

## Feasibility of retrieval of radioactive waste from a salt-mine repository: an overview\*

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### Abstract

Two options for permanent disposal of radioactive waste in rock salt are distinguished: the salt-mine repository and the deep boreholes and cavity combination. Of these, the salt-mine repository is treated in some detail.

The results of a feasibility study of waste retrieval from a salt-mine repository are reviewed. This study was carried out in the framework of the 'OPLA' research programme of the Netherlands. Three disposal concepts have been considered: a modification of a concept for permanent disposal, a concept incorporating thick-walled overpacks and a concept which involves cased boreholes. Circumstances that may influence the retrieval operation (e.g. salt temperature, and volume and weight of overpacks) are taken into account. As a conclusion, it appears technically feasible to retrieve radioactive waste from a salt-mine repository, provided that the period between disposal and retrieval is not longer than a few hundred years.

### Introduction

For the underground disposal of radioactive waste three geological media are usually mentioned: rock salt, clay and granite. In the Netherlands, the attention has been focused mainly on rock salt, because subsurface salt occurrences are common in the country. The consideration of rock salt as a potential host medium, moreover, is influenced by three favourable properties:

- Rock salt has a relatively high thermal conductivity. This implies that temperature rises, resulting from the heat generated by the high-active waste, will be limited.
- In rock salt, the absence of flowing water will ensure, for a very long time, a high degree of isolation from the biosphere of the highly toxic components to be buried in the salt.
- Rock salt exhibits creep behaviour. Excavations in the salt tend to be closed with time under the influ-

ence of the pressures prevailing in the underground. This self-healing effect enhances the quality of the isolation of materials brought into a salt environment.

The choice of salt structures for underground disposal of radioactive waste has been limited to salt domes. However, salt pillows and even salt layers can also be considered as potential host structures (Figure 1).

A rough classification of the radioactive waste to be buried is as follows:

1. High-active, heat-generating waste. The most important type of high-active waste is the solid, vitrified waste resulting from the reprocessing of the spent fuel elements of nuclear power plants. In the Netherlands, this reprocessing waste is denoted as KSA (kernsplijtingsafval, nuclear fission waste). The heat generated by the KSA decreases exponentially, with a half-life of about 30 years (Van den Broek 1989). Obviously, the total amount of KSA depends on the nuclear energy scenario. Thirty years of operation of the current 500 MWe nuclear power installed in the Netherlands at the Borssele and Dodewaard plants will amount to about 60 m<sup>3</sup>

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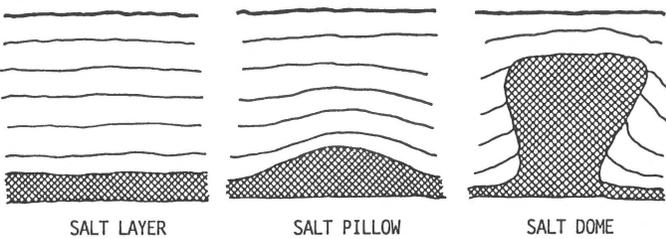


Figure 1. Vertical profiles through common rock-salt structures.

of KSA, i.e. 300 canisters of 200 l (Van Hattum en Blankevoort 1986). Some types of HAVA (hoog-actief vast afval, high-active solid waste) also generate heat, although the energy output per canister is much less.

2. Non-heat-generating waste. Apart from the less active part of the HAVA, the non-heat-generating waste consists of MAVA (middel-actief vast afval, medium-active solid waste) and LAVA (laag-actief vast afval, low-active solid waste). The volume of non-heat-generating waste for the nuclear energy scenario given above would be about 50 000 m<sup>3</sup> (Van Hattum en Blankevoort 1986). This volume includes a waste production during an arbitrary period of 70 years by hospitals and laboratories.

The KSA is enclosed as vitrified waste in thin-walled stainless-steel canisters (length 1.34 m, diameter 43 cm, weight 480 kg). The other waste types consist of canisters, sometimes with a large diameter (1.25 m; HAVA), of drums (MAVA, LAVA) and of bulk waste (LAVA). From the mining-engineering point of view it has to be taken into account that the heat-generating waste must be distributed over a large salt volume, in order to prevent large temperature rises to occur.

### Underground disposal options

In this section, we will assume that the aim of underground disposal is permanent disposal, so that isolation of the waste from the biosphere is guaranteed for a long time. The subject of retrievability will be discussed further on.

Two options for permanent disposal in rock salt can be distinguished (OPLA 1989; Van den Broek 1989; Figure 2):

1. Salt-mine repository. This can accommodate all waste categories. In such a mine, the heat-generating waste is envisaged to be emplaced in

boreholes drilled from galleries at a lower level, while the non-heat-generating waste will be located in excavations at a higher level. In this way the most active waste is the most remote from the biosphere, and the heat generated by this waste will have minimal influence on the mining operations.

