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DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTE IN DEEP BOREHOLES IN SALT

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ABSTRACT

For disposal of high-level radioactive waste in rock salt two techniques are available, viz. the mine repository and deep boreholes, drilled from the surface. This paper deals with the second, less-known technique. Firstly the technique as it can be used for permanent disposal is described. Subsequently the feasibility to incorporate the option of waste retrieval is investigated. To this end a number of modifications are proposed: installation of casing over the entire borehole length, decrease of the disposal interval and emplacement of a special sealing plug at the top of the borehole. Furthermore attention is given to a number of aspects and phenomena important in connection with waste retrieval, such as cementing, waste-canister protection and convection in the borehole. Finally the actual waste retrieval and the abandonment and sealing of the borehole are discussed. The main conclusion of the paper is that disposal of canisters with high-level waste in deep boreholes can be carried out in such a way, that retrieval of the of waste during a limited time period remains possible.

INTRODUCTION

For the geological disposal of high-level radioactive waste (HLW) several host media are available: clay, granite, salt and tuff. Usually the proposed disposal facility can be characterized as a mine repository, because the boreholes in which the waste canisters are to be buried are drilled from galleries, and transport to the disposal region occurs via a shaft (or shafts) or a long ramp. In the case of salt, however, there is an alternative for disposal in a mine repository, viz. emplacement of the waste canisters in the salt formation in deep boreholes, drilled from the surface of the earth. Marked advantages of this technique are the following. Firstly, the attainable depth is larger than for a mine repository and, consequently, the distance between the disposal region and the biosphere can be larger. This leads to more favorable results of scenarios with which possible long-term radioactive contamination can be calculated. Secondly, for relatively small amounts of waste the costs of the disposal operation are lower, making the technique attractive for countries which make only moderate use of nuclear power for electricity generation.

This paper treats the deep-boreholes disposal technique. In the first instance it is supposed that the aim of emplacement is permanent disposal of the HLW. Subsequently another possibility will be explored: to use the deep-boreholes technique for HLW disposal incorporating the option to retrieve the waste for a period of limited duration. In this part of the paper some procedures and methods to realize the retrieval of the waste will be presented. The paper ends with a discussion and the conclusions.

DEEP-BOREHOLES DISPOSAL TECHNIQUE

The idea to dispose canisters with HLW in deep boreholes is not new. In 1986 an extensive report was published in which the different possibilities to bury radioactive waste in rock-salt formations were described and analyzed (1). Apart from the deep-boreholes technique also the salt cavern (for low-level radioactive waste) and the mine repository (suited for all waste categories) were treated. Although there was (and still is), in the case of rock salt as geological host medium, a preference for the mine repository, the deep-boreholes technique remained the subject of attention (2). We remark that this attention seems to be limited to the Netherlands. This is contrary to the other methods for waste disposal in salt which are also considered (salt cavern) or under construction (mine repository) elsewhere, notably in Germany (3,4).

General characteristics of the deep-boreholes disposal technique can be summarized as follows:

1. The HLW is supposed to be present in the form of cylindrical waste canisters, with the dimensions of one canister being: length about 1.4 m, diameter 0.43 m (volume 0.20 m^3). Each canister consists of a cylinder with vitrified waste, which is contained in a thin-walled metal overpack.
2. A borehole is drilled into the salt formation in a way similar to drilling a hole for oil or gas production or for solution mining. This implies that the hole is drilled to a suitable depth, with drilling mud continuously being present in the borehole. Subsequently the hole is provided over its entire length with metal pipe sections of sufficient strength: the casing string or casing. Next the space between pipe and formation is filled with cement. In this way a stable borehole with a length between, say, 50 to a few hundred meters has been created. To reach larger depths the procedure is repeated: drilling, inserting a new (smaller) casing, cementing, further drilling etc., until the borehole, provided with casing, sticks well into the top of the salt formation. Then drilling is continued until the desired length in the salt is achieved, e.g. 500 m. In this situation the hole is filled with drilling mud, which at this stage must contain a high salt concentration to prevent dissolution of formation salt.
3. The next stage is the filling-up of the borehole. Waste canisters are successively lowered into the hole. This can be realized by means of a wireline, but it is also possible to just let each canister sink by its own weight. The limited room between the canister and the casing wall in combination with the relatively high viscosity of the drilling fluid will ensure that the downward velocity of a canister is not more than moderate. After the borehole is provided with canisters over the length of the disposal interval, the drilling mud is replaced by cement (an alternative scheme is: disposing a number of canisters, replacing drilling fluid by cement over this section, disposing a second batch of canisters, cementing etc.). At the end of this stage there is an open hole over a length of at least 100 m between the top of the disposal region and the lowest part of the casing, the casing shoe. The sections of this part of the borehole can be successively filled with e.g. salt concrete or cement, wet

crushed salt and bitumen, as was also proposed for the filling-up of the neck of a cavern for disposal of solid waste (3).

