WM'00 Conference, February 27 – March 2, 2000, Tucson, AZ

ADVANTAGES AND DRAWBACKS OF WASTE RETRIEVABILITY

Wim M.G.T. van den Broek
Delft University of Technology, Department of Applied Earth Sciences
Mijnbouwstraat 120, 2628 RX Delft, the Netherlands
Phone (31)-15-2786065, Fax (31)-15-2781189, E-mail w.m.g.t.vandenbroek@ta.tudelft.nl

ABSTRACT

Retrievability of radioactive waste is a subject playing a role in the policies on underground disposal in a number of countries. Important time scales are the period during which the waste can be regarded as retrievable (order of 100 years), and the period allowed for the actual retrieval operation (1 to 2 years). For disposal in rock salt, two disposal configurations are available: the salt-mine repository and the deep-boreholes/cavern combination. Both for the salt-mine repository and the deep boreholes, the disposal operation can be carried out in such a way that waste retrieval remains possible. Incorporation of retrievability is achieved through a number of technical modifications. An advantage of waste retrievability is that it provides an opportunity to shorten the period of surface storage. Main drawbacks of retrievability are a reduced degree of isolation of the waste during a limited time period, and increased disposal costs.

INTRODUCTION

For the disposal of radioactive waste in a geological host medium, two alternative strategies can be followed. The first strategy is final disposal: the waste is buried in the underground with the intention to isolate it completely from the biosphere. The second strategy is subsurface burial in such a way, that retrieval of the waste – for a certain time period – remains possible.

Whether waste retrievability is considered or not depends to some extend on the nature of the waste. To give an example: in the United States of America (USA) the fuel rods from nuclear power plants are not, after use, reprocessed and, thus, this type of high-level waste is synonymous with spent fuel. The economical value of this "waste", however, is still considerable and it is therefore not illogical that retrievability of this waste type, once it is buried in the underground, is a requirement. The maximum time period during which waste retrieval must remain possible is – in the USA – set at 50 years after emplacement (1). This example shows that, in connection with waste retrieval, a number of aspects are important. From these we mention: waste type, considered retrievability period, considered geological medium, technical measures to make waste retrieval possible, main argument for suggesting or imposing waste retrievability, and general philosophy on geological disposal. In this paper, we focus on technical implications, but also some other aspects are discussed.

The paper starts with a short overview on philosophies on disposal and retrieval of long-lived radioactive waste, followed by a discussion on how the term "waste retrievability" can be defined. Next, the techniques for final and retrievable disposal of waste in rock salt as a geological host medium are addressed. Finally, there is a more general discussion, on the advantages and drawbacks of waste retrievability.

WASTE RETRIEVAL PHILOSOPHIES

In concepts of disposal of radioactive waste in a geological host medium, retrieval of waste – once it had been brought into the underground – was at first not considered, the aim of the operation being final disposal. The philosophy was simply to have immobilized solid waste brought into an environment that was capable of isolating this waste for an extremely long time from the biosphere. From about 1990 onwards, the "retrievability option" is considered in one form or another in a number of countries in Europe. Countries considering this option include France, Great Britain, the Netherlands, Sweden, and Switzerland, while in Germany specifically the option is not being considered. We will concentrate on the situation in France and in the Netherlands, where the views on waste retrieval are the most pronounced. Some information on the situation in other countries can be found elsewhere (2).

The situation in France is described in a paper by Hoorelbeke (3). According to a 1991 law, three paths are followed simultaneously. The first path is pursuing the possibilities of decreasing the lifetimes of radioactive components by transmuting these into components with shorter lifetimes. The second path is investigating the feasibility and desirability of extending the period of surface storage. The last path is the investigation of both retrievable and final ("réversible ou irréversible") disposal in a deep geological formation. An evaluation of the studies will be carried out in the year 2006. The current situation is, that not only all radioactive but also all other waste categories, should these be disposed of in the underground, have to be retrievable. From the mentioned paper, we note the following relevant remarks:

- Final disposal need not be synonymous with waste retrieval being impossible. It can imply that the waste can be retrieved but that such an operation will be very complicated.
- For retrievable disposal, different levels of retrievability can be distinguished (we will come back to this subject later on).
- The duration of the period during which waste retrieval should remain possible is not specifically given; however, arguments are presented that this period should be shorter than 300 years.
- A premise for underground disposal of waste is, and must remain, that problems connected with waste products should not be transferred to future generations.