2. Deep boreholes and cavity combination. In this option the heat-generating waste is buried in deep boreholes drilled from the surface, while the non-heat-generating waste is disposed of in one or more salt cavities. Disposal in such a cavity in rock salt may take place (i) in a brine-filled cavity and (ii) in a cavity from which the brine has been removed.

The combination of three disposal techniques (mine, deep boreholes, cavity) with three types of salt structures (dome, pillow, layer) leads to a total of nine possibilities. In practice, however, some pairs, e.g. a mine in a layer or a cavity from which the brine has been removed in a layer, are not feasible because of instability of the facility or unacceptably high salt-flow rates (Van Hattum en Blankevoort 1986). Only the deep-boreholes technique can be applied in all structure types.

Following the OPLA research report (1989) on the disposal of radioactive waste, preference was given in the Netherlands to the disposal of such waste in a mine. Therefore, the attention in this paper is focused on the salt-mine repository.

### Salt-mine repository

In the Netherlands, two studies have been carried out on the design of a salt-mine repository for radioactive waste:

- A design based on disposal in a model salt dome with a height of about 3000 m and a diameter of 1500 m (Hamstra & Velzeboer 1978). The assumed energy scenario was 40 years of operation of 25 000 MWe installed nuclear power. It has to be emphasized that this scenario is not related to an actual nuclear power programme of the Government of the Netherlands.
- Designs based on typical data concerning a salt dome, a salt pillow and a salt layer (Van Hattum en Blankevoort 1986). In this study two nuclear energy scenarios were distinguished:
  - no new nuclear power plants, 500 MWe nuclear energy scenario;
  - extension of the installed nuclear power from 500 to 3500 MWe.

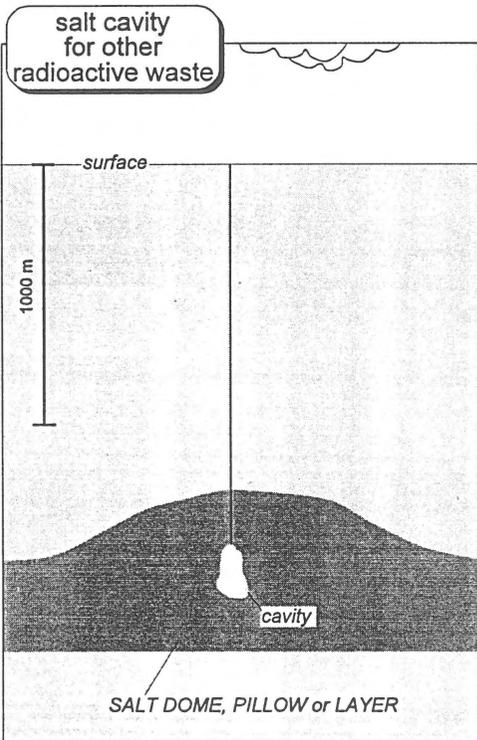
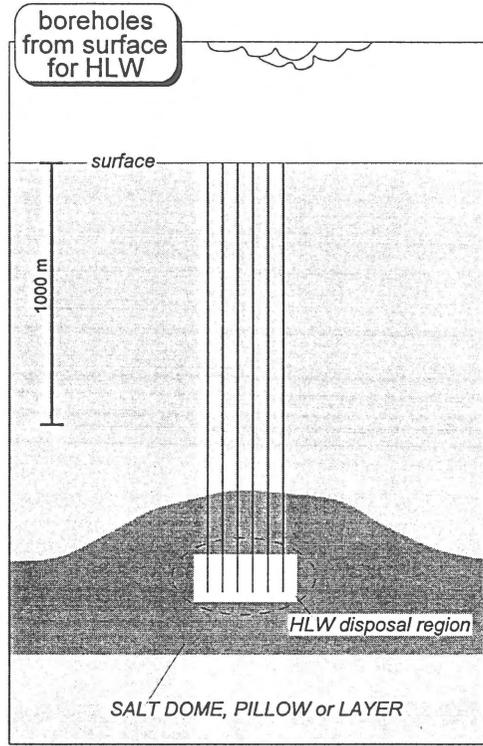
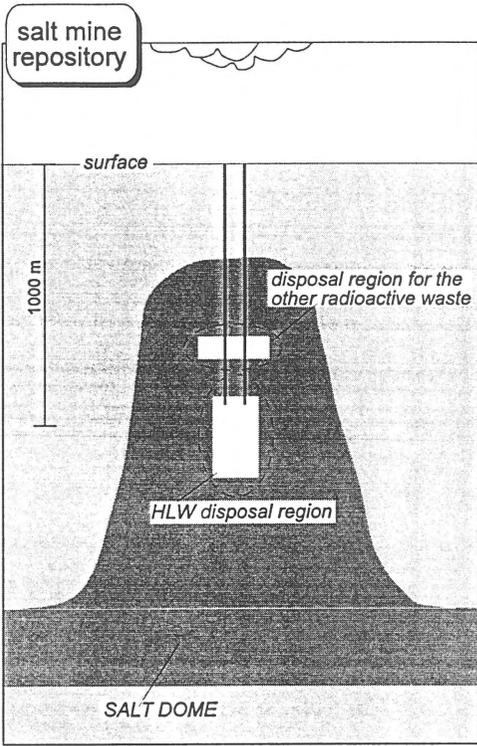


Figure 2. The two options for underground disposal of radioactive waste in rock salt: the salt-mine repository, and the combination of boreholes from the surface and a salt cavity. HLW = KSA = reprocessing waste.