4. The final stage is closure and sealing of the cased section of the borehole. This can be done in ways similar to those used in the petroleum industry. An appropriate scheme would be the emplacement of, say, three cement plugs, with a length of about 50 m each: one in the lowest part of the cased borehole, one at the top of the hole and one in between, with the spaces between the plugs filled with water (2).

Concerning the type of salt formation we note that the deep-boreholes technique can be used in any type of formation. While in the mine repository the HLW can only be disposed at depths not lower than about 1000 m, much larger depths (if desired even 2-3 km) can be reached with deep boreholes (2,5). This means that the last-mentioned technique can be used not only in salt domes, but also in (generally more deep-lying) salt pillows and salt layers. For the salt composition we assume that the salt region considered for disposal has a very high percentage of sodium chloride, that it relatively dry, and that salt types which would diminish the salt strength (notably potassium-magnesium and magnesium salts) are absent.

PERMANENT-DISPOSAL OPTION

Originally the final aim of the technique as sketched above was permanent disposal of the waste. After emplacement the disposal section will presumably remain intact during a reasonable period of time. As all foreign materials brought into the salt are solids, the deterioration of the waste, overpack or cement does not have negative consequences. One can even argue that this will lead to more favorable circumstances from a safety point of view because then salt will creep into cracks and fractures, and in this way the waste will be incorporated in the salt body so that the isolating properties of the salt will become effective. The region above the disposal section will gradually, but fairly rapidly, return to a situation which will resemble the original one. This will be mainly due to the presence of wet crushed salt which, due to a process of recrystallization, will be transformed to a material with properties close to those of natural rock salt. The velocity of this process increases with increasing depth. This implies that the period in which the desired isolation of the waste in the salt formation is achieved, will also decrease with increasing depth.

Thus far we have considered only one borehole. With a disposal interval of, say, 500-1000 m such a hole can accommodate 350-700 waste canisters (70-140 m^3 HLW). Consequently, usually a number of holes will be needed to bury the desired amount of waste. In connection with the heat generation of the waste, these holes must have mutual distances of at least some tens of meters (6). At this point we want to mention two advantages of the deep-boreholes technique compared to the mine repository. Firstly, after the filling-up of one hole, it can be closed and sealed. It is therefore open during a relatively short time, while a repository will have to remain open during a period of considerable length. Secondly, disposal with the deep-boreholes technique is realized in relatively small units, while a repository (for which expensive shafts must be constructed) can be seen as one large unit. In practice this means that, for the accommodation of small to moderate amounts of HLW, the deep-boreholes technique is less costly than the mine repository.

The casing material necessary for the deep-boreholes technique must fulfill a number of requirements. Firstly it is noted that the diameters have to be unusually large: the last casing must have an inner diameter of about 0.5 m, so that the other ones will have to be even wider. Secondly the casing must be capable of withstanding the forces exerted on it from the outside and maintain its cylindrical shape for a suitable period. Lastly the casing must be able to endure the downward transport of a few hundred canisters.

Since a number of years the attention for the deep-boreholes technique is limited. This has to do with the view that, in general, this technique has no advantages in comparison with the mine repository and, in addition, that is not suited for burying waste in such a way that it can be retrieved (which option can, in principle, be incorporated in a design for a mine repository in salt (7)). To investigate whether this last statement is correct is one of the aims of this study. To this we add that in a number of countries (France, the Netherlands, USA) regulations are effective in the sense that retrievability of the waste is a legal requirement. For a disposal technique it is therefore a definite advantage to be suited not only for permanent but also for retrievable waste disposal.

WASTE-RETRIEVAL OPTION

Obviously the procedures for drilling, cementing, waste emplacement etc. as sketched above are not in agreement with the option to retrieve the waste. We take, however, the technique as it is and investigate whether it can be adapted in such a way that waste can be retrieved during a limited time period which we will arbitrarily take as being of the order of 50-100 years. Obviously the first modification which must be introduced concerns the casing string, in the sense that now also over the entire disposal section the borehole has to be provided with casing. Moreover, at the bottom of the hole, it should be completely closed, which can be realized by placement of a special casing section at the bottom or, more simply, by a cement plug. Once the borehole is completely protected and closed off, the drilling fluid can be removed which will lead to a decrease of the pressure in the hole to atmospheric pressure. The casing must be strong enough to withstand the occurring forces, which will generally be larger than in the situation of permanent disposal. An alternative approach to complete removal of the drilling fluid is replacing it by a suitable liquid, i.e. water, which will lead to substantially lower stresses in the casing. Some deformation of the casing in radial or axial directions in 50-100 years is permitted, but this should be limited so that, in due time, retrieval of canisters will not be hindered.

