National consultation of licence application for construction and operation of a repository for spent nuclear fuel in Sweden: Overview of viewpoints and role in regulatory review

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Summary

National consultations have been an important basis for the licensing review of the Swedish Nuclear Fuel and Waste Management Company´s (SKB) application to construct and operate a repository for spent nuclear fuel at the Forsmark site in Sweden. The work with these consultations has been co-ordinated by the Swedish Radiation Safety Authority (SSM). The scope of comments received was broad, covering questions such as research needs, ambiguities in SKB's reporting, and operational issues related to implementation of the repository programme. This paper focuses on three subject areas judged to be critical for the acceptability of the application, namely site selection, method selection and SKB's handling of degradation of disposal canisters.

Introduction

National consultations of various types are valuable components of large societal decisions in general. Such consultations provide opportunities to consider new information and perspectives that may not have been addressed in the original application. Responses may originate from e.g. Swedish local authorities, academic institutions, government agencies, and environmental organisations. Throughout the Swedish programme for nuclear waste management, external reviews have been carried out on a regular basis both nationally and internationally. Since 1986, SKB has published in total 11 research, development and demonstration (RD&D) programmes, each of which has been a subject for national consultation. Given this comprehensive background, it is not surprising that many of the expressed viewpoints are familiar and have reoccurred many times in consultations on SKB's activities throughout the years.

The national consultations in the context of SSM's examination of SKB´s licence application according to the Act on Nuclear Activities started with an invitation in 2011 to in total 70 organisations to comment on the completeness of the application and to identify needed complementary information. The organisations were selected on the basis that they had previously commented on SKB´s RD&D-programmes. In a second call, the same organisations were invited to comment on the factual content of the application, with a final date for providing comments of 30 April 2016. After SSM´s public announcement of SKB's licence application, the general public were also invited to submit comments.

In SSM´s final reporting of the licensing review, a synthesis is provided of comments from the different respondents, including a summary and explanation of SSM´s position in relation to the comments (SSM 2018a).

General outcome of national consultations

Consultees' responses can be subdivided into different categories depending on general attitude to and coverage of the licence application: i) not responding or refrain from commenting, ii) narrow and mostly neutral scope, iii) comprehensive scope, neutral or supportive of application, iv) dismissive of the application in its entirety.

More than half of the invited organisations belong to the first category. Several of the invited organisations have only a peripheral subject overlap with the content of the application. For instance, other government agencies generally only commented on limited aspects of the application related to their respective areas of competence and responsibility. The most comprehensive responses involving many subject areas came from the involved municipalities (Östhammar, Oskarshamn), involved regional authorities and a few environmental organisations (Milkas, MKG and Naturskyddsföreningen). The involved municipalities and regional authorities raised a number of concerns related to, for instance, access to and preservation of information, transport of nuclear materials, indirect impact of conventional accidents during facility operation, measurement systems, and the implications of a zero (no action) alternative, as well as concerns related to post-closure safety. Environmental organisations in general had a negative view of the licence application. Ten respondents urged SSM to recommend that the Swedish Government reject the application. Academic institutions for the most part commented on general future research needs.

Responses from the first call for comments, related to the potential need for complementary information in support of the licence application, were recognized in SSM´s review processes by the fact that SSM indeed sought complementary information from SKB in a range of subject areas identified by the respondents, albeit to a somewhat more limited extent. In some cases, the scope of suggested requests for supplementary information were judged by SSM to be unreasonably large. These included, for example, requests for an entirely new safety assessment as well as additional detailed site investigations at other sites. In some cases, SSM agreed with the general intention of the suggested requests but made the judgment that such information could reasonably be developed at later stages in the stepwise regulatory review process, after granting of a general licence. The general subject areas covered in the responses can be summarised as: i) post-closure radiation safety, ii) selection of site and disposal method, iii) operational safety, and iv) other issues. The three first topics were addressed by SSM in regulatory review activities (SSM 2018b, 2018c, 2018d). The "other issues" category encompasses viewpoints on issues that fall outside SSM´s area of responsibility.

The critical viewpoints expressed by environmental organisations as well as a few academic researchers have had a significant impact on media reporting and public debate relating to SKB´s spent fuel repository program. Those viewpoints were not only clearly expressed by those main contributors, but also taken up by other concerned respondents. Critical responses relating to suitability of the Forsmark site, the comparison of SKB:s proposed disposal method with the deep borehole concept and mechanisms that might lead to corrosion of the copper canister are consistent with the outcomes from previous national consultations of SKB´s RD&D-programmes.