Important characteristics of the designs in both studies are the following:

- Limits are defined to ensure that a sufficient volume of rock salt is present between the disposal region and the boundaries of the salt. In the Van Hattum en Blankevoort study the minimum distances between the disposal region and the top, side and base of the salt structure are taken as 300, 200 and 100 m, respectively.
- The heat-generating waste is emplaced in vertical boreholes with depths of several hundred metres. The holes are drilled from a gallery according to a dry procedure. Simultaneously with the emplacement of the waste canisters, crushed salt is brought into the borehole. This salt will gradually be compacted. In the long term, each canister will be surrounded by a material closely resembling natural rock salt, and be separated from the adjacent canisters above and below by a small, compacted salt volume.
- The non-heat-generating waste is emplaced in excavated rooms. Crushed rock salt is added to the waste, so that also here the waste will eventually be embedded in a material similar to natural rock salt.
- The galleries through which the waste has been transported to the boreholes or excavated rooms, are also backfilled. Use is made of dams constructed with pre-compacted salt bricks, bitumen and other materials.
- The KSA generates heat. Consequently, the salt temperature will gradually rise as soon as the KSA canisters have arrived at their final position.

Figures 3–5 illustrate some design characteristics. In Figure 3 a sketch is presented of a gallery with a borehole for KSA canisters. To accommodate the canisters, the borehole diameter must be of the order 60–70 cm. Figure 4 shows a mine level with excavated rooms, a gallery system and one of the shafts. Figure 5 shows graphs of the temperature rise in salt due to the heat generated by the KSA. Dependent on the design parameters and the prevailing circumstances (primarily: initial KSA heat generation, borehole length, and distance between boreholes), the maximum temperature rise will be between, say, 30 and 150 °C (Van den Broek 1989).

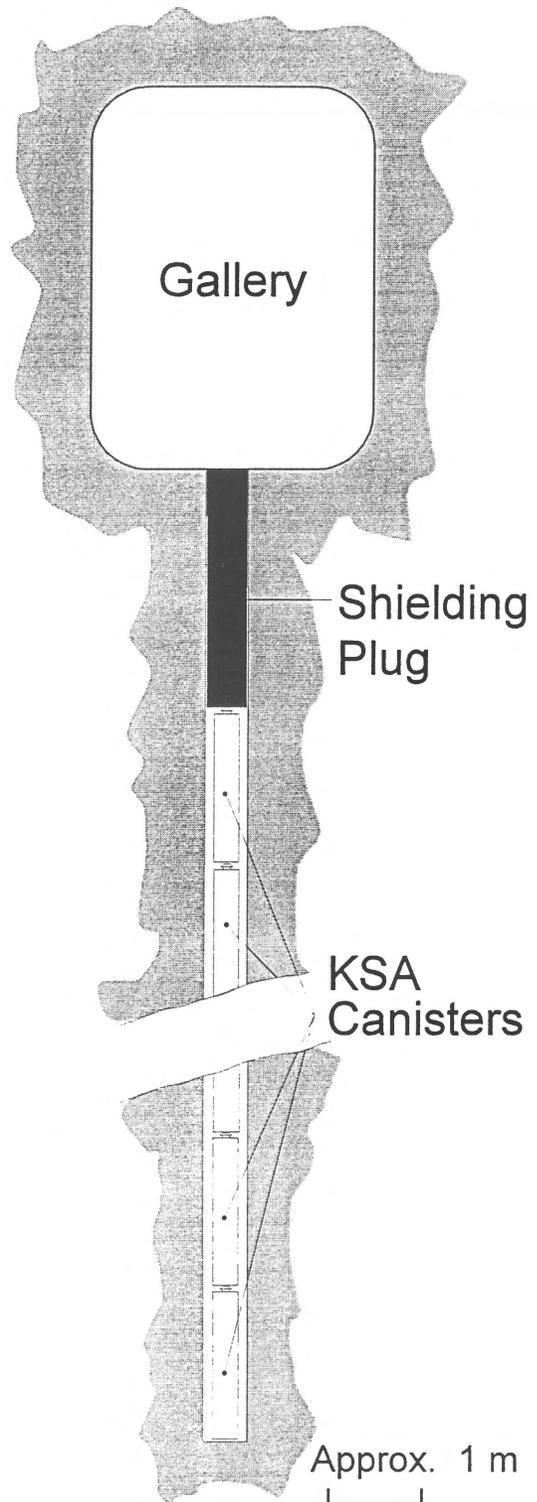


Figure 3. Disposal of KSA in a dry borehole.