In the Netherlands, the situation on radioactive waste can be described as follows (4). The first objective is limitation of the amount of radioactive waste. The second objective is reuse of materials. It is realized, however, that a need for long-term storage or disposal of a number of waste products will remain. For these waste products, underground disposal can be considered. Concerning underground disposal, the following is valid:

- Storage/disposal must be carried out according to the criteria: isolation (the waste must be separated from the biosphere), control (it must be possible to reach the waste), and monitoring (it must be possible to have knowledge of the condition of the waste).
- It is important to keep the waste available for reuse. In case reuse is not currently feasible or desirable, it may change in some future situation; therefore, the waste should be retrievable.

In the regulations given above, there is no mention of different waste categories; thus, the requirements are applicable to all waste types. For the discussions in this paper, however, we simplify things by assuming the existence of only two waste categories, viz. solid high-level waste or reprocessing waste, which can generate appreciable amounts of heat and solid low-level waste, for which the heat generation is negligible.

A comment has to be made on the philosophies and regulations as given above. There is an extensive amount of studies on underground disposal in which it is shown that disposal of solid toxic waste products is not only feasible but also safe. In the case of radioactive waste, an additional factor is that the radiation level decreases with time, so that – very slowly and gradually – this waste becomes less dangerous. Not all problems may have been solved yet, but many workers in this engineering field are convinced that underground disposal of radioactive waste – given the right disposal technique and a suitable disposal medium and site – is a very adequate solution. However, in most countries there is a lack of public (and sometimes governmental) acceptance of this view, resulting in a deadlock situation. As very long storage at the surface is unacceptable, an alternative must be found, and waste retrievability is, or at least can be seen, as an intermediate solution between surface storage and final disposal.

DEFINITION OF WASTE RETRIEVABILITY

As there is some confusion about what is meant by waste retrievability, we will try to derive a definition. To arrive at such a definition we treat five separate subjects:

1. Retrievability period. Retrievability means that, for a certain time period, it is possible to remove the waste from the underground facility and bring it to the surface (see above). There are three arguments against a long period: (1) future generations should not be burdened with the waste problems; (2) how society will develop in the future is unknown; (3) there may be technical difficulties connected with waste retrieval in the far future. All three arguments have a specific time period: that is 50 years, 100 to 200 years, and 200 to 500 years, respectively. This means that it would be unwise, given the existence of a retrievability requirement, to impose a retrievability period longer than about 100 years.
2. Retrieval operation period and accessibility. Once a decision has been made to retrieve the waste, the actual retrieval operation could be short. However, a short "retrieval period" implies that the waste is easily accessible, and this will be unattractive from safety points of view. Therefore, it would be unwise to require a short retrieval period. A reasonable period would be several months, with an upper limit of, say, 1 to 2 years.
3. Waste types. As things stand now in some countries, a retrievability requirement is not only valid for highly toxic waste products, but also for less toxic waste categories. It does not seem good policy to be very rigid in this respect because one of the negative aspects of waste retrievability will be the substantially higher disposal costs. A more appropriate line of action for low-level waste is surface storage for a certain time period followed by either shallow land burial or final disposal in a deep geological formation. In other words, store the low-level waste at the surface if a decision for shallow or deep burial cannot (yet) be made, but do not consider retrievable disposal for this waste category.
4. Recovery percentage. It is tempting to demand that a recovery percentage of 100 % should be possible. However, a situation could arise, for which recovery of, say, the last 0.2 % of waste will lead to e.g., enhanced exposure of personnel carrying out the operation. Therefore, it is a wiser course of action to demand that, in case retrieval of all the waste is desired, the aim should be 100 % recovery but that this is not an absolute requirement.
5. Transition to final disposal. The objective of underground disposal is final disposal. Retrievable disposal is, therefore, the phase preceding final disposal. It is not always possible, but it should be an aim of a design of a configuration for retrievable disposal to make it relatively easy to go from the "retrieval" phase to the "final disposal" phase.

The above discussion brings us to a proposal for a definition of waste retrievability.

Waste retrievability in connection with geological disposal implies the following:
- Once the waste is brought into the repository, it remains possible to bring it again to the surface of the earth. The period during which this is possible is limited and is, at most, of the order of 100 years.
- Once the decision for retrieval of the waste (or part of the waste) has been made, a period of 1 to 2 years should be allowed for the recovery operation. Concerning the recovery, a percentage of 100 % should be an aim rather than an absolute requirement.
- Only very toxic waste products should be considered for waste retrievability.
- At the end of the retrievability period (or, if desired, at an earlier point of time), retrievable disposal should go over in final disposal by taking the appropriate and necessary technical measures.