A second difference with permanent disposal is the smaller amount of canisters per borehole. As it is essential that the canisters remain intact during the 50-100 year period, the situation must be avoided that the first-emplaced canisters are damaged in one way or another as a result of the combined weight of the rest of the canisters. A number of technical measures are thinkable to exclude the occurrence of damage: providing each canister with an overpack (5) or a protective metal frame around each canister (furthermore the canisters must be provided with a so-called fishing neck (5) so that they can be readily retrieved). It seems, however, unavoidable that, as a consequence of introducing retrievable disposal, the length of the disposal section must be limited to, at most, a distance of the order of 100 m. At this point we note that, also for the mine-repository technique, limitation of the disposal length is one of the consequences of incorporating the option to retrieve the waste (7).

The most difficult problem concerns the sealing of the borehole. On the one hand it is necessary to close the borehole in an adequate way in order to isolate the waste properly. This must be done by placing a cement plug of a few tens of meters in the upper section of the borehole. On the other hand it must be possible to remove this sealing plug in such a way that the waste canisters can be retrieved. In the petroleum industry the removal of a cement plug by drilling through it is part of the normal operational procedures. An important effect is, however, that the resulting cement debris will fall into the long, gas- or water-filled, section of the borehole between the surface and the top of the disposal section onto the uppermost waste canister. It is uncertain whether this phenomenon would leave this canister undamaged, even when it is protected by a metal cap. It is certainly a phenomenon which could seriously hinder or even prevent canister retrieval, and this implies that plug emplacement and removal as described is not suitable. To solve this problem we propose a different approach, see Fig. 1. The top of the second casing should not be located at the surface but some tens of meters lower (known in the petroleum industry as a liner construction). On the top of the second casing a thick steel plate is lowered, which in the middle is provided with a long pipe of a type normally used for drilling. Upon this plate a number of prefabricated cement discs or cylinders are placed, manufactured of relatively light cement. Each cylinder has a hole in its center, to be able to pass over the drill pipe. Furthermore the cylinders are provided with hooks, so that they can be lowered smoothly and, in due time, removed out of the borehole. To provide room for the hooks, the cylinders have, at their underside, empty spaces at the appropriate places. Fig. 2 illustrates this. In this way the upper part of the borehole is filled up to, say, 10-20 m below the surface. Next the two small channels connecting disposal area and surface (one between the casing and the last-emplaced cylinder, the other between the drill pipe and this cylinder) are provisionally closed off. This can be done with two circular rubber tubes filled with compressed air. Subsequently the remainder of the borehole is filled, which can be done in two ways. The first way is emplacement of a number of cylinders or, alternatively, one large cylinder. Then the last section of the borehole is thoroughly sealed by filling the remaining spaces with cement (the presence of the rubber tubes ensures that this cement will only seal this last section). The second and presumably best way is simply filling up the upper section of the hole with cement and allowing it to harden. Also in this case the rubber tubes ensure that the cement does not creep into the lower sections of the sealing plug. Fig. 3 gives an overview of the situation after the closure of the borehole.

