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GEOTECHNICAL REQUIREMENTS OF SUBSURFACE REPOSITORIES IN MINES, ROCK AND SALT CAVERNS FOR INTERIM OR FINAL DISPOSAL OF HAZARDOUS WASTES

EXIGENCES GÉOTECHNIQUES POUR LE STOCKAGE SOUTERRAIN TRANSITOIRE OU DÉFINITIF DE DÉCHETS TOXIQUES DANS DES MINES OU DES CAVITÉS DE SEL OU DE ROCHES DURES

Hans-Joachim SCHNEIDER*

Abstract

The storage of hazardous wastes in subsurface facilities, i.e. in mines, salt caverns and hard rock caverns, offers a high degree of security potential. This is because the contaminants are entombed in geological formations of the deep underground a long way from the biosphere. In order not to prejudice the security offered by the geological barriers certain geotechnical demands have to be met with respect to stability, tightness and sealing in the construction of these subsurface waste repositories. Furthermore, prior to their emplacement, wastes have to be conditioned to exclude the possibility of reactions between the wastes and between the wastes and the surrounding material, e.g. rock or lining. Depending upon the intended function of the subsurface facility, i.e. for interim or final storage, different demands are pertinent with respect to the emplacement technology and the facility seal.

In the following paper the geotechnical security objectives for subsurface repositories for interim and final storage are discussed and technical concepts for the construction and operation of mined, salt and hard rock caverns presented. The possibilities for using current mine operations and abandoned underground spaces for the storage of hazardous wastes are discussed.

Résumé

Le stockage de déchets dangereux dans des sites souterrains tels que des mines, des cavités dans le sel ou dans des roches dures, offre un haut niveau de sécurité, car ces produits sont enfouis dans des formations géologiques profondes éloignées de la biosphère. Pour ne pas remettre en cause la sécurité offerte par les barrières géologiques, certains critères géotechniques doivent être respectés, concernant la stabilité, l'étanchéité et l'obturation de ces lieux souterrains de stockage. De plus, avant leur mise en place, les déchets doivent être conditionnés pour empêcher toute possibilité de réaction soit à l'intérieur même des produits soit avec la roche ou le revêtement. En fonction du type de stockage, c'est-à-dire selon qu'il est provisoire ou définitif, les spécifications concernant la mise en place et l'obturation seront différentes.

Dans l'article, les auteurs discutent des objectifs géotechniques de sécurité pour les stockages transitoires ou permanents, de même que des conceptions techniques de réalisation de cavités dans le sel ou les roches dures. Les possibilités d'utilisation des mines existantes et des espaces souterrains abandonnés pour le stockage des déchets toxiques sont également examinées.

1. Introduction

Are subsurface waste disposal facilities the solution waste management has been waiting for? The argument that the high degree of safety associated with subsurface disposal leads to a higher degree of public acceptability for this form of waste disposal, and hence to the solution of current bottienecks, is in fact an over simplification of the problem. The opposite is the case: in order to avoid making the same mistakes that were made in the past in the field of surface disposal — which has led to the current problems known under the title *"waste legacy"* — it is an absolute prerequisite that prior to construction the planning, suitability, security and environmental acceptability of a subsurface waste disposal facility be satisfactorily dealt with. The above must fully match the functional objective of the repository, i.e. interim or final disposal, with careful consideration of the overall waste spectrum intended for placement therein.

A number of concepts have been put forward recently with regard to surface and subsurface locations; these proposals include a wide disparity of technical standards.

In order to check the system and case specific suitability of a repository it is necessary for certain considerations to be carefully looked into, bearing in mind the spectrum of waste intended to be disposed of, e.g. the general geotechnical objectives of the site's safety with

* Priv.-Doz. Dr.-Ing. Dipl.-Geol. H. J. Schneider Kavernen Bau- und Betriebs-GmbH, Roscherstr. 7, D-3000 Hannover 1.

respect to sealing against the biosphere, stability, tightness and operational security, the geochemical and waste-chemical demands with respect to inter-reactivity within the repository and with the surrounding rock.