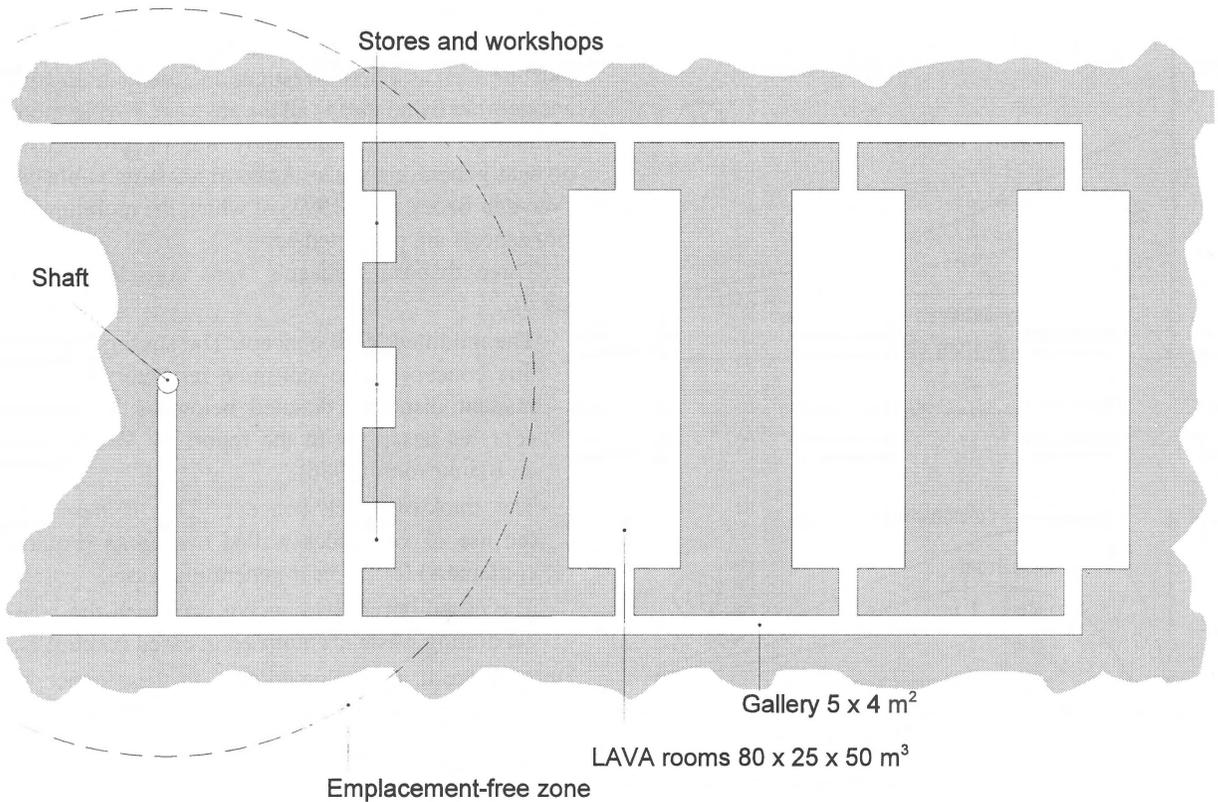


Figure 4. Map showing the lay-out of a LAVA (low-active solid waste) disposal area. Source: Van Hattum en Blankevoort (1986).

## Retrievability of radioactive waste

### General remarks

In the Netherlands, retrievability of radioactive waste has become a precondition as a result of the Government's position of May 1993 which states that disposal in the deep underground of high-toxic waste should 'not be irreversible' (Norder 1993). In the United States of America, the retrieval of radioactive waste is covered in the Code of Federal Regulations (CFR 1990). This code prescribes that it must be possible to retrieve, for a period of 50 years, the spent fuel from nuclear power plants buried in the underground. Spent fuel is not reprocessed in the USA and is therefore the most important type of radioactive waste. The predominant reason for retrieval in the USA is economic: the future value of the materials present in the spent fuel could be considerable. Another argument for waste retrieval is, that this provides an additional guarantee for the safety of the disposal (Van den Broek et al. 1991).

For a retrieval operation, one may consider a short time of, say, a few days in the case of recovery from a facility with a high accessibility, to a long time of, say, 20 years in the case of re-mining. In the USA, the period allowed for waste retrieval equals the period necessary for the disposal operation; this implies that the retrieval period can be fairly long. For a rapid retrieval operation, the accessibility of the waste needs to be high: it must be relatively easy to recover the waste from its geological environment. This can be realized by not, or only partly, closing the transport galleries and shafts in the repository. Such procedures differ from those to be used in permanent disposal. Evidently, this difference in procedures will have an effect on safety, notably for the period during which it must remain possible to retrieve the waste. In this connection, it seems advisable to avoid a high degree of accessibility during a long time.

