THE REVIEW OF THE SWEDISH R&D PROGRAMME 1992 FOR THE HANDLING AND FINAL DISPOSAL OF NUCLEAR WASTE

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INTRODUCTION

The Swedish Act on Nuclear Activities states that it is the owners of the nuclear power reactors that bear the responsibility - technically and financially - for the safe disposal of radioactive waste (including the spent fuel). In summary, the act imposes the following on the owners of the nuclear power stations:

- To ensure that the necessary measures are taken in order to safely handle and finally dispose of the nuclear waste generated, and to decommission and dismantle the nuclear power plants in a safe manner.

- To ensure that the comprehensive research and development activities required to carry out these activities are conducted, including studies of alternative methods for the handling and final disposal of the waste.

- To submit, for approval, a programme of research, development and other appropriate measures - including an account of results of completed research - every third year starting in 1986.

In response to these demands, the nuclear power companies have formed a jointly owned company, the Swedish Nuclear Fuel and Waste Management Company (SKB) and commissioned it to carry out these tasks.

On September 31st, 1992, SKB submitted its latest programme for Research, Development and Demonstration (RD&D) [1-4] to the Swedish Nuclear Power Inspectorate (SKI) for review and evaluation. After having received comments on the programme from a large number of organisations in Sweden - as well as from a few consultants - SKI compiled the conclusions of its evaluation and sent its report to the Government on March 31st, 1993 [5-6]. An independent review is being made by the Swedish National Council for Nuclear Waste (KASAM).

SKI has been responsible for the review and evaluation of the SKB programme since July 1st, 1992. The previous programmes - of 1987 and 1989 - were reviewed by the Swedish National Board for Spent Nuclear Fuel (SKN).

The main goal of the SKB RD&D efforts is to achieve an adequate and safe disposal of the radioactive waste and to demonstrate the safety of this disposal in a comprehensive analysis. Thus, the SKI evaluation focuses on the overall aim and direction of the RD&D efforts to achieve this goal in a feasible manner. Essential elements in this process include structure, strategy and planning.

The SKB programme is ambitious. SKB intends to fulfil stringent criteria (presently in a draft format) from the nuclear safety and radiation protection authorities by utilizing conservative design, in-depth defence, quantitative predictions and a thorough understanding of underlying phenomena. According to the plans presented in its RD&D Programme 92, SKB intends to make its selections of disposal system and site, and to carry out the construction planning for its encapsulation facility. SKI, on the other hand, in its role of reviewing SKB's RD&D programme, has made a comprehensive analysis of the plans for the continued SKB work. Consequently - and by the nature of the situation - the review reports contains numerous comments and points of criticism.

The purpose of the present paper is to present a few of the SKI conclusions that may be of general interest. Although the SKB RD&D Programme 92 deals with both spent fuel and other long-lived waste, this paper is limited in scope to spent fuel.

BACKGROUND

Sweden has twelve nuclear power reactors generating about 50 % of the electricity consumed. The spent nuclear fuel from these operations is stored at a central facility (CLAB) located close to the Oskarshamn nuclear power plant. The short-lived low and intermediate level radioactive waste is being deposited in the repository for reactor waste, SFR, located close to the Forsmark nuclear power plant. Transportation of spent fuel and nuclear waste is carried out using a purpose-built ship called M/S Sigyn.

The major remaining tasks - from the standpoint of waste - are the building of the encapsulation facility and the final repository needed for the disposal of the spent nuclear fuel.

The main alternative studied in Sweden for the repository system for spent fuel is the so-called KBS-3 method which originates from the mid-seventies. In this system, the spent fuel will be enclosed in thick canisters (containers) made of either copper or a combination of copper and steel. The canisters are

to be deposited in holes drilled through floors of tunnels with compacted bentonite clay around the canisters. The tunnels will be excavated in good quality crystalline rock at a depth of about 500 meters.

THE MAIN FEATURES OF SKB's RD&D PROGRAMME 92

In its review of SKB's R&D Programme 89 [7], SKN proposed that SKB should consider whether the disposal could be carried out in stages. During the spring of 1992, SKB changed its programme in accordance with this recommendation. During 1992, SKB has also published its first safety analysis in almost ten years, SKB 91 [8] and reported its conclusions from its comparative studies of disposal methods (PASS) [9].

In its RD&D Programme 92, SKB concludes that - within the next few years - the time will be ripe for selecting (the main alternaive for) the disposal method as well as candidate sites for the repository. SKB also intends to characterise these sites and to adjust the layout of the repository to local conditions. Furthermore, within a few years, SKB intends to construct a plant for the encapsulation of spent fuel, co-located with CLAB. Applications for detailed site investigations and for building the encapsulation plant are expected to be submitted to the authorities by the end of 1996. A time-table for the future activities (showing the earliest possible dates) can be found in Figure 1.