Site suitability

Several of the respondents engaged in the consultation process question the suitability of the Forsmark site from different perspectives, claiming that:

- The site is located in a potentially seismically active area.
- Regional groundwater flow patterns suggest that a well-located inland site would be better than the costal Forsmark site.
- The site location close to a nuclear power plant is unsuitable since nuclear reactor accidents can hamper safe repository operation.

Two respondents with an academic background in geoscience (Henkel, Mörner) argue, based on the regional and local geology, that Forsmark is not a suitable repository site. Henkel claims that the site is located in a potentially seismically active area. Mörner similarly claims that SKB underestimate the frequency and magnitude of earthquakes linked to the waxing and waning of future ice sheets (see Mörner (2017) and references therein). Mörner also refers to his own research work on methane venting tectonics as a basis for criticism of SKB. The respondents conclude that future seismic activity and its implications are not sufficiently reflected in SKB's safety analysis report (SKB, 2011). For example, SKB's concept of "respect distance" (i.e. shortest distance from disposal cells to the nearest deformation zone) is claimed to be excessively short.

Several environmental organisations (MKG, Naturskyddsföreningen, Milkas) point out that the coastal location of the Forsmark site results in short groundwater flow paths from repository depth directly towards the surface. By contrast, an inland location within a regional "recharge" area could potentially provide long flow paths, which in turn might provide more effective retardation of radionuclides released from the repository and therefore offer significant safety advantages. The coastal location is also regarded as problematic since possible radionuclide releases would occur to the ecologically sensitive Baltic sea recipient.

A specific feature of the Forsmark site is the low frequency of water conducting features at repository depth. Whereas SKB argues this is a significant safety advantage, several respondents (e.g. MKG, Milkas) are concerned that this will mean that the bentonite buffer in disposal cells does not swell sufficiently, leading to aggravated corrosion conditions for the canister with accumulation of salt due to evaporation and a persistent presence of a potentially reactive gas phase (see discussion below about corrosion of the copper canister).

Some negative aspects regarding the proximity of the proposed Forsmark site to an operating nuclear power plant, for instance that a severe nuclear accident would impede safe operation of the repository, are also identified (MKG, Milkas, Naturskyddsföreningen Kalmar län).

SSM´s general position in relation to site selection is that the sparsity of water-conducting features at the proposed Forsmark site is generally a significant advantage, both in terms of limiting degradation of engineered barriers and constraining the release and dispersal of radionuclides in the event of canister failure. Criticism of SKB´s handling of earthquake magnitudes and frequencies was judged by SSM to have some validity but ultimately only a quite limited impact on the potential number of affected canisters (SSM, 2018b). The Forsmark site is according to SSM´s judgement regarded as seismically stable based on existing information. It should be recognised that SKB has accounted for the possibility of future large earthquakes in the area as part of associated risk calculations (SKB, 2011). SSM regards the measures proposed by SKB to minimize their impact as reasonable, i.e. the implementation of "respect distances" and deposition hole rejection criteria. The precise distances and criteria should be kept under review, but the overall concept of risk minimization is considered acceptable. SSM agrees with the respondents that long regional flow paths would in principle be beneficial. However, those inland sites that SKB had realistic opportunities to explore during its siting programme offer either no clear hydrogeological performance benefits or any significant overall safety benefits. SSM concludes that disposal activities at a future repository site at Forsmark could be temporarily halted in the event of a nuclear reactor accident without serious safety implications.

Alternative disposal concepts apart from KBS-3

One persistent viewpoint in the national consultation process among critics of SKB’s programme is that deep borehole disposal could/would be a significantly better alternative than SKB’s proposed KBS-3 method, and that this method must be explored to a greater extent as part of the repository licensing procedure (MKG, Milkas, Karlstad University). Other alternative methods brought up in the consultation process were the DRD-method (Dry Rock Disposal, Mörner), the WP-cave concept (Sagefors) and the HOSS-method (Hardened On Site Storage, Milkas).