In order to discuss the retrievability of radioactive waste, definitions of relevant periods have to be introduced. Other definitions are possible, but here the following have been chosen:

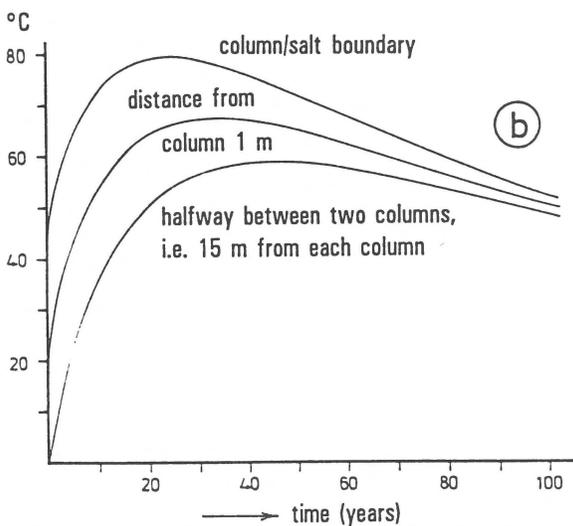
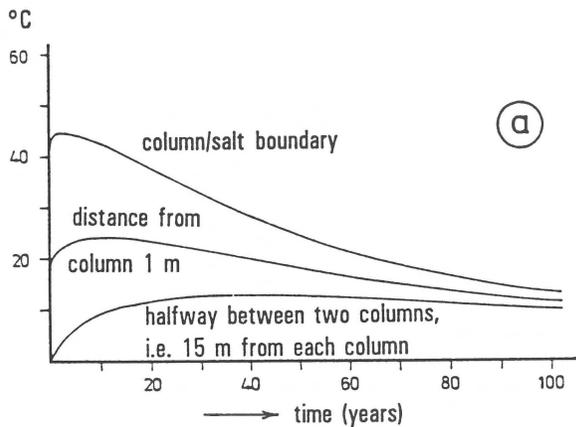


Figure 5. Typical results of the calculations of temperature rise around a KSA canister-filled borehole (heat-source column lengths are 10 and respectively 50 m for Figure 5a and b). Source: Van den Broek (1989).

- Retrieval period: the period during which one can decide to retrieve the waste. Once this period has ended, retrieval may no longer be possible.
- Retrieval period: the period required for the retrieval operation. The period starts with the decision to retrieve the waste and ends when the waste under consideration is above ground.

#### TU Delft study

The Delft University of Technology (TU Delft) has investigated the technical consequences for the disposal of radioactive waste in a salt-mine repository from which waste retrieval remains possible. The study was

part of the so-called OPLA (storage on land) research programme of the Ministry of Economic Affairs. It must be seen as a first investigation, giving interesting answers but by no means all the answers. Furthermore, it must be noted that the study was mainly focused on heat-generating waste. A report has been published (Van den Broek et al. 1993) of which the more important aspects are presented here.

Three disposal concepts were considered (Figure 6):

- The modified VHB concept. The starting point of this concept is the salt-mine repository for permanent disposal, denoted below as VHB concept, as described in the report by Van Hattum en Blankevoort (1986).
- The thick-overpack concept. This is based on the use of very thick-walled overpacks (Pollux-containers) for the heat-generating waste.
- The cased-boreholes concept, in which the heat-generating waste is emplaced in cased boreholes.

Furthermore it was assumed that, in these concepts, the galleries are backfilled at the end of the disposal operation. For the modified VHB and thick-overpack concepts, the shafts were supposed to be closed and sealed, while for the cased-boreholes concept the shafts were to remain open.

#### Modified VHB concept

There are evident drawbacks in the original VHB concept if this concept is used as basis for a design incorporating waste retrieval:

- The emplacement of canisters with high-active waste in long, vertical, uncased boreholes will considerably hinder the retrieval by a re-mining operation.
- The presently envisaged canisters for high-active waste are not meant to withstand the underground salt pressures.

These drawbacks lead to the following modifications of the concept. Firstly, it is recommended to use short instead of long boreholes. Waste retrieval can then be realized by overcoring. For an overcoring operation the maximum diameter and depth are about 2 and 10 m, respectively. Therefore, a drastically reduced borehole length would have to be introduced. As a compensation for this, more than one KSA canister could be emplaced next to each other in a wider borehole. The alternative of using longer horizontal boreholes has not been considered in the TU Delft study.