Certain geotechnical security objectives are presented as formulated by the LTWS working group, commissioned by the West German Federal Ministry for the Environment, in their delibrations on *"caverns for the disposal/storage of water hazardous materials"* [1]. The objectives discussed here do, however, require revision by the sub-committee for subsurface waste disposal, because the security objectives of the adhoc LTWS working group are exclusively related to water protection and do not specifically deal with the problem of the waste spectrum.

2. Position of Subsurface Repositories within the Overall Waste Management Strategy

The 4th Amendment to the law covering wastes [2] in the Federal Republic of Germany is expected to result in a major reorganisation of current waste management practice. Primary here is the allocation of waste flows according to waste type in the corresponding waste management track of either material recycling or chemical-physical treatment; also listed are improvements to pyrolysis, differentiation between interim and final storage and improvements to the technology of waste treatment and disposal plants (Fig. 1). One of the major problems posed by this reorganisation is to amend the existing practice whilst maintaining adequate waste management levels.

In the surface disposal facility sector measures are targeted towards raising the safety levels — a trend is currently noticable towards engineered facilities. Since engineered facilities have only a limited operational lifetime of several decades, this concept raises certain questions on the function and lifetime of the technical and geological barrier system.

The American Environmental Protection Agency (EPA) issued guidelines including a monitoring period of 30 years. This represents a non-satisfactory situation,

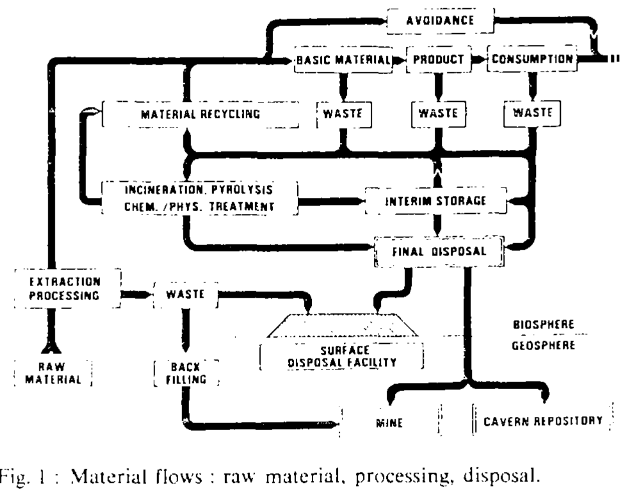

Fig. 1 : Material flows : raw material, processing, disposal.

since the technical and geological barriers at the surface are subject to extensive geodynamic and geochemical processes [3]. For this reason it is recommended that hazardous wastes containing contaminants posing a high environmental risk should be disposed of in the deep lithosphere, in order to prevent the contaminants entering the biosphere via the hydrosphere [4]. Materials posing this environmental threat are those with toxic and/or highly water soluble contaminants. Since subsurface disposal facilities offer high geotechnical security they represent an excellent instrument for the disposal of waste, and as such the flow of waste into the underground can be expected to increase in the future.

3. Geotechnical Security Objectives of Subsurface Repositories for Hazardous Wastes

In general subsurface disposal facilities for hazardous wastes have to be constructed, operated and maintained in such a way that there is no possibility of the environment being exposed to hazards due to contaminants within the atmosphere, hydrosphere or other. Furthermore, additional general demands are made within the overall environmental acceptability, e.g. provisions to exclude risks to the life and health of operating personnel and third parties, the protection of the landscape and the surface, including the reclaiming of the land after repository sealing.

Based on these general security objectives a number of technical guidelines can be formulated whereby in principle those of a final storage facility are at variance with those intended for an interim storage for hazardous waste (Fig. 2).

FINAL REPOSITORY	INTERIM STORAGE
- LONG - TERM CONFINEMENT	- LIMITED STORAGE PERIOD
- INACCESSIBLE	- EASILY ACCESSIBLE
- NON - RECOVERABLE	- RECOVERABLE
- SERVICE AND MAINTENANCE FREE	- SERVICE AND MAINTENANCE OBLIGATION

Fig. 2 : Criteria for final storage and interim storage of hazardous wastes.