WASTE DISPOSAL IN ROCK SALT

Disposal of radioactive waste in a salt formation can be realised in two ways: (1) in a salt-mine repository or (2) in deep boreholes in combination with a salt cavern. General characteristics of a salt-mine repository are: surface facilities, shafts leading to the disposal regions, a region for the low-level waste at approximately 500 m depth, and a region for the high-level waste at approximately 800 m depth; see e.g. Van den Broek (5), and Prij (6). The region for the low-level waste consists of galleries and large excavated rooms to accommodate the waste drums. The procedure for filling a room is simultaneously bringing in the drums and sufficient quantities of crushed salt so that no empty spaces remain between the drums. Once a room has been completely filled up, it is closed and sealed with salt blocks. The high-level waste, in the form of waste canisters, is lowered from a gallery into dry-drilled boreholes. Also in this case, crushed salt is added for additional filling-up. In the end, each borehole is closed and sealed by filling the last few meters with salt. Eventually, all the rooms and boreholes are filled up and sealed, after which the galleries are closed by bringing in salt blocks and crushed salt. Finally, the repository is closed by sealing the shafts.

An alternative, less-known way of waste disposal is the combination of deep boreholes and a salt cavern (or salt caverns). In the deep boreholes, the high-level, heat-generating waste canisters can be buried. These boreholes are different from the dry boreholes in the following respects:

- The holes are not drilled from galleries in a salt repository but directly from the surface of the earth. They are not drilled dry but, according to the methods used in the oil and gas industry, with drilling fluid in the hole and strengthening of the upper part of the hole with metal pipes ("casing string" or "casing").
- Placement of canisters occurs by lowering waste canisters into the lower, uncased section of the hole, where drilling fluid is still present. Once a suitable number of canisters has been installed, the drilling fluid is replaced by cement. Eventually, the disposal section is completely filled up. Closing of the borehole includes: sealing the section between the uppermost canister and the casing shoe with mainly crushed salt and salt concrete (in a similar way as suggested, by Crotogino (7), for the sealing of a cavern neck). After this sealing, the cased section of the hole is provided with a number of cement plugs (e.g. three); this concludes the sealing/abandonment procedure.
- One of the functions of the drilling fluid is to counteract convergence of the hole under the influence of the rock pressure. As a consequence of this procedure, much larger depths can be attained for the deep boreholes than for the dry holes of the salt repository.

The low-level, non-heat-generating waste can be disposed of in a salt cavern. Before filling up such a cavern, a removal of the brine is required so that – after filling-up and closure of the cavern – the permeability of the salt roof remains extremely low. (That the permeability of the roof of a brine-filled salt cavern may eventually be enhanced was demonstrated by Kenter et al. (8).) Absence of brine implies that the pressure in the cavern will be atmospheric, and this limits the depth of a disposal cavern to about 1000 m. Larger depths can be reached in case, during the filling-up phase, a modest internal cavern pressure is used; see Van den Broek (9).

RETRIEVAL OF WASTE FROM A DISPOSAL FACILITY IN ROCK SALT

In the case of a waste retrievability requirement, the disposal procedures as given above are unsuited. However, it has been shown (10,11) that – for the mine repository and the deep boreholes – modifications can be introduced so that retrieval of the waste remains possible. For the salt cavern, this incorporation of waste retrievability is not possible. Below, is a brief description of how these two other techniques can be modified.

For the salt-mine repository the main modification is to supply additional protection for the waste canisters so that, when they are retrieved, their condition is the same as at the time of disposal. In principle, this can be realized in two ways. The first possibility is to bring 6 to 9 waste canisters into a thick-walled vessel, a Pollux container (consequently, the high-level waste is not placed in boreholes but in separate galleries). The metal wall of the vessel is a protection against radiation, but also makes it so strong that it can withstand the underground stresses. A disposal procedure could then be as follows: filling a Pollux vessel, transporting it to a gallery in the high-level waste disposal area, and closing the gallery with crushed salt and salt blocks at the moment that sufficient vessels are brought into the gallery. In this situation (the shafts are still supposed to be open), the waste has been disposed of, but in such a way that retrieval of the waste is relatively easy. For retrieval, the salt in the gallery has to be removed and the vessels recovered. The strength of the vessels guarantees that the waste canisters are unimpaired. The second possibility to ensure that the high-level waste canisters remain undamaged is to provide the boreholes with casing, which protects the canisters against the salt stresses. With cased boreholes, it is advisable to limit the number of canisters per borehole so that the probability of other canisters in some way damaging the lowermost canister can be ruled out. A disposal procedure would be to fill a cased borehole with a limited number (e.g. 10 to 15) of high-level waste canisters, close and seal the borehole with a metal plug, and eventually, when also the other boreholes in the gallery are filled, close the gallery with crushed salt and salt blocks. Also in this case, it is supposed that the shafts remain open. The waste can be retrieved by re-opening the gallery, opening the borehole, and carrying out the disposal procedure in a reversed order. For completeness, we mention that a scheme has been developed for retrieval of waste canisters (without additional protection), disposed in horizontal holes drilled from galleries, and backfilled with crushed salt after placement of the canisters; see Dodd et al. (2). Retrieval of these canisters must be carried out with special, large-sized coring equipment.