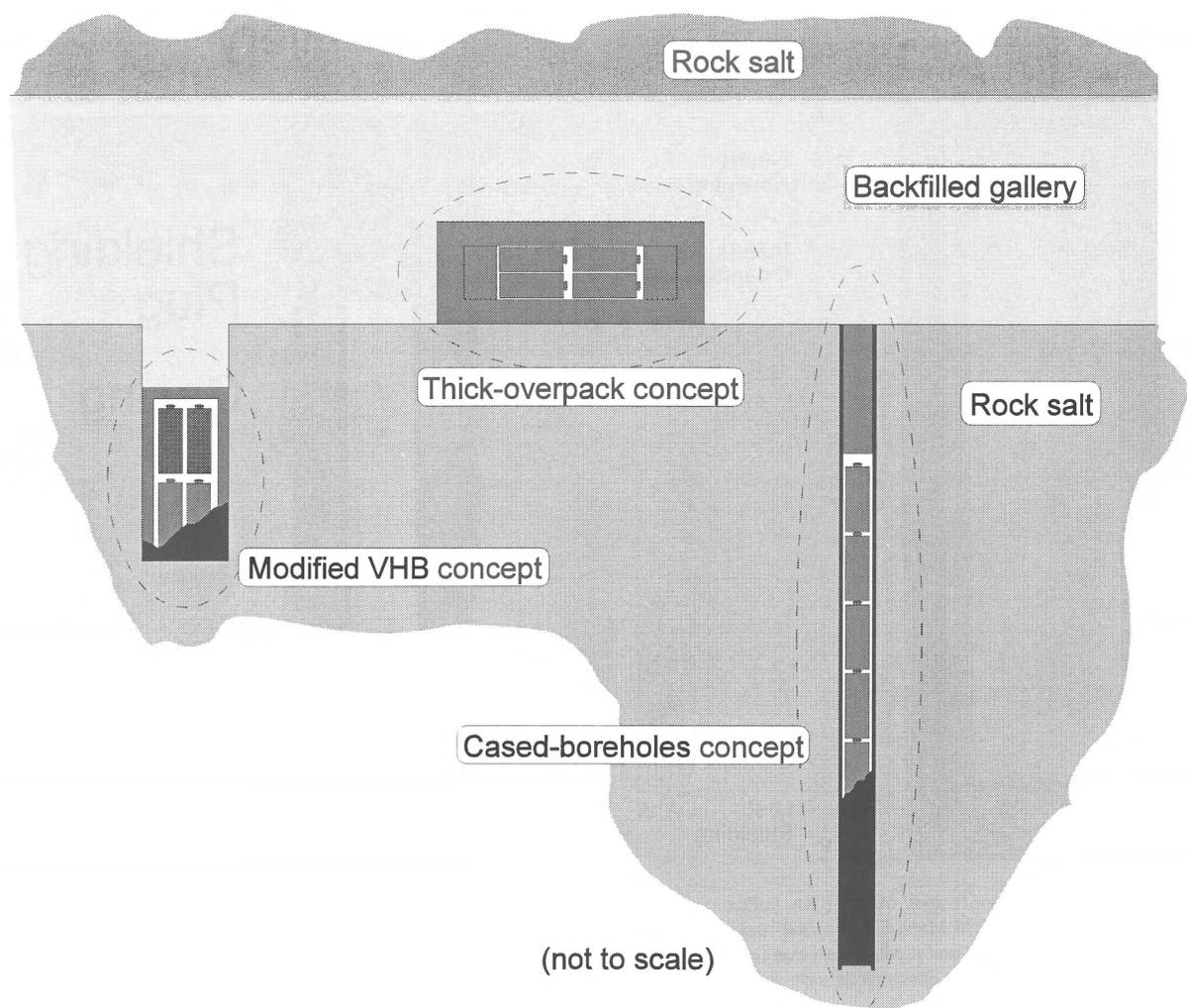


Figure 6. Schematic drawing showing the three disposal concepts which incorporate the option to retrieve the KSA canisters.

Secondly, it is strongly recommended to provide the canisters with an overpack, so that they are protected against the in-situ stresses and can be recovered undamaged in due time. It can even be argued that the use of an overpack is a prerequisite for realizing waste retrieval. The VHB concept with the two modifications proposed above, i.e. very short boreholes and overpack, is denoted as the modified VHB concept. This concept is considered as a realistic way of waste disposal incorporating the possibility to retrieve the waste through re-mining.

#### *Thick-overpack concept*

In Germany, a special, very thick overpack is developed for the geological disposal of spent fuel. Designs

for overpacks for other waste categories are also being developed. This family of overpacks has been named Pollux containers (Projektgruppe Andere Entsorgungstechniken 1989). Figure 7 presents the design and dimensions of the Pollux container for KSA. The wall thickness is of the order of 40 cm. This leads to a large reduction of the radiation level of the KSA to less than 2 mSv/h at the container surface, and facilitates the handling and transportation of the container, from the radiation-protection point of view. Drawbacks are the large weight (approx. 60 tonnes, including 6 KSA canisters) and high costs (approx. 400 000 Netherlands Guilders, or US \$ 260 000) per container.