Final storage involves emplacement of wastes in the lithosphere, i.e. the wastes are sealed off from the biocycle for geological time periods, whereby over the long term a mineralization of the wastes would be ideal. Therefore, final disposal requires that the design of the storage facility seal is final and secure over the long term since the wastes are by definition non-retrievable. The access to the storage space has to be completely backfilled for stability reasons. In addition the final storage must be independent of maintenance and control since over geological time periods the upkeep of maintenance and control schedules cannot be guaranteed.

A completely different demand profile characterizes interim storages. Since the wastes are intended to be stored only for a limited time period the function of the barrier systems has only to be maintained over the limited operational time. In interim storages wastes should be those with a recycling potential (the facility could be interpreted as a future resource) or waste for which an inertisation process is prognosed with advancing technology. In this case it would be necessary to ensure emplacement such that material retrieval is possible without putting personnel or the environment at risk and using only simple technical ancillary equipment. Because of this retrievability of the wastes an interim storage has to have easy access, which places higher technical requirements on the sealing system. Because of the limited lifetime of the barrier system, and the fact that no hermetic seal is guaranteed between the storage and the biosphere, all interim storages have to be subjected to maintenance and control regimes for their entire operational period. After decommissioning, an interim storage has to be completely decontaminated and shut down such that no maintenance is required in the future.

It is absolutely essential that clear guidelines are prepared within any new waste plan for final and interim storage facilities, because at the present time discussions at a political level into *"retrievable final storage "* and *"long-term interim storage "* could result in the tight safety requirements outlined for final storage facilities becoming diluted and loop holes in current practice being painted over.

Current levels of know how and technology make the reopening of underground final storage facilities using mining techniques at least theoretically feasible (at astronomical costs). The current political demand for final storage facilities to be reopened makes no sense, either economically or from a waste management point of view. Quite apart from the exorbitantly high costs the new technical report on waste sees a strict division of wastes into those with a recycling potential and future inertisation (in the interim storages) and hazardous wastes with no recycling value and without any possibility of inertisation (being directed into waste repositories).

Both interim and final storage facilities have to be isolated from the biosphere via multiple barrier systems. Barriers for subsurface storages have to be reviewed bearing the following points in mind :

1. The geology and hydrogeology of the location.

2. The sealing systems of the facility incl. technical barriers.

3. Safety audit of the total system based on an incident analysis.

4. Analysis of the waste spectrum with respect to storability, chemical reactiveness with the barrier systems and surrounding rock.

When constructing subsurface storages, a prime requirement is a suitable geological underground, in which not only direct location factors need to be considered but also the overall regional-geological vicinity. This primarily refers to the presence of tight geological formations offering an effective isolation of the facility from usable groundwater, the rock mechanical properties of the host rock, the topographical location of the facility with respect to the overall hydrogeological situation, the hydrochemistry and also possible geodynamic risks.

Water migration to the biosphere has to be excludable from first principles. When selecting a site for an underground waste facility factors such as rock permeability, distance to the nearest groundwater channel, chemistry of the groundwater and the presence of drinking water and mineral water springs have to be considered.

The stability of the cavity or the lining/rock mass composite system, has to be proven bearing in mind certain factors, e.g. operational loading cases, and also possible incidents. Such an expertise proving stability must be prepared for the operational phases for both interim and final storages. In the case of final storages the stability of the waste containing cavity must be assured by backfilling that cavity.

When the cavity is completely full the access must be properly sealed. Seals intended for interim storage facilities have a different demand profile to those of final storages because of the different principles involved, i.e. retrievability and non-retrievability. Seals for interim storages have, by definition, not to meet the same high safety standards as are technically possible and required for the seal of a final storage. This weak point has to be compensated for in interim storage facilities by continuous control and maintenance regimes during operation. In the technical design of the seals it must also be borne in mind that any artificial water permeability created as a result of actual driving of the cavities, e.g. in the weakened disaggregated margin of the cavity, requires appropriate sealing and grouting measures.

Prior to the construction of a subsurface disposal facility it is necessary to provide proof of safety by presenting case by case analyses of incidents and risks for both the operational and post-operational phases. During the construction phase safety relevant components should be subjected to quality assurance tests. To guarantee operational safety the subsurface and surface installations should be subjected to continuous controls insofar as they are relevant to the overall security of the facility. These controls vary according to the system, i.e. are different for mines, hard rock and salt caverns. All variations have in common that regular surface levelling is carried out, that all surveillance and measurements are properly recorded and that written records are made of all waste materials emplaced. Environmental protection demands have to be met by setting up suitable air, water and noise measuring systems.