The above is valid for disposal of high-level waste in a salt-mine repository. In principle, the same idea (additional protection for the waste by the use of special overpacks) could also be used for low-level waste. Due to the absence of heat generation and to the lower radiation level, the difficulties to incorporate waste retrievability for low-level waste do not seem large. But is considering retrievability for low-level waste meaningful? Earlier in the paper, we advised against a retrievability requirement for this waste category.

For deep boreholes, the situation is slightly more complicated. At first, it was assumed that it was not possible to incorporate waste retrievability for this technique; however, this is not the case. For incorporation of waste retrievability, three modifications are essential. The first modification is installment of casing over the entire borehole, thus including the disposal section. The second modification is limiting the number of canisters per borehole, just as for the cased boreholes of the salt-mine repository (and for the same reason). The last modification is a different construction of the borehole seal at the surface, so that – after closure – the borehole can be opened again without too much difficulty. Another reason for a special closure technique is the prevention of damage to the uppermost waste canisters as a result of drilling through the surface seal; see Jahic and Van den Broek (11). With these modifications, the disposal operation goes as follows. A limited number of canisters is lowered into the cased borehole by means of a wireline provided with a grappling mechanism. The position of these canisters is well within the salt formation. Then, the removable surface seal is installed. In case the canisters must be retrieved, the surface seal is removed and the canisters are retrieved. In case it is, after a number of years, decided not to retrieve the canisters, several courses of action are open. The first course is to do nothing. Eventually, after hundreds of years, the casing will lose its strength and the waste will be incorporated in the salt formation. The second course is to open the borehole and to install a number of cement plugs in the upper section, as was already described in the paragraph on final disposal. The last (and best) course of action is to open the borehole, cement the disposal section, mill away the casing between the disposal section and the top of the salt formation and fill this part of the borehole with crushed salt. Also in this case, the final action is to place a number of cement plugs. The end result is nearly identical to the end result for final disposal of high-level waste canisters in deep boreholes.

DISCUSSION

Above we have given information on: (i) countries for which waste retrievability plays a role or where it is, in some way or another, imposed; (ii) techniques for final disposal of radioactive waste; and (iii) technical measures that can be taken to incorporate waste retrievability. The information on countries was not extensive and, for underground disposal, we have limited ourselves to rock salt as geological host medium. Nevertheless, we think that, with the given information, we can contribute to the general discussion on waste retrievability by addressing the following subjects.

Final Disposal versus Retrievable Disposal

It was already stated that the ultimate aim of underground disposal is final disposal. Sometimes, retrievability is justified on the grounds that it poses an advantage in a situation when, in the underground, at some point in time in the future, unfavorable processes may occur. In our opinion, this is the wrong approach. Underground disposal should be started only after one is certain that such an operation (transport, disposal, closing the facility, long-term processes) is safe and can be carried out safely, whereby it is evident that the safety level that is required is extremely high. We are, therefore, of the opinion that on technical grounds, final disposal is to be preferred over retrievable disposal. However, it cannot be denied that retrievability plays a role in some national policies and, thus, if these policies are not changed, one will have to take into account retrievability requirements.

Waste Minimization

Apart from the choice between final and retrievable disposal, efforts for waste minimization and decrease of the half-lives of waste components should be continued. However, there will always remain waste components and/or categories for which no further use exists and for which underground disposal is and will remain a very good solution.

Definition of Waste Retrievability

Evidently, definitions of waste retrievability other than that proposed are possible. Essential for such definitions is that a limit is given for the time during which retrieval can be required. We have proposed a retrievability period of about 100 years or less. From a technical point of view, this period could be longer, but it is our opinion that – in case waste retrieval is a requirement – it is unwise to impose a relatively long period on the grounds mentioned earlier in the paper.