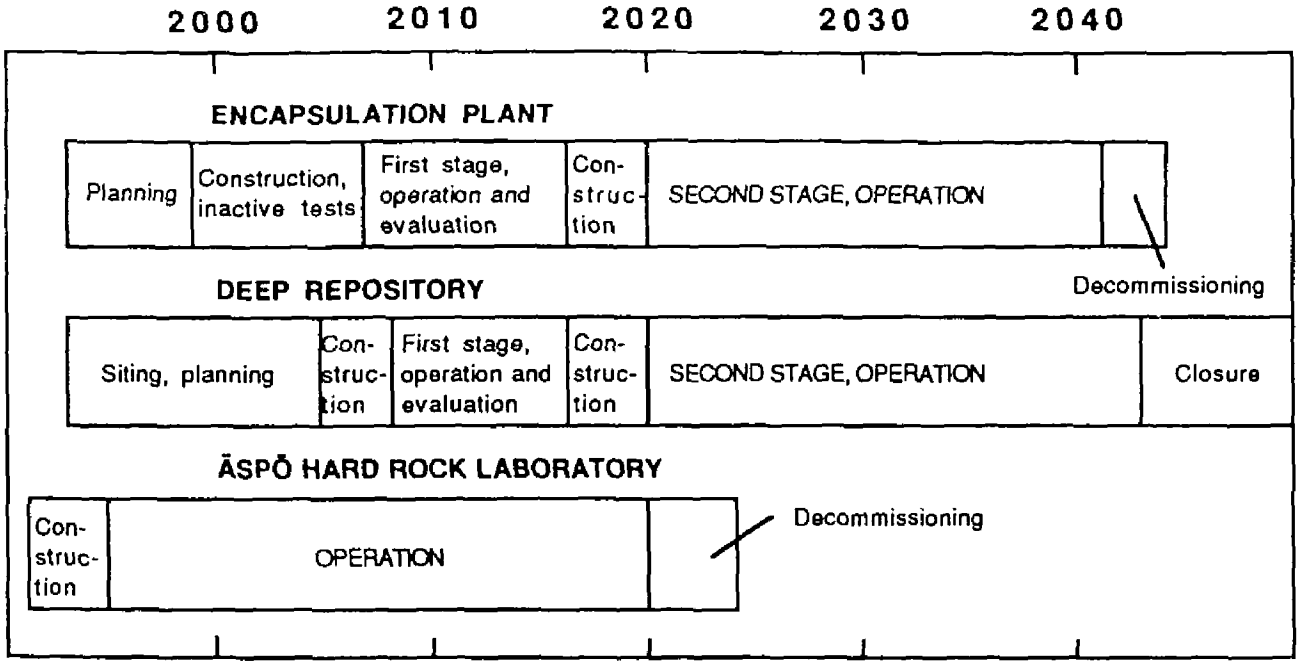

Figure 1. Approximate time-table showing earliest possible dates for future activities of SKB. The Äspö Hard Rock Laboratory is intended for experiments in a non-radioactive environment.

PREREQUISITES FOR THE WASTE MANAGEMENT

In its RD&D Programme 92, as well as in previous programmes, SKB has presented guidelines for the waste management, including the following:

- The radioactive waste products shall be disposed of in Sweden.
- The spent fuel shall be temporarily stored and finally disposed of without reprocessing.
- Technical systems and facilities shall meet high standards of safety and radiation protection as well as satisfy the requirements of the Swedish authorities.
- The systems for waste management shall be designed so that requirements on the control (safeguards) of fissile material can be satisfied.
- The work shall be guided by the regulatory authorities' continous review and assessment and the directives issued by them.
- The activities shall be conducted openly and with adequate public insight.
- Future safety should be based on a disposal method that does not require supervision and/or maintenance, since this would entail that generation after generation, far into the future, would have to retain knowledge of the waste and have the will, capacity and resources to perform such supervision and maintenance. We know too little about the society of the future to base long-term safety on this assumption.
- While working concretely and resolutely towards realizing the final disposal of all nuclear fuel, it is advisable to retain as much freedom of choice as possible with a view towards the possibility that alternative, and somehow, superior or simpler solutions may be found, or the possibility that there may be a re-evaluation of the current attitude towards the re-use (reprocessing) of some of the fissile materials in the fuel.

