechnical and Review Plan for Safety Analysis Report design parameters, including natural processes, pertaining to the geologic setting) encountered and changes in those conditions (including any interactions between natural and engineered systems) during construction and waste emplacement operations are within the limits assumed in the licensing review; and

(ii) natural and engineered systems and components that are designed or assumed to operate as barriers after permanent closure are functioning as intended and anticipated;

(b) Overall schedule for performance confirmation; and

(c) Plans to implement the performance confirmation program, so the program:

(i) does not adversely affect the ability of the geologic and engineered elements of the geologic repository to meet the performance objectives;
(ii) provides baseline information and analysis of that information on those parameters and natural processes of the geologic setting that may change because of site characterization, construction, and operations; and
(iii) monitors and analyzes changes from the baseline condition of parameters that could affect the performance of the geologic repository.

(2) Confirmation of geotechnical and design parameters, including:
(a) Technical measuring, testing, and geologic mapping program during repository construction and operation to confirm geotechnical and design parameters pertaining to natural systems and components that are designed or assumed to operate as barriers after permanent closure, to verify they are functioning, as intended and expected;

(b) Technical program to monitor, *in situ*, the thermo-mechanical response of the underground facility until permanent closure to ensure the performance of the geologic and engineering features is within design limits; and

(c) Surveillance program to evaluate subsurface conditions against design assumptions, including procedures to:

(i) compare measurements and observations with original design bases and assumptions;

(ii) determine the need for changes to the design or construction methods, if significant differences exist between the measurements and observations and the original design bases and assumptions; and

(iii) report significant differences between measurements and observations and the original design bases and assumptions, their significance to health and safety, and recommended changes, to the U.S. Nuclear Regulatory Commission.

(3) Design testing including
(a) Technical program to test engineered systems and components, other than waste packages, used in the design during the early or developmental stages of construction. This includes, for example, borehole and shaft seals, backfill, and drip shields;

(b) Technical program to evaluate the thermal interaction effects of waste packages, backfill, drip shields, rock, and unsaturated zone and saturated zone water;
(c) Schedule for starting tests of engineered systems and components used in the design;

(d) Plan to conduct a test, before permanent backfill placement begins, to evaluate the effectiveness of backfill placement and compaction procedures against design requirements, if the U.S. Department of Energy includes backfill in the repository design; and

(e) Plan for conducting tests to evaluate the effectiveness of borehole, shaft, and ramp seals before full-scale sealing.

(4) Monitoring and testing waste packages, including:
(a) Plan for monitoring the condition of waste packages at the geologic repository operations area, including an evaluation of the:
(i) representativeness of those waste packages chosen for monitoring, and

(ii) representativeness of the waste package environment of the waste packages chosen for monitoring;

(b) Plan for laboratory experiments that focus on the internal condition of the waste packages, including an evaluation of the degree the environment experienced by the emplaced waste packages within the underground facility is duplicated in the laboratory experiments; and

(c) Duration of the waste package monitoring and testing program.)

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The Swedish Radiation Safety Authority has a comprehensive responsibility to ensure that society is safe from the effects of radiation. The Authority works to achieve radiation safety in a number of areas: nuclear power, medical care as well as commercial products and services. The Authority also works to achieve protection from natural radiation and to increase the level of radiation safety internationally.

The Swedish Radiation Safety Authority works proactively and preventively to protect people and the environment from the harmful effects of radiation, now and in the future. The Authority issues regulations and supervises compliance, while also supporting research, providing training and information, and issuing advice. Often, activities involving radiation require licences issued by the Authority. The Swedish Radiation Safety Authority maintains emergency preparedness around the clock with the aim of limiting the aftermath of radiation accidents and the unintentional spreading of radioactive substances. The Authority participates in international co-operation in order to promote radiation safety and finances projects aiming to raise the level of radiation safety in certain Eastern European countries.

The Authority reports to the Ministry of the Environment and has around 315 employees with competencies in the fields of engineering, natural and behavioural sciences, law, economics and communications. We have received quality, environmental and working environment certification.

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