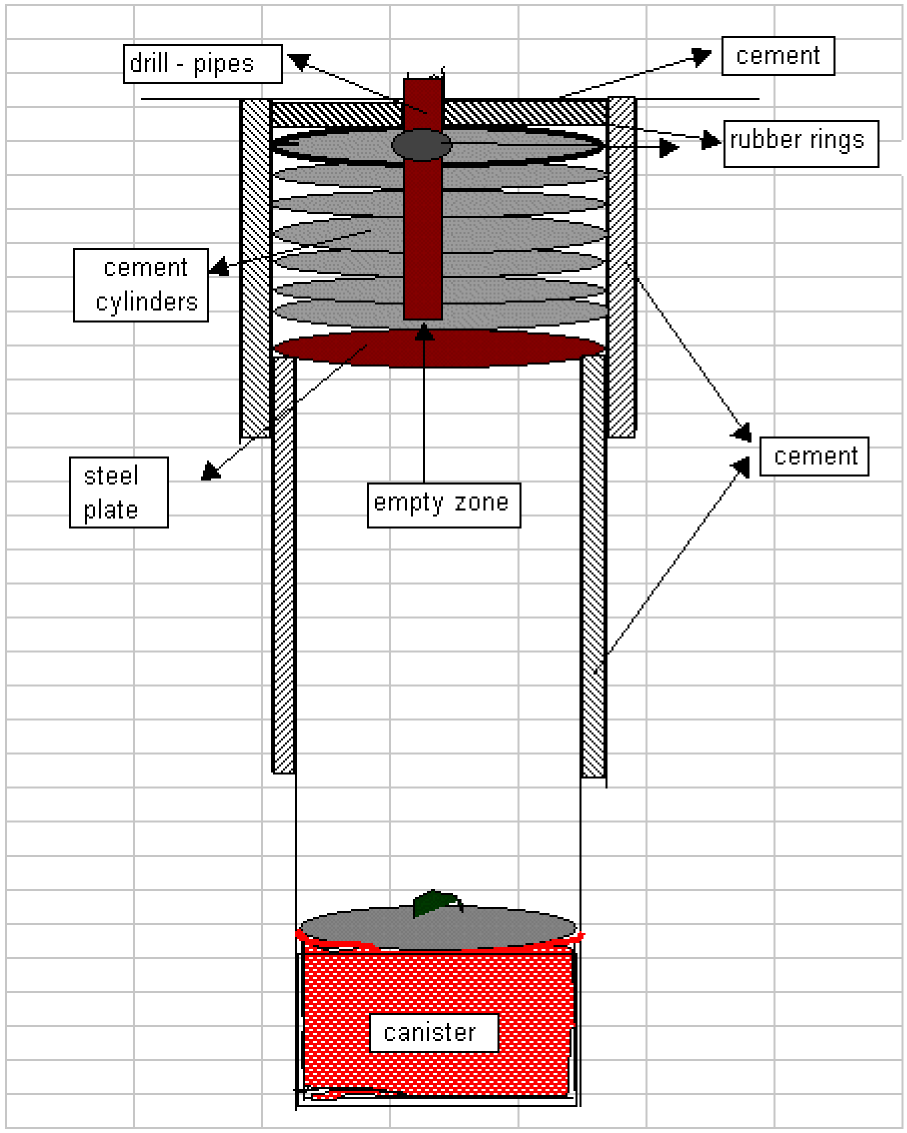

Figure 1.
Construction of the sealing plug on top of the second casing.
Note: the horizontal dimensions are exaggerated with respect to the vertical ones.

