Handling of Spent Nuclear Fuel and Final Storage of Vitrified High Level Reprocessing Waste

Summary

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HANDLING OF SPENT NUCLEAR FUEL AND FINAL STORAGE OF VITRIFIED HIGH LEVEL REPROCESSING WASTE

SUMMARY

In april 1977 the Swedish Parliament passed a Law, which stipulates that new nuclear power units can not be put into operation unless the owner is able to show that the waste problem has been solved in a completely safe way. The task of investigating how radioactive waste from a nuclear power plant should be handled and stored was previously the responsibility of the National Council for Radioactive Waste Management (PRAV). This Council was formed in November 1975 as the result of a proposal made by the Government Committee on Radioactive waste (the AKA Committee).

In response to the Government bill proposing the Law, the power industry decided in December 1976 to give top priority to the investigation of the waste problem in order to meet the requirements of the Law. Therefore, the Nuclear Fuel Safety Project (KBS) was organized. The first report from the KBS project entitled "Handling of spent nuclear fuel and final storage of vitrified high level reprocessing waste" was submitted in December 1977.

The requirements of the Law regarding completely safe storage

The Law stipulates that the owner of a reactor must show how and where a completely safe storage can be provided for either the high level reprocessing waste or the spent, unreprocessed nuclear fuel. "The storage facility must be arranged in such a way that the waste or the spent nuclear fuel is isolated as long a time as is required for the activity to diminish to a harmless level". "These requirements implies that measures should be taken which, during all phases of the handling of the spent nuclear fuel, can ensure that there will be no damage to the ecological system".

In the strictest meaning of the word, no human activity can be considered completely safe. The fact that such an interpretation of the wording of the Law was not intended is evident from the formulation of the statements made by the Government in support of the Law indicating that the storage of waste shall fulfil "the requirements imposed from a radiation protection point of view and which are intended to provide protection against radiation damage". Questions regarding protection against radiation damage are regulated by the Radiation Protection Act. This means that the requirements imposed on the handling and storage of high-level waste are, in principle, the same as those which apply for other activities involving the handling of radioactive substances.

This interpretation is supported by the statements made by the Committee of Commerce and Industry in its review of the Law, in which the Parliament also concurred. The Committee thus finds the expression "completely safe" to be warranted in view of the very high level of safety required, but considers that a "purely Draconian interpretation of the safety requirement" is not intended. Draconian means "excessively severe, inhuman".

The requirements of the Law regarding the scope of this report

In the statements made by the Government in support of the Law it is said: "The descriptions to be submitted by the owner of the reactor shall include detailed and comprehensive information for the evaluation of the safety. Consequently, over-all plans and drawings will not suffice. Furthermore, it should be specifically stated in which form the waste or spent nuclear fuel is to be stored, how the storage is to be arranged, how the transportation of the spent nuclear fuel or of the waste will be carried out and whatever else may be required in order to ascertain whether the proposed final storage can be considered completely safe and possible to construct."

To fulfil these requirements, this report presents relatively detailed information on the design of facilities and the transportation systems which are part of the handling and storage chain. Certain parts of this information are relatively unessential for evaluating the safety of the waste storage, while others are vital. A detailed evaluation of the safety aspects of the proposed design is presented in a safety analysis. The handling and processing carried out abroad is also described, although more in general.

The alternatives given in the Law

The Law requires a description of the handling and final storage of either the high level reprocessing waste or the spent, unreprocessed nuclear fuel. This report deals with the first alternative. An application to the Government to charge nuclear fuel to a new reactor based on this alternative must, in addition to this report, include an agreement which covers in a satisfactory manner the anticipated need for reprocessing of spent nuclear fuel. This aspect is, however, not dealt with in this report.

A report on the second alternative, i.e. spent unprocessed fuel, is planned for publication during the firsthalf of 1978.

Layout of the report

This report has been divided into five volumes as follows:

I General
II Geology
III Facilities
IV Safety analysis
V Foreign activities

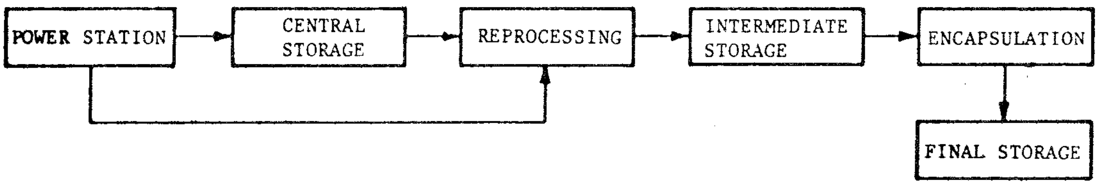
In order to provide a basis for the report, KBS has carried out a great number of technical-scientific investigations and surveys. The results of these are published in KBS Technical Reports. 56 volumes of these reports have so far been published, (see volume I, appendix 3.)