Following facility shutdown suitable measures must be undertaken to seal it, monitor groundwater and control the surface. Full documentation on the decommissioned facility has to be presented to the responsible authority.

4. Technical Concepts of Subsurface Disposal Facilities

Technical concepts of the mined, hard rock and salt cavern variations are currently being studied with respect to suitability for subsurface disposal of hazardous wastes including rad wastes. The concepts are not compatible in themselves, but can fulfil certain functions as interim or final storages with respect to a certain waste spectrum.

4.1. Subsurface Disposal Facilities in Mines

The possibility in using salt and/or coal mines for the storage of hazardous wastes in driven galleries is currently being investigated and in some cases already practised [5, 6, 7]. Despite the obvious economic advantages of using existing underground cavities created during mining for a secondary cycle of waste disposal it should not be overlooked that the cavities left from the mining of a deposit are the result of economic considerations related to the exploitation of that resource.

When constructing subsurface waste disposal facilities the driving of the cavity is done so bearing the storage technology in mind, and involves leaving the geological barrier as untouched as possible. To what extent these two objectives *"economic exploitation of a deposit "* and *"construction of a subsurface disposal cavity "* overlap has to checked on a case by case basis. The check must be based on the following aspects, waste spectrum to be deposited, function, i.e. as interim or final storage, geological factors such as properties of the deposit or the host rock, the hydrogeological situation, mining specific aspects such as the mining method (procedure and roof treatment), the shape of the cavity and its size, water management, disposal rate and so on.

The wastes can be introduced either in containers via shafts or access tunnels, or containerless via pipe transportation, as slurry using pneumatic pumping methods or in a gravity feed system. The pneumatic and the gravity feed methods place certain limits on the spectrum of waste because of exhaust gas/ventilation problems. These methods also require additional protection and ventilation for personnel working underground.

With regard to interim and final storage of wastes in containers the most suitable mines are those built in the chamber-pillar-method in horizontally situated deposits [5], whereas for containerless final storage using the wastes as backfill material, those mines employing caving mining or block caving are best suited [8]. In caving mining, stowing puzzolanic-type solidified wastes can in fact produce a stabilizing effect on the mined zone. For all mines, in particular caving mining, it is extremely important that the creation of artificial water ways and possible links to groundwater aquifers are thoroughly investigated. Comparable limitations also apply to mines with water maintenance. Because of the large spatial capacity offered by existing mines which have a potential as sites for the disposing of wastes, it is not currently necessary to construct a special final disposal mine in Germany for hazardous waste. Especially when one considers that the high investment costs rule out any chance of such a mine being competitive economically.

4.2. Subsurface Disposal Facilities in Hard Rock Caverns

Hard rock caverns constructed for the purpose of interim or final storage of hazardous wastes are driven using conventional excavation methods [9, 10]. Selecting the site depends on certain geological and hydrogeological preconditions, on the petrographic and tectonic properties of the rock and its permeability, distance and height as well as possible water links to neighbouring groundwater aquifers.

Rock cavern facilities can be built using a number of different methods, of which gallery, cavern and shaft designs are examples (Fig. 3). Parameters for the selection of one of the methods are based on the target function as interim or final storage, the type of waste, the storage technology and the properties of the rock mass.

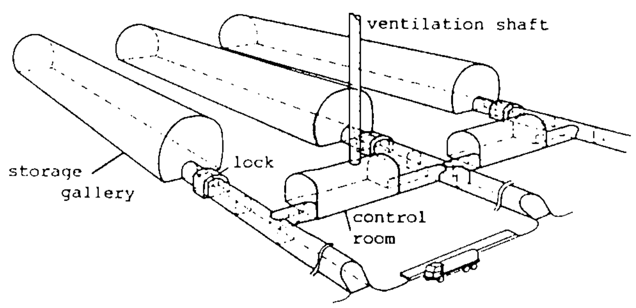

Fig. 3 : Rock cavern disposal facility in a gallery design.