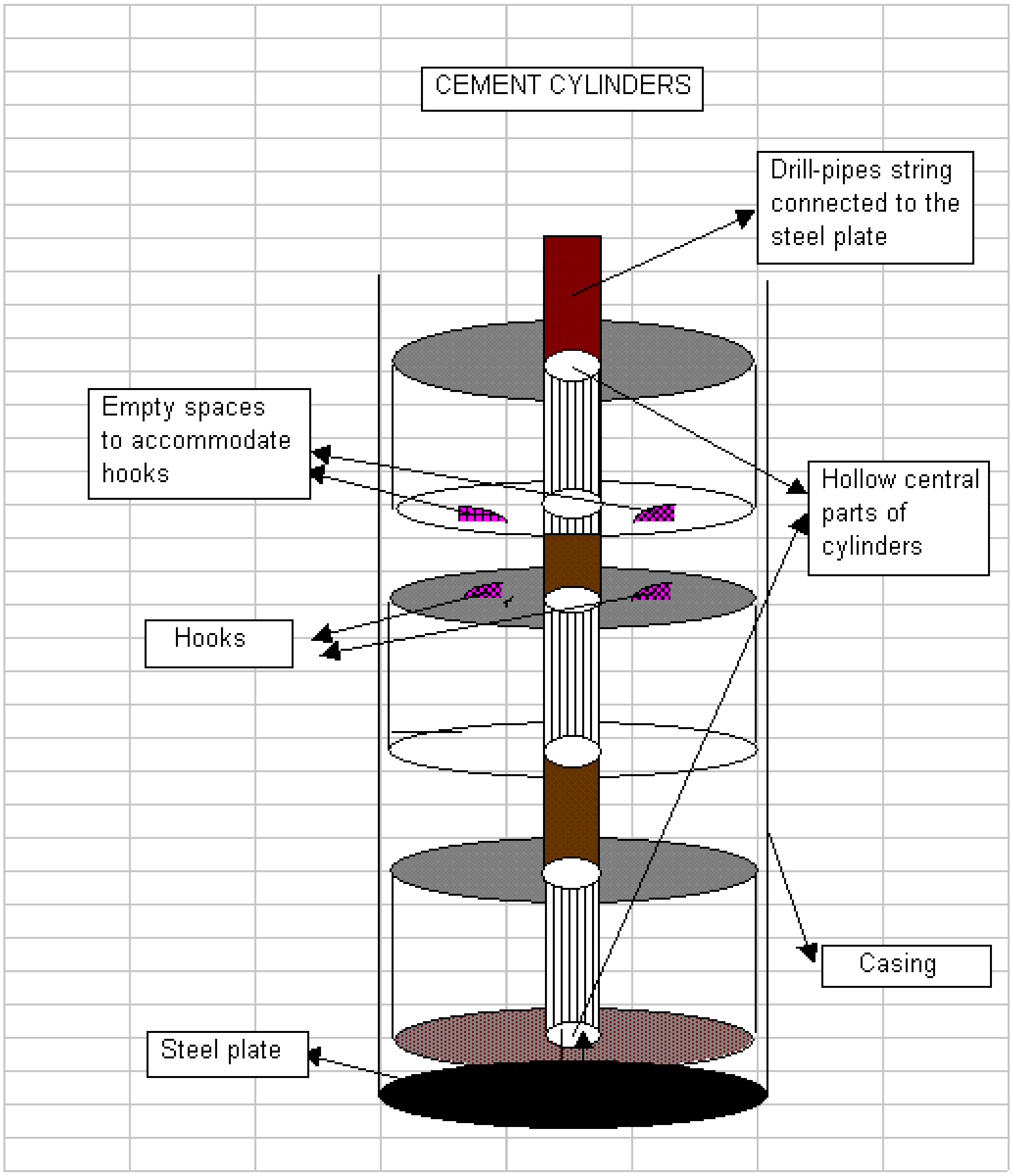

Figure 2.
Lower part of the sealing plug with steel plate and cement cylinders.