A key argument to support the deep borehole disposal concept is that groundwater should be stagnant at the disposal depth of 3-5 km. Such stagnant conditions are related to the high density of very saline water. One respondent also pointed out that even if this were not the case the hydraulic conductivity and gradient would be very low at such depths (MKG/Gibb). It is postulated that there is no feasible mechanism for transferring radioactive contaminants to the surface, even if no physical containment within waste packages is achieved. The concept is regarded as more robust since there is less reliance on achieving containment through engineered barriers such as a copper canister and bentonite buffer. It is further claimed that even though containment is not required except during the operational phase, containment lifetimes of at least 1000 years can probably be achieved anyway in specially developed canisters (MKG/Gibb). Advantages in the context of nuclear materials control were also suggested (Karlstad University, MKG). Several respondents (e.g. Henkel, MKG, Milkas) also point out that the safety implications of future human actions are not sufficiently taken into account by SKB in their selection of a preferred disposal concept. Concerns relating to the overall feasibility of the borehole disposal concept (e.g. hazards arising during the disposal sequence and achieving reliable sealing of disposal boreholes) are claimed to be almost entirely outdated due to recent developments (MKG/Gibb).

SSM generally agrees with some of the identified deficiencies in SKB´s original analysis of the deep borehole disposal concept, but judges that reasonable clarifications were provided in their response to supplementary information requests. SSM concludes that the deep borehole concept could in theory have appreciable potential radiation protection benefits compared with the KBS-3 method. Nevertheless demonstrating such benefits in practice requires that rock and groundwater conditions at great depth can be explored and assessed to be reliably well-known and favourable at a specific site. It cannot be regarded as self-evident that such conditions could be found and verified reliably. Such conditions must be assumed to be persistent over the safety assessment timescale which at least would require a range of comprehensive investigations and analysis. SSM therefore regards it as unreasonable to continue interim storage of spent fuel against an unknown time horizon in order to develop what remains at present only a conceptual alternative to the KBS-3 method (SSM, 2018c). That SSM assesses SKB´s safety analysis for KBS-3 to have demonstrated its maturity and potential to fulfil regulatory requirements forms an important basis for this judgment.

The DRD-method is not regarded by SSM as a potential candidate for best available technique (BAT) on the basis that it requires a continuous surveillance and monitoring.

Copper canister and safety assessment

A recurring concern in the consultations has been SKB´s asserted corrosion resistance of the copper canister. These concerns have been raised over many years first and foremost by a research group from KTH (Royal Institute of Technology), but later also by MKG. Other respondents also highlight the debate surrounding copper corrosion, albeit in a more cautious context (e.g. Milkas, Lund University, Uppsala University). The objections can be broadly divided into two broad categories: i) that corrosion may take place in pure anoxic water under hydrogen formation, ii) that other forms of corrosion, including localised sulphide corrosion phenomena, radiation-induced corrosion, earth-current induced corrosion and combination effects need to be addressed in more detail. The respondents either claim that the information reported by SKB is insufficient to draw reliable conclusions regarding canister performance or that corrosion will proceed in such a manner that the containment time is much shorter than assessed by SKB (SKB, 2011). The respondents suggest that more research is needed to support SKB´s choice of copper, or alternatively that copper is not a suitable canister materials

The first category concerns a corrosion reaction that was first brought up in the context of the SKB program by KTH already in the 1980s. The debate has was mostly confined to academic circles and gained only intermittent wider interest, but in 2007 an experimental study was published by members of the research group showing measurable hydrogen generation in experiments with pure copper and water (Szakálos et al, 2007). This scientific paper generated media interest and public debate. The critics' key argument, based on an empirical research perspective, is that SKB relies on simplistic modelling and has not experimentally proven that copper corrosion rates in the repository environment will be within the extremely slow range (nm per year) assumed in its long-term safety assessment (SKB, 2011). The critics claim that most experimental studies have in fact reported corrosion rates in the µm per year range. Even if SKB agrees that copper corrosion rates initially can be in that range owing to intermittent availability of oxygen, the critics argue that this is rather a mean corrosion rate that progresses indefinitely. The evidence cited by the critics is a list of publications mainly by the KTH research group.