The above-mentioned points are relatively undisputed in Sweden and conform with the views of SKI.

It is, however, of interest to discuss the issue of how far the present generation should proceed in not only solving but also implementing a solution to the waste question.

It might seem reasonable that the generation that has benefitted from the utilisation of nuclear power also shoulders the responsibility of finding and im-

plementing a technical solution. It would also seem fair, that this generation should incur all the costs of the waste management.

On the other hand, new waste processing methods and disposal techniques will probably be developed. Premature and irreversible decisions should therefore be avoided, or it might become evident, within a foreseeable future, that the technique selected is not the best choice. However, postponement of the decision would imply that future generations will have to assume the responsibilities for implementing a solution. Furthermore, it appears impossible to guarantee the stability of monetary funds in a hundred year's perspective.

A STAGE-BY-STAGE APPROACH

In its review of SKB's R&D Programme 89 [7], SKN proposed that SKB should consider if the disposal could be carried out in stages, making it possible to re-evaluate the situation at the end of each stage. Thus, it was suggested that the first stage of the disposal should cover perhaps 5-10% of the total amount of spent fuel in the Swedish programme (which amounts to about 7 900 tonnes of spent fuel, calculated as uranium).

In its RD&D Programme 92 SKB has considered this recommendation and found that a stage-by-stage approach has significant advantages. Thus, the present generation should:

- develop a safe deep repository system
- find a suitable site
- build the repository, with retrievability, under strict supervision by the authorities and with requirements on long-term safety
- set aside funds to cover the future costs of the entire system

It would then be the responsibility - and freedom - of the next generation to:

- evaluate the experience from the first stage of the repository
- perform a new independent assessment of the long-term safety of a full-size repository
- evaluate alternative methods
- decide either to
  - continue with the second stage (full-size repository), or
  - to retrieve the spent fuel for alternative management

In its review, SKI finds that SKB in its approach is considering the uncertainty that will always be associated with the solution selected, as well as the uncertainty regarding the future development of our society, and the prospects of future generations finding a better solution. SKI therefore, in general, supports the plan put forward by SKB to proceed in stages.

In connection with the review of the previous programme, SKI pointed out that long-term safety cannot be demonstrated in a "pilot" facility. SKB shares this view. It should be recognised that that the first stage already implies major commitments, both financially and politically. A stage-by-stage approach does not imply a less stringent licensing procedure.

In its RD&D Programme 92 SKB states that one reason for its plan to carry out the final disposal in stages is that, by implementing the first stage, the disposal method would be "demonstrated" to the public and lead to a gaining of confidence of non-experts. This was not a reason put forward by SKN, which instead emphasised the possibility of obtaining feedback from working on a technical scale and the advantage of being able to make re-evaluations. It is SKI's view that the major reason for a stage-by-stage approach should not be to gain confidence. Instead SKB is recommended to consider in what sense and to what degree the approach actually is a stage-by-stage one and how experience might be gained and utilised by such an approach.

SYSTEM SELECTION

The Act on Nuclear Activities imposes requirements on comprehensiveness in the SKB programme. This means that alternative disposal methods should be followed up and studied.

In response to this requirement, SKB has recently published its PASS-study [9] in which the following four concepts are compared: deep boreholes, long tunnels, medium-long tunnels and KBS-3. In its RD&D Programme 92, SKB draws the following conclusions from the PASS study:

- KBS-3 will be maintained as the reference system and
- the copper/steel canister will be the reference design with the copper/lead canister as an alternative.

SKI realises that it is not feasible to carry out technical development over a long period of time along alternative routes. It is therefore necessary to focus the programme, to an increasing degree, on one method.

It is, furthermore, important that the selection of a method should be carried out in such a manner that it might stand the test of time. Thus, promising alternatives should be explored to such an extent that that the method selected can be shown to be either superior (from a technical, economical and safety-related point of view) to competing ones, or that the efforts required to develop an alternative can be considered unreasonably high.

Another important aspect of system selection is that the decisions made - and the reasons for these decisions - should be clearly documented. Thus, SKI

finds that the recently published PASS study [9] has increased the possibility for a well-founded system selection considerably.

SKI finds that deep geological disposal appears to be the only realistic approach. SKI also finds that the drilled deposition hole in KBS-3 as well as the size of the canister in KBS-3 appear to be feasible. SKI therefore draws the conclusion that it is reasonable for SKB to use KBS-3 as the reference system for the continued RD&D work. However, the potential for close-packing consolidated fuel rods in smaller canisters needs to be further evaluated.