The gallery design has, for example, the advantage that it allows cavities to be made in low competent rock types and yet still at economic prices. This method allows simultaneous construction at several points leading to shorter construction times. Dividing the galleries into individual chambers allows flexible operation.

Disadvantages are the unfavourable volume/surface ratios of lined systems.

Hard rock caverns are generally constructed with a lining and inner seal. In certain exceptions, where the geological and hydrogeological preconditions are particularly favourable, the design may waive linings or seals. The cavern lining fulfills the role of providing a static support to the cavity during the operational phase and also serves as a subconstruction for the inner seal. Seals normally consist of watertight and acid resistant synthetic materials which are employed in the form of either spray coats or some supplied in sheets. In some cases metal linings made of stainless steel are a possibility.

Hard rock caverns are suited to both the interim storage of liquid and solid hazardous wastes. Solid wastes are stored in principle in containers to allow the material to be retrieved. In the case of containerless storage of liquid wastes similar operation procedures can be assumed as apply to a storage of liquid hydrocarbons [1]. For final storage only solid wastes come into consideration. If these wastes are stored in containers, then the residual cavities have to be completely backfilled. The backfill material has the job of providing long-term stability to the cavity and tight enclosure around the containers. Because of their high strength and low permeability the most suited backfill materials are fly-ash mixtures which can be hydraulically backfilled and hence ensure the cavern is stowed without leaving any free cavities. When storing solid wastes in a containerless method caverns built on the shaft design are preferred. Here as well, the wastes should be hydraulically backfilled using a puzzolanic binding material in order to provide tight storage.

4.3. Subsurface Disposal Facilities in Salt Caverns

Salt cavern disposal facilities are suited to the final storage of solid wastes with no recycling potential [11]. Similar to the storage methods used for liquid hydrocarbons salt caverns could also be used for the interim storage of certain liquid waste materials. Salt caverns are constructed using solution mining. Their construction places certain prerequisites on the geological properties of the salt deposit, for example sufficient thickness and lateral extension of the salt deposit and also that the salt deposit be homogeneous in its properties. The solution mining of caverns is carried out from wells drilled from the surface. When the solution mining phase is finished the brine-filled caverns are emptied. The emplacement of wastes into these empty caverns is via the access well, in a continuous operation via either gravity feed through an additional pipe string for bulk materials or using additional boost power for slurries.

In this latter case, the wastes are mixed with puzzolanic binding additives to ensure in situ solidification. In order to exclude the possibility of reactions between the wastes themselves and the cavern walls preconditioning is necessary. Only a limited waste spectrum can be stored in salt cavern waste disposal facilities. When the cavern is completely full the access well is hermetically sealed. Maintenance and control is not necessary.

5. Conclusion

Storing hazardous wastes in subsurface facilities is a method well suited to waste disposal because of the high security potential offered. However, the extended use of the subsurface storage technology above and beyond current practice requires first of all clear political objectives on the role of such sites as final storages or as interim storages and also as to the retrievability and non-retrievability of the wastes concerned. The characteristics of wastes intended for storage vary according to the disposal site: for an interim storage the major consideration is optimum technical retrievability, and for a final storage the

Fig. 4 : Salt cavern waste disposal facility.

long-term behaviour of the waste becomes a prime factor in order to assess processes in the facility over the long term.

In Germany the new guidelines on waste should therefore not consist merely of a chemical waste catalogue in which waste flows are ordered depending upon disposal method, but should also bear in mind possible treatment methods of wastes to provide a storage which is immission-neutral. In order to optimize the selection of waste sites according to geological aspects new regulations should be on a supraregional basis in order to end the current system in which the producer of a waste is expected to dispose of that waste within a localized area, a method which ignores the geological criteria. Careful thought should also be given to the strategy of enforcing waste avoidance or waste recycling via the lever of high disposal prices. Just as in other market sectors, disposal methods should not be chosen dependent on price but according to the best, i.e. the safest, solution. Furthermore, discussions of waste strategies should involve a greater distinction between current status and future demands, whereby it must be clearly distinguished between that which is technically realizable and that which is desirable in the long-term. The current situation is often that discussions concerning waste disposal sites become stuck: the desperate need for the new construction of waste disposal sites to enable effective waste management, is delayed by controversal discussions with unhelpful talk of future waste avoidance strategies.

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