The second category of copper corrosion issues brought up by respondents is more diverse and complex. This topic concern a whole range of corrosion related phenomena that will according to the respondents either on their own or in concert with other phenomena significantly impair the protective capability of the canister. For example, localised corrosion phenomena such as stress corrosion cracking induced by sulphide are suggested to have much more severe consequences than allowed for in SKB's analysis. The respondents also argue that a number of circumstances in the repository environment will tend to aggravate degradation processes of the copper canister. This includes for instance the presence of a reactive gas phase next to the canister during the period with significantly elevated temperatures and the accumulation of salt in deposition holes as a result of evaporation (the so-called "sauna effect") in the predominantly dry Forsmark conditions. The effects of normal or elevated earth currents associated with the Baltic power transmission cable are also highlighted. Respondents also claimed that embrittlement will be a problem due to corrosion-related uptake of sulphides and/or hydrogen in the copper metal. The estimated overall effect of these phenomena has been expressed slightly differently by the respondents at different stages of the review process. Their most recent estimate is that canister failures will be initiated within 100 years and be completed for a majority of canisters within 1000 years.

Respondents also raised detailed questions relating to buffer properties and degradation processes (MKG/Pusch) as well as the canister's structural integrity, although these were given less emphasis in the overall criticism of SKB's analysis. There were also limited comments related to SKB´s secondary safety function based on retardation of radionuclides as well as associated risk calculations, highlighting topics such as groundwater flow rates and spent fuel dissolution rates in reducing groundwater.

According to SSM's analysis of the question of copper corrosion in pure water, this should have only a small impact in the repository environment regardless of whether known thermodynamic data (i.e. SKB's approach) or the empirically-derived rates from the KTH corrosion research group are applied. The reason is that the measured partial hydrogen pressures (e.g. Szakálos et al, 2007) at which the reaction is expected to cease is low, albeit considerably higher than partial hydrogen pressure at equilibrium derived from existing thermodynamic data. This finding, together with a reasonably confident knowledge of transport conditions in the repository environment, suggests that long-term effective corrosion rates will also be low in relation to general sulphide corrosion in anoxic groundwaters.

Regarding other corrosion phenomena SSM agrees with the respondents that localised corrosion in a sulphide environment cannot be completely ruled out. Only a small number of experimental studies have been conducted under relevant repository conditions and more efforts are needed prior to further steps in SSM's regulatory scrutiny process. Nevertheless, SSM notes that extensive progression of such mechanisms throughout the full thickness of the canister's copper shell requires a continuous supply of sulphide to exposed canister surfaces to avoid sulphide depletion. Furthermore, measures to mitigate the detrimental effects of such processes exist. SKB's licence application identifies, for example: i) limiting mass transfer with surrounding groundwater by rejecting deposition holes intersected by high groundwater flow, and ii) limiting the organic content of buffer and backfill materials, which can give rise to microbial sulphate reduction.

Conclusions and Discussion

The input from the national consultation in connection SSM's examination of SKB´s licence application was mainly addressed by requests for complementary information and identification of items that need to be further addressed in a future repository programme. Regarding the most SKB critical viewpoints those were more or less already well known to SSM. Nevertheless, the importance of these critical viewpoints was underscored by the fact that very similar arguments were raised at the Swedish Land and Environment Court's hearings during the autumn of 2017 in relation to SKB's licence application according to the Environmental Code. From the court's statement, published in January 2018, it is clear that neither site suitability nor method selection arguments raised by critics were decisive for the outcome of the hearings process. However, the court concluded that SKB had not sufficiently accounted for a number of corrosion or corrosion-related processes affecting copper canister integrity (Nacka District Court, 2018). Uncertainties regarding these processes were judged to be significant. The licence applications are now being managed by the Swedish government, which has requested complementary information from SKB regarding those aspects. SKB is scheduled to submit the required information by the end of April 2019.

It may be noted that critical respondents in general had a consistent set of viewpoints both from prior to submission of the licence applications and through the entire review procedure from 2011 to 2017. In other words, supplementary arguments presented by SKB during the course of the review seemed to have had little impact on the respondents' position. Evaluation of the validity of the alternative perspectives is always a key challenge for national consultation processes. The degree of specificity and support for alternative positions to those presented by SKB varied considerably. A few respondents referred to research findings provided by themselves or others independent of SKB. For example, work undertaken as part of the now-cancelled US program on deep borehole disposal was used as a basis for arguments regarding method selection.

Opposition to SKB´s licence application was not isolated to scientific or technical arguments alone. The most critical respondents also tended to have their own strategic perspectives on spent fuel management, such as the use of alternative canister materials, an alternative site, an alternative repository concept or other approaches such as prolonged interim storage. By contrast, less critical and supportive respondents as expected tended to accept the basic premises of SKB´s licence application.

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