The sturdy Pollux container for the KSA will remain intact under in-situ circumstances. This is important, as it will make retrieval possible. A re-

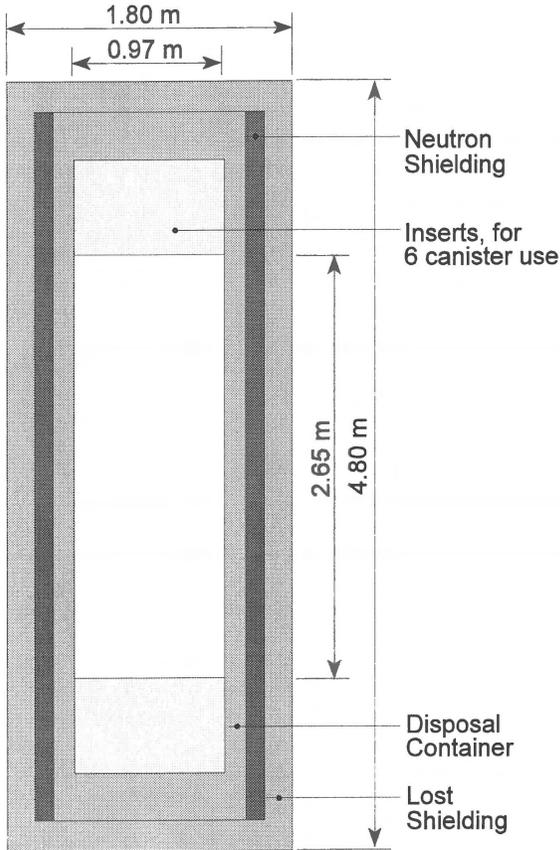


Figure 7. Design and dimensions of the KSA Pollux container. Employed materials: steel 15 MnNi 6.3 (disposal container), polyethylene (neutron shielding) and modular cast iron (lost shielding). Source: Projektgruppe Andere Entsorgungs-techniken (1989).

mining operation will be relatively simple because of the excellent radiation shielding by the overpack. A disadvantage, however, is the relatively large container weight. Retrieval remains possible as long as the container maintains its strength, and the only process endangering this strength is corrosion. This aspect is mentioned further below.

#### *Cased-boreholes concept*

An obvious way of preventing the salt to enclose the canisters, and thus to enhance the accessibility of the waste, is to provide the borehole with a protective metal hollow cylinder, the casing (Figure 8). In the petroleum industry, the use of casing is a standard technique for borehole protection and stabilization. Moreover, operations including the use of casing are also known from in-situ experiments with radioactive waste (Rothfuchs

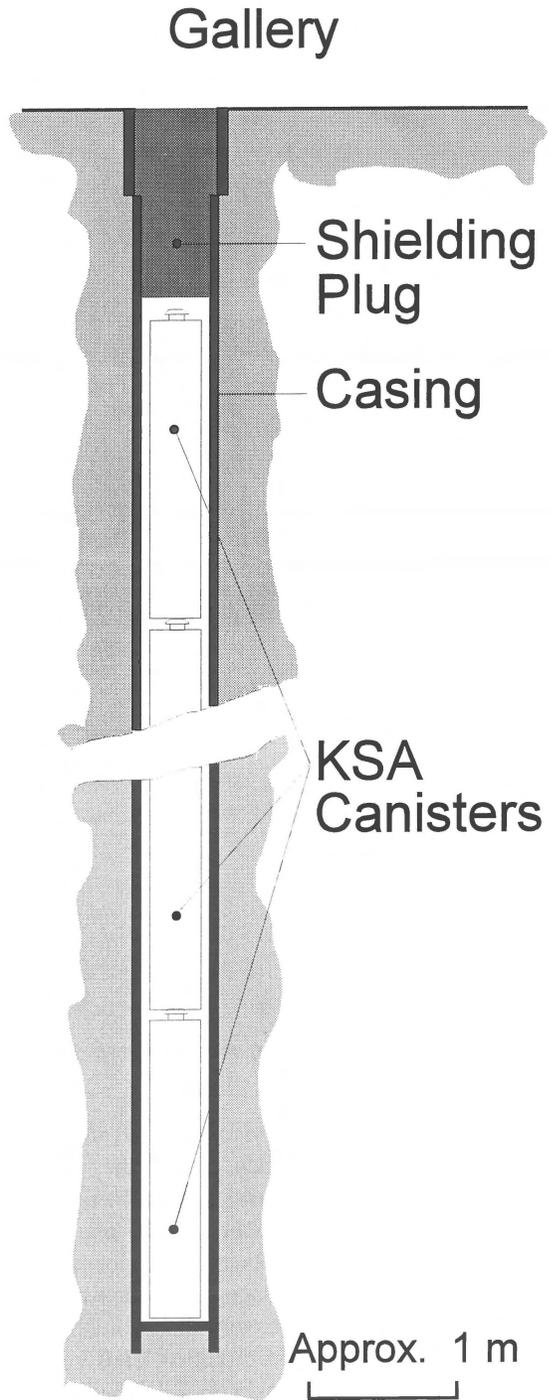


Figure 8. KSA canisters employed in a cased borehole.

& Duijves 1991). Here, the casing is used as a guarantee that the emplaced waste can be removed after the end of the experiments.