Volume I (General) can be read independently of the other volumes. It comprises mainly a summary of the more detailed reports presented in volumes II, III and IV.

Chapter 3 in volume I is a summary of the proposed method for handling and storage of nuclear fuel and high-level waste from the nuclear power plant fuel pools up to and including final storage in Swedish bedrock.

Chapter 13 in volume I summarizes the more detailed presentation of the safety analysis in volume IV. This chapter summarizes the safety evaluations of the whole handling chain from a radiological point of view. The effects of radiation have been calculated for normal conditions and for accidents. Special emphasis has been placed on the long-term aspects of the final storage of high level waste.

Final stage of nuclear fuel cycle



The handling chain for spent nuclear fuel and high-level reprocessing waste is illustrated in the above block diagram.

Nuclear power stations always have storage pools for spent nuclear fuel. They are needed so that the fuel can be discharged from the reactor and also to provide storage space for spent nuclear fuel before it is dispatched for reprocessing or for storage elsewhere.

Today, the available reprocessing capacity is limited, and it is not clear to what extent spent nuclear fuel will be reprocessed. As a result, it is necessary to extend the storage capacity for spent nuclear fuel. For economic reasons and for the planning of the back end of the nuclear fuel cycle, the extended capacity should not be provided at the nuclear power stations. Instead, a central fuel storage facility should be constructed. This facility is needed regardless of whether the spent nuclear fuel is to be reprocessed or not before final storage. The fuel can be stored in this facility for about ten years.

As a rule, radioactive waste must be stored in the country where it is produced. The high-level reprocessing waste will be sent back to Sweden in vitrified form in 1990 at the earliest. The vitrified waste will be contained in stainless steel cylinders having a diameter of 40 cm and a height of 1.5 m. If all of the fuel is reprocessed, 9 000 cylinders will be obtained from 13 reactors that have been in operation for 30 years.

The waste cylinders will be placed initially in an intermediate storage facility where they will remain for at least 30 years before being transferred to the final storage. The cylinders will be kept in dry conditions in the intermediate storage facility, and radiactive substances cannot be released to the environment. During this storage period, the amount of heat generated by the waste will be reduced by half, thus simplifying final storage. Intermediate storage postpones the date when final storage must commence, thus providing more time to optimize the final storage method. A longer storage period than 30 years is entirely possible. Such a prolonged storage period is considered in France, for example. However, intermediate storage requires a certain amount of supervision, even though this supervision is very limited.

It is planned that the final storage, which will not have to go into operation until 2020 at the earliest, will be constructed in rock about 500 metres underground. The facility is designed in such a way that it can be sealed and ultimately abandoned. In the final storage, the waste will be exposed to the ground-water in the rock. After intermediate storage and before the waste cylinders are transferred to the final storage, they will therefore be encapsulated in a canister made of titanium and lead. These materials have good resistance to corrosion.

The siting of the facilities for the various handling stages may be arranged in different ways, in accordance with what is deemed to be practical.

Spent fuel has already been shipped abroad from Sweden for reprocessing. Similar transports will also be required between the various phases of the handling. The design and procurement of transport casks and vehicles thus form part of the waste handling.

Geological requirements for a final storage

Extensive investigations and tests have been carried out to determine the suitability of Swedish bedrock for final storage. In this connection, interest has been concentrated on precambrian chrystalline rocks. In other countries, studies have been made of storage in salt, shale and clay depending upon the natural prerequisites of each country.

Field investigations have been carried out at five sites, three of which have been selected for more detailed studies. A number of holes have been drilled to a depth of 500 metres. It should be emphasized that the objective of this work was not to find a site now to be proposed for final storage. The purpose was to show that suitable bedrock is available within Sweden for such a facility.

The factors that will determine the suitability of a rock formation for final storage are its permeability and strength, the composition of the groundwater and its flow pattern and the delaying effects on radioactive substances when groundwater passes through cracks in the rock. Of special interest is also the risk of rock movements which could affect the pattern of groundwater flow or damage the encapsulated waste.

Assessing these factors, a depth of about 500 metres is considered to be suitable. At this depth, the bedrock contains fewer cracks and has lower water permeability than closer to the surface. This depth also gives a satisfactory protection against acts of war and such extreme events as meteorite impacts and the effects of a future ice age.