In its RD&D Programme 92, SKB presents a plan for studies of alternative methods. However, further system studies in support of the detailed system selection are only dealt with briefly. The PASS study mentions that the alternatives compared are not optimised. This implies that the conclusions made by SKB should be regarded as preliminary - at least regarding the detailed system selection. SKI finds that further efforts in this area are urgently needed since results from such studies are prerequisites for other key activities, e.g. canister manufacturing and sealing. In its review, SKI therefore provides a number of comments and recommends SKB to supplement its RD&D Programme 92 in this respect.

PERFORMANCE ASSESSMENT

In its decision regarding the previous programme, the Government stated "that no commitment shall be made to a given handling and disposal method until sufficient knowledge has been obtained to fully grasp and assess the existing safety and radiation protection problems. If a new and better method emerges during the continued work, this should instead be chosen."

In the spring of 1992, SKB published its first safety analysis in almost ten years, SKB 91 [8]. This report has been informally reviewed by members of the staff at SKI [10]. To a large extent, this review was based on the experience from Project 90 which is a performance assessment carried out by SKI and published in 1991 [11].

The results from SKB 91 form the basis of much of the strategy of SKB. However, some of the conclusions are not undisputed.

Thus, SKB states that SKB 91 shows that a repository constructed deep down in Swedish crystalline basement rock with engineered barriers possessing long-term stability fulfils the safety requirements proposed by the authorities with ample margin. SKB also concludes that the safety of such a repository is only slightly dependent on the ability of the surrounding rock to retard and sorb leaking radioactive materials. Moreover, SKB finds that the studies and investigations that have been conducted show that the requisite properties exist in many places and that there are many sites which possess

the necessary geological and technical prerequisites for the construction of a safe repository.

The major reason for the reluctance of SKI to fully accept these conclusions is that SKI finds the analyses in SKB 91 to be too limited. All pertinent processes that affect the function of the repository need be analysed and the underlying basic knowledge needs be compiled in such a way that the source data and references can be identified.

In its review reports, SKI therefore recommends SKB to improve its accounting for the justification of relations, models, and data that form the basis of the analysis. SKI strongly advices that SKB without delay should analyse the properties of the copper/steel canister as well as the chemical and physical processes in the near field. Also, SKI suggests that SKB should develop its description of the far field.

SKI emphasises the significance of recurrent safety analyses both for defining the direction of the supporting R&D work and for integrating the technical activities. Thus, safety analyses can be utilised - to a larger extent than previously - as a tool to identify needs for further knowledge, as well as areas where the level of knowledge is satisfactory. Safety analyses also have an important role to play in integrating the encapsulation and the repository projects as well as the continued R&D work regarding e.g. system selection, canister design, encapsulation, and siting. SKI strongly recommends SKB to perform such analyses.

CANISTER MANUFACTURE AND ENCAPSULATION

In its RD&D Programme 92, SKB has presented plans for the manufacturing and sealing of the containers, see Figure 1. The most promising methods for canister manufacturing are extrusion of a billet to either a pipe or a canister, as well as hot rolling, bending, and welding. Electron beam welding technology is under development by SKB for both the manufacturing and the sealing of the canister. An alternative method for sealing is friction welding. Ultrasonic techniques as well as x-ray tomography are being developed for the inspection of welds. Some of these efforts have been identified as being highly prioritised by SKB.

SKI points out that the methods mentioned by SKB are still under development and that the pace of progress so far raises the question of whether SKB's time-table is actually realistic. Moreover, not much is written in the program as to how and where the canisters will be manufactured or how the encapsulation facility will actually be designed and constructed.

SKI therefore recommends SKB to further analyse the technology and logistics of canister manufacturing and sealing as well as related activities, and to supplement its RD&D Programme 92 in this respect.

SITE SELECTION AND GEOLOGICAL DISPOSAL

A summarised outline of SKB's planned activities on site selection, site investigations, excavation, and operation is given in Figure 1.

In general, SKI finds that SKB's plans for site selection and geological disposal is a good starting point for the continued planning of the repository project. Furthermore, it is essential for the repository design that there should be information available from investigations of possible sites. It is therefore reasonable that SKB should initiate activities that provide such knowledge.

On the other hand, it should be emphasised that as soon as the commitment to any specific site becomes considerable, there will be high demands regarding the basis needed for the planning. It is SKI's opinion that the initiation of detailed investigations implies such a commitment. An application to start detailed investigations can be supported by SKI only if decisive uncertainties regarding the safety of the repository are resolved and, if there is an appropriate plan for the investigations.