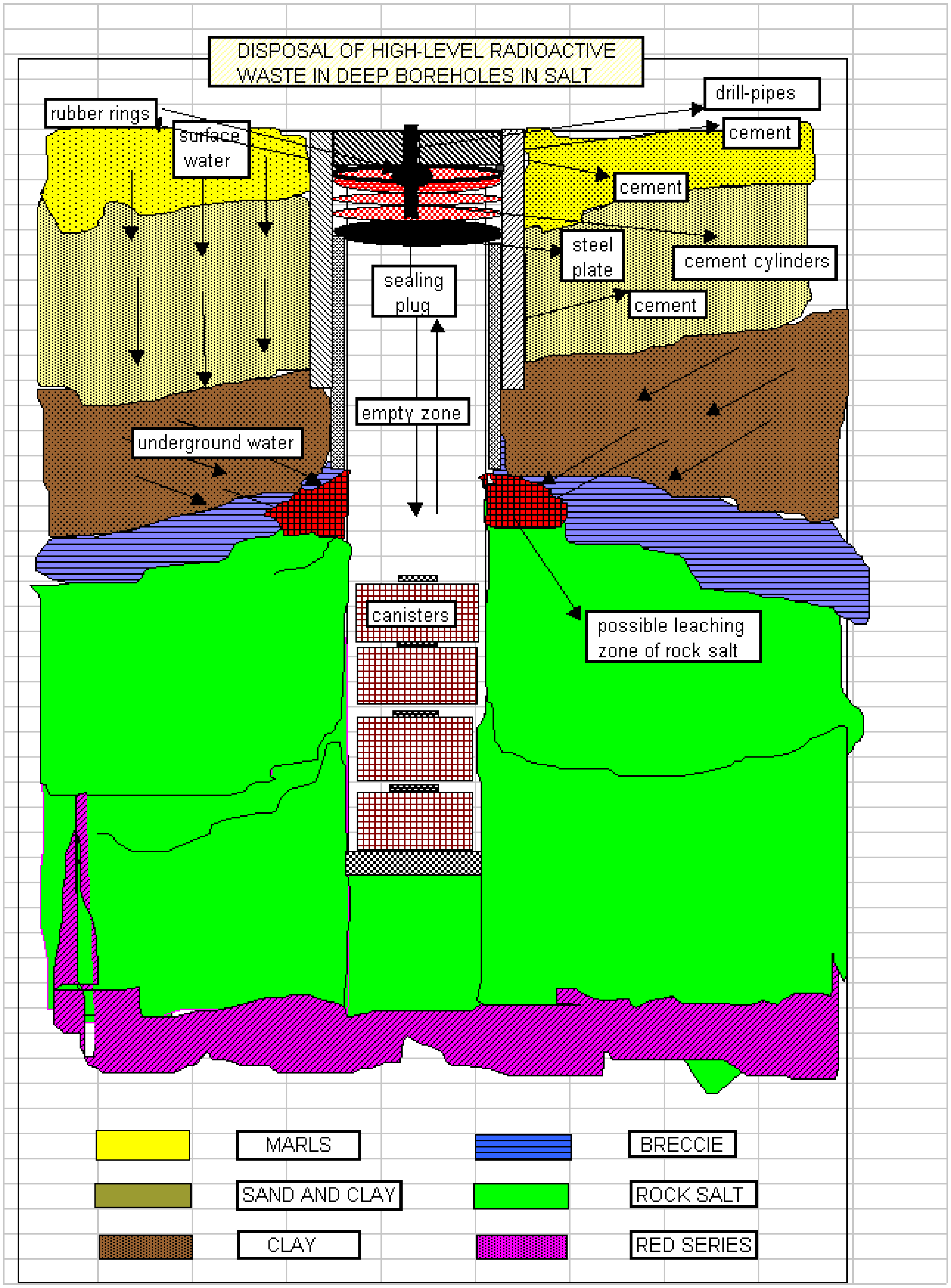

Figure 3.
Overview of configuration for HLW disposal in deep boreholes incorporating the option of waste retrieval, for an arbitrary geological configuration above the rock-salt formation.

Note: the horizontal dimensions are exaggerated with respect to the vertical ones.

Finally we present some remarks on cement and cementing in connection with the deep-boreholes technique as proposed for the waste-retrieval option:

1. *Cementing of the casings.* As the deep boreholes are used for disposal of highly toxic waste, the requirements for isolation of its contents are more strict than for normal (petroleum-engineering) purposes so that the possible occurrence of leakage of water or brine outside the casing, especially near the top of the salt formation, can be ruled out. Furthermore the presence of cement must diminish or, better still, avoid casing corrosion. This implies that the cement to be used for filling up the spaces between casing and formations must be carefully selected. Special attention must be given to the strength and the hardening time. This last parameter is not just a function of the composition of the cement, but also of pressure and temperature. As both pressure and temperature are a function of depth, this last parameter is of crucial importance for the hardening time. This time must be chosen in such a way, that it is certain that the cement has arrived at the appropriate places before hardening sets in. In Fig. 4 an example of a cement-hardening curve, for a depth of 1200 m, is given. For the strength it is important that the cement, during the 50-100 years period, remains acting as a barrier between the borehole and the underground formations. Special attention must be given to the strength of the cement/casing system below the steel plate, which must partly bear the weight of the cement seal.
2. *Cement to be used for sealing.* As discussed above, we propose the use of prefabricated cement cylinders for the larger part of the sealing interval, while these could also be used for the top section. An important requirement for this type of cement is that it must be relatively light, so that the weight exerted on the steel plate and on the liner construction does not become excessive. Furthermore the hardening time is important for the cement needed to close off the uppermost cylinders - in case this option is chosen - so that a thorough sealing of the top section is ensured (obviously the hardening time is irrelevant in case the top section is made up by means of filling it with liquid cement).