The investigations and surveys carried out have shown that the three sites selected offer satisfactory conditions for final storage. At these sites, the bedrock consists of Sweden's most common types of rock - granite, gneiss and gneissified granodiorite. Consequently, it is reasonable to expect that rock formations with equivalent conditions are also available at many other places within Sweden.

Safety of the handling chain

The extensive safety analysis carried out has shown that the release of radioactive substances which could occur in connection with normal operation or with an accident in the different stages of the handling chain within Sweden, would be insignificant in comparison with corresponding conditions at a nuclear power station. This is because the vitrified waste has a low temperature and is encapsulated without overpressure. Consequently a sudden and extensive release of radioactivity can not occur. The safety of the steps of the handling chain, which will be carried out abroad (reprocessing and vitrification), will be evaluated by Government authorities in the country concerned and are dealt with in a more superficial manner in this report.

Radioactive substances from a final storage can only be released by the groundwater. The final storage must be arranged in such a way that such a release cannot damage the ecological system. It is then important to remember that the activity of the radioactive substances in the waste diminishes very slowly. The final storage is therefore arranged so that the migration of these substances is either prevented or delayed for a long time, thus ensuring that the concentration of radioactive substances which may reach the biosphere will be harmless. For this reason, the design of the final storage provides for a number of successive barriers.

For any release of radioactive substances in the waste to the environment, the groundwater must first penetrate both the canister made of titanium and lead and the stainless steel container.

These materials have excellent resistance to corrosion. The waste cylinders will be placed in holes drilled into good-quality rock and surrounded by a buffer material consisting of quartz sand and bentonite. Since the buffer material has a low permeability, only very small amounts of water will be able to affect the encapsulated waste.

In the event of the penetration of the canister and the stainless steel container, the groundwater can affect the vitrified waste. However, the glass has a very low leaching rate under the conditions that prevail in the final storage.

The low flow rate of the groundwater, the long distance which the water must cover to reach the biosphere and the chemical processes in the crack system in the rock and in the buffer material provide effective barriers that prevent and delay the migration of the radioactive substances. Moreover, dilution in huge volumes of groundwater will take place before entry into the biosphere.

The safety of the final storage of high-level waste is dominating the safety issue. The safety analysis is based, in each phase that entails uncertainty, on assumptions and data that provide a reassuring margin of safety. Possible routes for the migration of radioactivity to the biosphere have been studied in the safety analysis, and the group of people which can be exposed to the highest level of radiation has been identified (the critical group). The critical group consists of persons taking their drinking water from a deep well drilled in the vicinity of the final storage. Under unfavourable circumstances this group can be exposed to a maximum radiation (individual dose) of 13 millirem per year in addition to natural background radiation.

This maximum additional dose of 13 millirem per year will not occur until after about 200 000 years. This long delay is caused by the retainment in the buffer material and the rock of the radioactive substances providing the highest additional dose. Radioactive substances which are not delayed relative to the flow of water in the bedrock could come into contact with the biosphere after only some hundreds of years. However, the additional dose attributable to these substances is very much lower than the value given above.

An individual dose of 13 millirem is considerably lower than the dose recommended by the International Commission on Radiological Protection (ICRP) as the upper limit for permissible additional doses for individuals namely 500 millirem per year. This limit is intended to protect individuals against delayed radiation effects such as cancer and genetic effects.

Governmental authorities impose lower limits for the operation of nuclear power plants. In Sweden, operational restrictions can be imposed and other measures taken if the additional dose tends to exceed 50 millirems per year for people living near the power plant.

In order to reduce radiation exposure as much as reasonably possible, the Swedish Radiation Protection Institute requires that nuclear power plants be designed and constructed so that the expected additional dose for the critical group living in the vicinity of the plant is less than 10 millirems per year.