Two problems must be mentioned in connection with cased boreholes. Firstly, the protection of the KSA canisters against the salt is contrary to the idea of isolation of the waste by the salt. This problem can be largely solved by requiring that the boreholes are of limited length. In this way the total package of waste plus overpack, i.e. waste plus casing, remains relatively small and does not essentially differ from packages presented in the other two concepts considered above. Secondly, there is a limit to the stacking of waste canisters, because above a critical number (19 has been mentioned) the lower canister will be damaged by the combined weight of the other canisters. Also here the solution is a limited borehole length, and thus a limited number of canisters per borehole. The waste can be retrieved by carrying out the emplacement procedure in a reversed order.

The above three disposal concepts are considered realistic in the sense that waste retrieval is technically possible. However, the retrieval period will be long, because the retrieval will have to be realized by complete re-mining for the modified VHB and thick-overpack concepts, and by partial re-mining for the cased-boreholes concept. Of the three concepts, the cased-boreholes concept offers the highest accessibility.

Apart from the disposal concepts, other aspects are also of importance in judging the feasibility of waste retrieval. Four of these aspects are briefly discussed below.

#### *Temperature effect*

The waste is distributed over a large salt volume in order to limit the temperature rise. If retrievability is required, the waste will have to be spread even more, so that the temperature rise of the salt will be moderate and mining operations remain possible. A first, probably conservative, estimate for the maximum allowable temperature in the salt is about 70 °C (Reuther 1989). With a suitable choice of parameters, including measures to spread the heat-generating waste, this temperature limit can be met. The temperature effect has to be taken into account for any disposal concept incorporating waste retrievability.

#### *Non-heat-generating waste*

So far, the retrievability of non-heat-generating waste has not been mentioned. All the design concepts given above deal with heat-generating waste. For the non-heat-generating waste, three points are of importance:

- The temperature effect is unimportant, and this will facilitate a retrieval operation, because mining activities are not hindered by a temperature rise in the salt.
- No published data have been found on the long-term behaviour of non-heat-generating waste in a salt environment. It is to be doubted whether this type of waste will remain intact in its current form. Therefore it must be recommended to provide this type of waste with an extra overpack so that, in due time, it can be recovered from the salt in an undamaged state.
- In the USA, there is only a retrievability requirement for high-active waste. The question can be raised whether, in case it is considered meaningful to impose such a requirement, this requirement should be extended to lower-active waste types.

#### *Safety aspects*

In the TU Delft study, only limited attention has been given to the aspect of safety. In coming studies on retrievability, this aspect must be worked out, preferably in the form of a detailed quantitative safety analysis of a specific disposal design. Such a study must analyse not only the safety aspects of the disposal operation and the subsequent period, but also the safety aspects connected with retrieval. Important is, that no fundamental differences exist between the VHB concept, aimed at permanent disposal, and the modified VHB and thick-overpack concepts, which both allow to retrieve the waste. A safety analysis of the two last-mentioned concepts may be expected to give results which are comparable to those for the VHB concept. A preliminary conclusion therefore is, that the incorporation of the option to retrieve the waste need not necessarily have negative safety consequences.

#### *Retrievability period, corrosion*

An important aspect of the three considered disposal concepts is the introduction of an overpack. Use of this overpack appears to be essential to realize the waste retrieval. This implies that the length of the retrievability period is determined by the time during which

the overpack remains intact. However, the integrity of the overpack is threatened by corrosion. Corrosion data for a very stable overpack, the Pollux container, indicate that its integrity can be guaranteed for at least some hundreds of years. Consequently, it is realistic to assume that the retrievability period can be as long as, say, 500 years.

### Summary and conclusions

Two mining options are available for the permanent disposal of radioactive waste in rock salt: the salt-mine repository and the deep boreholes and cavity combination. Both options can be realized in a salt dome, but for example also in a suitable salt pillow. Important characteristics of the salt-mine repository are: the different ways of disposal, in boreholes and rooms, of different waste types, the existence of more than one disposal level, and the occurrence of temperature rises in the salt. Other characteristics are that the waste is embedded in a dry environment and that the creep behaviour of salt guarantees optimal isolation.

This preliminary study on the retrievability of radioactive waste from a salt-mine repository considered three disposal concepts: the modified VHB, the thick-overpack, and the cased-boreholes concepts. Important conclusions from this study are:

- All three disposal concepts are realistic in the sense that waste retrieval appears technically feasible.
- A retrieval operation will take a relatively long time, mainly because the waste must be recovered from the salt by complete or partial re-mining. The accessibility of the waste is highest for the cased-boreholes concept.
- The retrievability period, i.e. the period during which it can be decided to retrieve the waste, is of the order of some hundreds of years. The thick-overpack concept provides the best possibilities for achieving such a long period.
- The incorporation of the option to retrieve the waste need not necessarily have negative safety consequences. Further study of these consequences is recommended.

### Acknowledgement

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