SKI expects that assessments of the suitability of sites based on technical, geoscientific, and societal factors will show that certain parts of Sweden are less suitable than others for the design and construction of a repository. SKB is therefore recommended to initiate an analysis of the suitability of sites with the purpose of identifying areas that are likely to be of less interest.

On the other hand, SKI also emphasises that it is not meaningful to attempt a ranking of sites with the purpose of finding the most suitable one. Several important properties, e.g. relating to groundwater flow and retention of radionuclides, can probably not be determined before extensive investigations at a site have been completed. SKI therefore realizes that SKB will need to make its selection of a site on an - at least partially - incomplete basis.

This calls for a considerable flexibility in the siting process. Further investigations might yield results that imply that a site has to be abandoned. It is therefore important for SKB to avoid sites for which the prognosis may be unfavourable.

One important basis of the application to carry out the detailed site investigations is the design and construction of the repository. Important questions include the layout to be used (tunnel systems on one or more levels), the method of excavation (tunnel boring or blasting), and the method for applying the bentonite buffer (in situ or by using pre-compacted blocks).

It is SKI's impression that the time-table presented may be overly optimistic. SKI therefore stresses the importance of SKB proceeding with its work with due regard both to the time-table and to the actual progress made.

SUPPORTING R&D

In general, SKI finds the supporting R&D work of SKB to be comprehensive and of high quality - even in an international perspective. This provides no guarantee, however, that all pertinent questions have been resolved when results are needed.

As mentioned above, the approach available to determine whether safety-related issues have been actually resolved consists of systematic and scientifically supportable performance assessments. In this context, SKI makes the general observation that such analyses could be utilised to a greater extent in the SKB programme in order to improve the coordination between the different research efforts.

Another comment of a general nature concerns validation, which, to SKI, is much more than merely a comparison between results from modelling and observations. Several routes should be pursued in order to attempt evaluations of whether or not a model describes reality in an adequate manner, e.g. reliability of parameters used, consistency of all data used and consistency between the results obtained for different models. Furthermore, the validity of a model should also be tested against available scientific knowledge, different alternative hypotheses, and against the relevance of the input data intended to be used in the model.

For the studies on the behaviour of spent fuel in a repository environment, SKI finds a need for a higher degree of integration between modelling and experimental studies.

Regarding the canister, SKI suggests further studies regarding the details of the future environments and the composition and properties of the surface layer that may form on the copper canister. Such information is essential for assessments of any possibilities of local corrosion and stress corrosion.

In all essential aspects, SKI supports SKB's programme on the bentonite buffer material. There is, however, a need to develop technology for pretreatment and emplacement of the buffer.

In the areas of the geosciences, SKI emphasises the need for integration between structural geology, hydrology, geochemistry, and rock mechanics. Furthermore, the need for prioritisation is especially urgent in the area of site characterisation since most of the measurable data is of little *direct* significance to the safety. It is frequently difficult to collect data that can be used directly in the form that they are obtained, and it is also often difficult to make the appropriate interpretations needed for other data that cannot be used directly. A good example of this is the ability of the rock to retard radionuclides which is highly important but very difficult or perhaps even impossible to

measure. Further developments of techniques for site characterisation and evaluation are recommended.

With regard to the work planned for the Äspö Hard Rock Laboratory, SKI stresses the importance of the utilisation of the results from the experiments conducted at Äspö for the subsequent pre-investigations at the disposal site.

CONCLUSIONS

In general, SKB finds that the SKB programme is directed in a manner that is pertinent with regard to the overall objectives. However, SKI requests a response from SKB regarding SKI's recommendations, as well as certain supplements to the program within about one year.

Thus, SKI finds that the high ambitions of SKB, in combination with the shift towards technology and the somewhat optimistic time-schedules, call for interaction relating to the SKB programme to take place more frequently than every third year. SKI therefore requests that SKB should promptly consider the comments from SKI and present the results of its considerations. Moreover, SKI requests supplementary RD&D plans regarding design and construction of the container and the encapsulation facility. SKB is also requested - before any sites are presented to SKI - to present a suitable process for site selection. In this process, areas that do not appear feasible for a deep repository should be identified.

SKI concludes that a complete and comprehensive performance assessment - with a substantially wider scope than that of SKB 91 - is required before any strong commitments can be made regarding the design and construction of canisters and the encapsulation facility as well as regarding investigations of a candidate site. SKI also requests a plan for this work - containing objectives, limitations in scope and other prerequisites. One important aspect of such a safety analysis is to define a direction for subsequent RD&D work.

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SKB = the Swedish Nuclear Fuel and Waste Management Company
SKI = the Swedish Nuclear Power Inspectorate

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