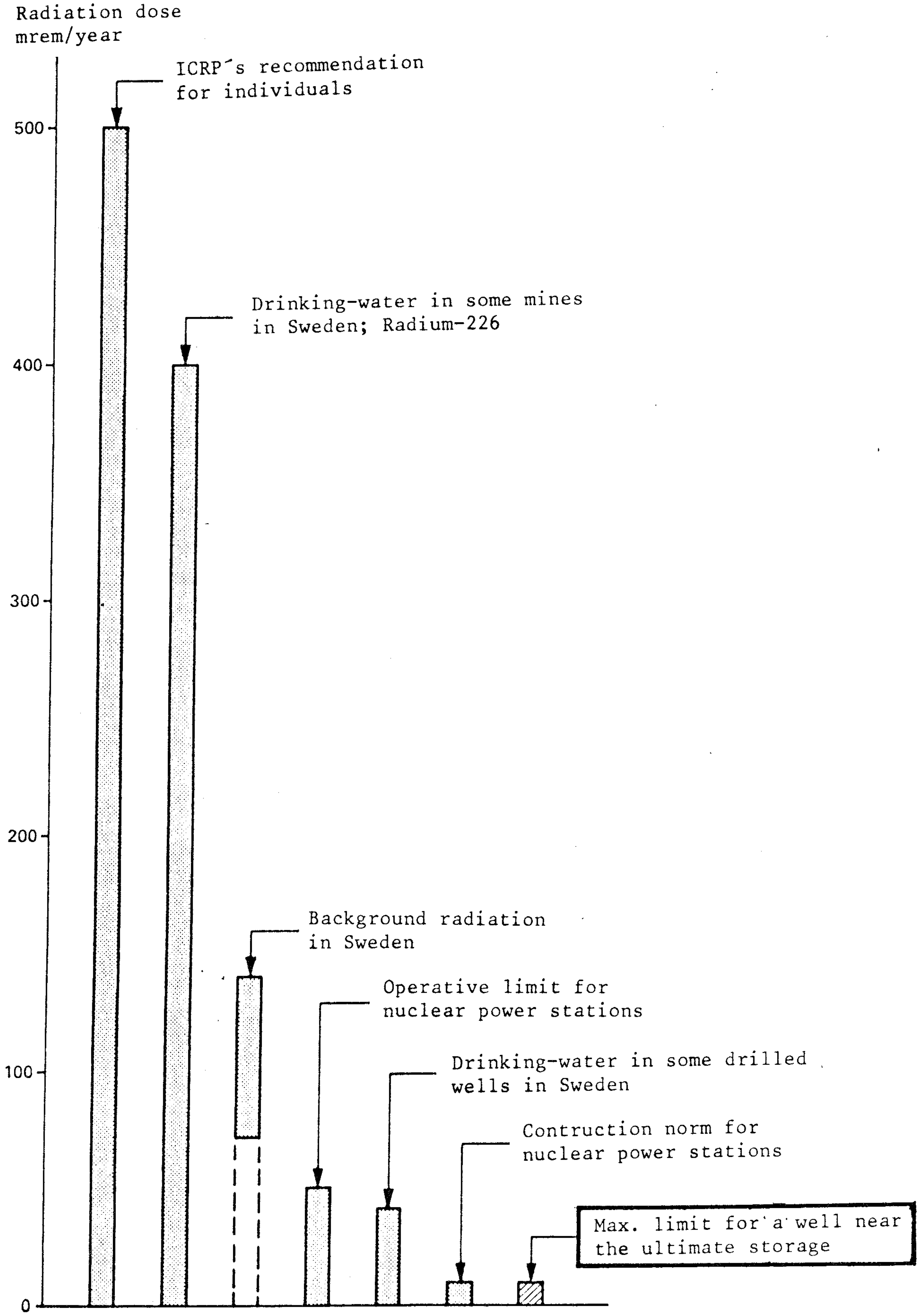
As mentioned above, the assumptions and data used in the safety analysis were selected with safety margins. It is considered probable that the dosage will be approximately 1/100th of the maximum value of 13 millirems per year given above. One reason for this is that the very low rate of water flow in the bedrock is not sufficient to break through the encapsulation or leache the vitrified waste at the rates assumed in the safety analysis presented in this report. However, verification of this lower value would require additional investigations not yet been completed.

The following bar-chart shows the dose rates mentioned above. It also indicates the dose rates from natural radiation in Sweden. As appears from the bar-chart local variations in natural radiation are considerably greater than the maximum contribution from a final storage of high-level waste obtained from 13 reactors which have been in operation during 30 years. The bar-chart also shows that the doses obtained from radium in natural drinking water in Sweden often lies considerably above the level reported for a final storage.

Moreover, the safety analysis shows that radiation doses for large population groups attributable to a final storage will be virtually insignificant and that the longterm effects on health will be negligible.

The design of the back end of the nuclear fuel cycle presented in this report thus fulfils the requirements set forth in the Law for a completely safe final storage of the high-level reprocessing waste.

Stockholm November 1977
NUCLEAR FUEL SAFETY PROJECT (KBS)


Radiation dose
mrem/year
500
400
300
200
100
0
ICRP´s recommendation
for individuals
Drinking-water in some mines
in Sweden; Radium-226
Background radiation
in Sweden
Operative limit for
nuclear power stations
Drinking-water in some drilled
wells in Sweden
Contruction norm for
nuclear power stations
Max. limit for a well near
the ultimate storage

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