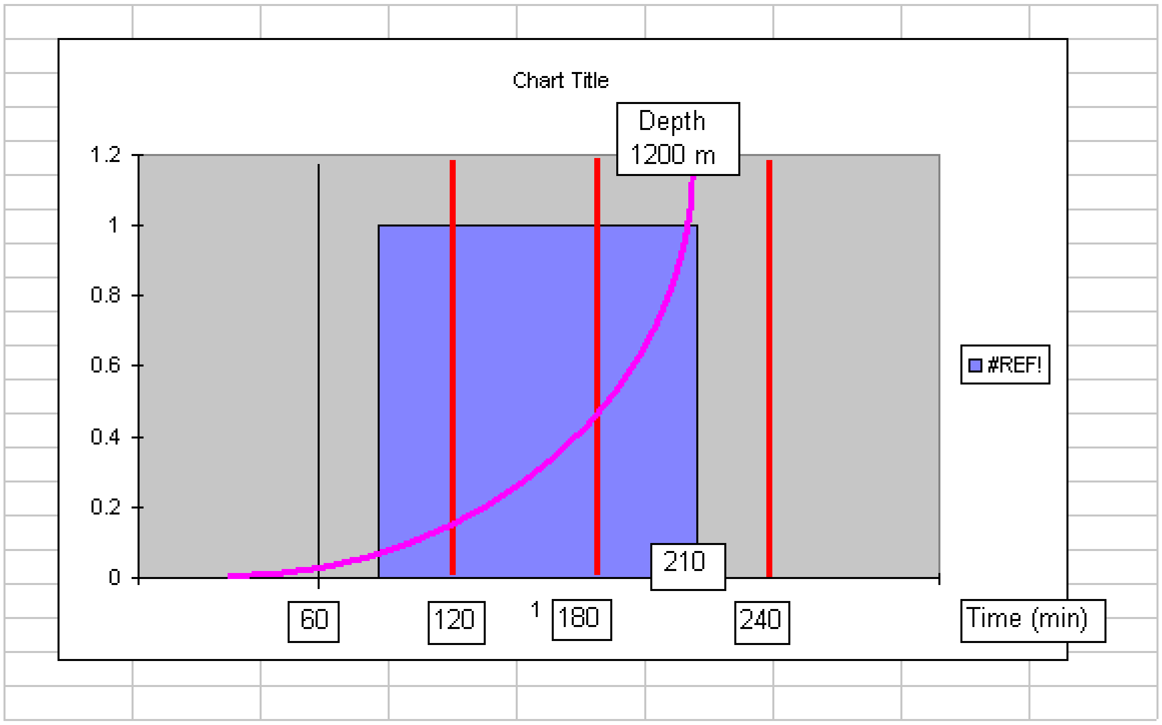

Figure 4.
Example of viscosity increase (hardening) of cement, for conditions at 1200 m depth.

RETRIEVAL PROCEDURE

Once the borehole can be used for fill-up, the canisters, provided with overpack and fishing neck, are lowered into the borehole, preferably with the help of a wireline (in case of gas in the borehole this is the only suitable method). On top of the last canister a protective cap is placed. Subsequently the borehole is closed and sealed with cement cylinders, as described in the previous section.

When, after the mentioned period of 50-100 years, it is decided to retrieve the waste, the following steps have to be taken. Firstly the sealing plug is removed. For the top of this plug (0 to 10-20 m) this implies drilling through it and removing the resulting cement parts and debris. After this the inner casing wall and the central pipe are freed from attached cement parts. The remaining part of the plug (10-20 to about 40 m) will still be unimpaired and, as it consists of loose cement cylinders, can be easily dismantled and taken out of the borehole. Then the thick steel plate with the central pipe is removed. After the protecting cap is removed, the retrieval of the waste canisters can start. In principle the procedure for this is carrying out the emplacement procedure in a reversed order.

After the emptying of the borehole it should be investigated whether all waste has indeed been removed. Once the hole is judged to be clean, it can be closed and sealed. One of the ways which can be considered is cementing it over the interval sticking into the salt formation, leaving water above it and closing the borehole in more or less the same way as described in the previous section. It is noted, however, that better procedures may exist or can be developed.

ABANDONMENT OPTION

The idea of waste retrievability is not that the waste should be retrieved after a certain time period, but that the possibility is kept open to decide to such an operation. Therefore also the situation of non-retrieval must be treated. It is of course possible, once it has been decided not to retrieve the waste, to leave the borehole as it is. This is, in principle, not totally unacceptable. However, the sealing of the borehole was done in such a way that waste retrieval remained relatively easy, and therefore a better and more responsible course is to pursue a more thorough isolation and sealing. As an abandonment procedure we propose the following. Firstly the borehole is opened in the same way as already sketched in the retrieval procedure. Next the space between canisters and borehole wall is filled with cement, so that the entire disposal interval is cemented. Then the casing is milled away (5) over the interval between the top of the disposal region and the top of the salt formation. Subsequently this interval is filled with salt concrete or cement, wet crushed salt and bitumen, in the same way as mentioned in the general description of the deep-boreholes technique. Also the final closure and sealing of the borehole are similar. Consequently, with this procedure an end-situation is created which is nearly identical to the one of permanent disposal using the deep-boreholes technique, the two differences being the presence of casing material in the disposal section and the shorter length of the borehole.

DISCUSSION

A subject not mentioned up till now is the temperature effect in the borehole. The waste canisters produce heat, and this can give rise to the occurrence of (free) convection in the long, open section of the hole. The best way to suppress this convection is emplacement of a special device above the cap protecting the uppermost waste canister. Requirements for such a device are: length of a few meters, low permeability (the device need not be massive, but must have a high resistance for fluid flow) and a low thermal conductivity (so that flow of heat in an upward direction is minimized). Specific ideas for the design of such a device have not been worked out yet. Concerning the material of which this device must be constructed one can think of fine-meshed steel wool, but other materials may well be more suitable or convenient.