Technical Implications

The technical implications for disposal in rock salt have been treated. It appears that, both in the case of the mine repository and the deep boreholes, a number of modifications have to be introduced. However, it also appears that, in both cases, the general design of the underground facility need not be altered.

Advantages

As stated above, from a technical point of view, final disposal is to be preferred to retrievable disposal. The main advantage that we see in the incorporation of waste retrievability is the following. As a result of prolonged discussions on underground disposal, actual disposal is, in most cases, postponed for an indefinite time period. The result may well be long to very long periods of surface storage of very toxic components, which is not an attractive outlook. In this situation, retrievability can be a means to achieve some progress. In other words, the incorporation of retrievability makes the reduction of the period of surface storage possible, which is an important advantage.

Drawbacks

Main drawbacks of retrievability are as follows:

- The main negative point of waste retrievability concerns isolation. Geological disposal implies isolation from the biosphere and retrievability implies that some form of accessibility is present, and evidently the combination isolation/accessibility poses a serious problem. It is unavoidable that introduction of retrievability has a negative influence on the degree of isolation.
- Another drawback is that imposing retrievability with the argument that it is a safeguard against unfavorable processes in the underground can give the impression to the public that underground disposal is unsafe. Again, we remark that underground disposal should only be commenced in the

situation that such an operation can be carried out and completed responsibly and safely, whereby long-term developments are taken into account.

- A last point of concern is costs. Incorporation of retrievability will lead to substantial additional costs, because of technical modifications. Furthermore, there will be a tendency, for safety reasons, for a not-too-high degree of accessibility (in the case of the salt-mine repository the closure and sealing of galleries while the shafts remain open, which will lead to relatively high costs of a retrieval operation). Apart from costs connected with modifications, there will also be additional costs in connection with the keeping open of part of the disposal facility.

CONCLUSIONS

Main conclusions of the paper are:

1. Retrievable disposal has several drawbacks, of which a decreased level of waste isolation is the most important one. Therefore, final disposal should have preference over retrievable disposal. The only advantage of waste retrievability is that it poses an alternative for surface storage.
2. In case waste retrievability is imposed, the retrievability period should not be longer than about 100 years.
3. For disposal in rock salt, it is possible to incorporate waste retrievability. For this incorporation, a number of technical modifications are necessary, but the general disposal configurations need not be altered.

REFERENCES

1. CODE OF FEDERAL REGULATIONS 10 (ENERGY), United States Government Printing Office, Washington, D.C., 1990.
2. WORKSHOP (Proceedings 4th International Workshop on Design and Construction of Final Repositories), Lucerne, October 1997.
3. HOORELBEKE, J.M., Underground disposal of radioactive waste and waste retrievability, according to the French Law (in French), Geology and Confinement of Toxic Wastes, Vol. 1, pp. 531-536, A.A. Balkema, Rotterdam, 1993.
4. ILONA-BULLETIN NO. 8 (in Dutch), pp. 1-4, Ministry of Economic Affairs of the Netherlands, 1994.
5. VAN DEN BROEK, W.M.G.T., Aspects of underground disposal of radioactive waste in rock salt, Ph.D.-thesis, Delft University of Technology, Delft, 1989.
6. PRIJ, J., On the design of a radioactive waste repository, Ph.D.-thesis, Technical University Twente, Enschede, 1991.
7. CROTOGINO, F., Technical concept for a hazardous waste cavern in salt in accordance with the German regulations of hazardous waste, Proceedings Solution Mining Research Institute Fall Meeting, Paris, 1990.
8. KENTER, C.J., DOIG, S.J., ROGAAR, H.P., FOKKER, P.A., and DAVIES, D.R., Diffusion of brine through rock salt roof of caverns, Proceedings Solution Mining Research Institute Fall Meeting, Paris, 1990.
9. VAN DEN BROEK, W.M.G.T., Alternative disposal possibilities in rock-salt formations, paper presented at the Waste Management Conference, Tucson, March 1998.
10. VAN DEN BROEK, W.M.G.T., HEILBRON, H.C., and MENKEN, M.J.V., Feasibility of retrieval of radioactive waste from a salt-mine repository: an overview, Geologie en Mijnbouw, Vol. 75, 1996, pp. 1-10.
11. JAHIC, N., and VAN DEN BROEK, W.M.G.T., Disposal of high-level radioactive waste in deep boreholes in salt, paper presented at the Waste Management Conference, Tucson, February/March 1999.