Another subject not yet addressed is the question of water or gas (e.g. nitrogen) in the open section of the borehole. Both options have their advantages and disadvantages. Use of an inert gas will ensure that corrosion of the canisters will be minimal or absent. However, also in the case of water corrosion can be prevented. Earlier in the paper it was mentioned that, for extra protection, the canisters are provided with an overpack. Consequently, for overpack a material can be chosen with a very high corrosion resistantance. The main advantage of using water is, that it leads to lower values of the difference between the formation stress and the pressure in the borehole, notably in its lower section. With lower values for this difference also the forces exerted on casing and cement will be lower, so that the strength demands to be made on casing and cement can be lower, too.

Finally we want to summarize briefly the deep-boreholes technique as a whole. Some technical details must still be worked out, but the general picture is quite clear. Firstly the deep-boreholes technique can readily be used for permanent disposal of HLW. In this respect the technique has some disadvantages but also definite advantages in comparison with the mine repository, e.g. the relatively large depths which can be reached and the relatively short time period during which there is a more-or-less open connection between the disposal facility and the surface/biosphere. Secondly it has been demonstrated that it is, in principle, possible to incorporate in the deep-boreholes technique the option to retrieve, undamaged, the HLW canisters during a period of limited duration. Also the last operational phase has been addressed, for which we considered (i) retrieval of the canisters, (ii) abandonment of the borehole without further action and (iii) abandonment of the borehole in combination with emplacement of thorough, permanent seals.

CONCLUSIONS

The main conclusions of this paper are the following:

1. The deep-boreholes technique as a method for permanent disposal of high-level waste canisters has been described in terms of drilling, casing installation, cementing, canister emplacement and isolation from the biosphere.
2. The feasibility of incorporating the option to retrieve the waste canisters after a certain time period has been investigated, with the result that - by introducing a number of modifications - retrieval of the canisters can be realized. Important modifications are: installation of a casing string in the entire borehole, decrease of the disposal interval, providing the canisters with an overpack and emplacement, in the uppermost section of the hole, of a seal partly consisting of prefabricated cement cylinders which can, in due time, be removed without damaging the waste canisters. Also the last operational phases have been briefly described: re-opening of the borehole, waste retrieval and borehole abandonment.
3. Measures can be taken to ensure the integrity of the borehole during the time that waste retrieval is considered: use of casing material of sufficient strength and of suitable cement. Also the occurrence of convection in the open section of the borehole can be minimized or suppressed with relatively simple measures.
4. The question of water or gas in the open section of the borehole remains unanswered. In principle each of these materials can be used. It is noted, however, that each material has its own specific advantages and disadvantages.

REFERENCES

1. VAN HATTUM EN BLANKEVOORT, “Location-Independent Study Concerning the Construction, Management and Sealing of Possible Facilities for the Permanent Disposal of Radioactive Waste in Rock-Salt Formations in the Netherlands”, Report Koninklijke Volker Stevin, Beverwijk, 1986 (in Dutch).

2. W.M.G.T. VAN DEN BROEK, M.J.V. MENKEN and D.G.M. VAN OERS, “Aspects of the Deep-Boreholes/Cavity Option” (final report of OPLA project MIJBO-4A/52610), Delft University of Technology, Subfaculty of Applied Earth Sciences, 1993.
3. F. CROTOGINO, “Technical Concept for a Hazardous Waste Cavern in Salt in Accordance with the German Regulations on Hazardous Waste”, Proceedings Solution Mining Research Institute Fall Meeting, Paris, 1990.
4. J.P. LEMPERT and E. BIURRUN, “Safe Disposal of Radioactive Waste: Status and Perspectives of the German Waste Management Concept”, Proceedings Symposium on Waste Management, Tucson, 1998.
5. W.M.G.T. VAN DEN BROEK, “Alternative Disposal Possibilities in Rock-Salt Formations”, Proceedings Symposium on Waste Management, Tucson, 1998.
6. W.M.G.T. VAN DEN BROEK, “Aspects of Underground Disposal of Radioactive Waste in Rock Salt”, PhD-thesis, Delft University of Technology, 1989.
7. W.M.G.T. VAN DEN BROEK, H.C. HEILBRON and M.J.V. MENKEN, “Feasibility of Retrieval of Radioactive Waste from a Salt-Mine Repository: an Overview”, Geologie en Mijnbouw, Vol. 75, 1-10, 1996.