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Underground Disposal of Hazardous Wastes in German Mines

A.ÖzarsIan
Department of Mining Engineering, Zonguldak Karaelmas University, Zonguldak, Turkey
P.N.Martens, T.Olbrich & M.Röhrlich
Institute of Mining Engineering I. Aachen University of Technology, Aachen, Germany

ABSTRACT: This paper provides a comprehensive overview of the status and development trends of underground disposal of hazardous wastes in Germany. First, the legal bases for underground waste disposal in Germany are presented. Then, the waste properties and quantities as well as safety concepts recommended for the underground disposal of non-radioactive wastes are explained. The disposal of wastes in underground openings and the utilisation of non-mining wastes as backfill in mines are treated separately. In addition, the most important features of these systems are explained. The final disposal of radioactive wastes in Germany is also discussed. Finally, the future of underground hazardous waste disposal in Germany is considered.

1 INTRODUCTION

Sustainable development is one of the main tasks facing society today. Environmental protection plays a very important part in achieving this goal. Our society should not cause any environmental problems which could jeopardise the bases of life for future generations. The problem of waste ranks highly here. Despite all the efforts and successes in the field of waste reduction and recycling, quantities of waste will still remain, and they have to be disposed of in an environmentally friendly manner. Long-lived, hazardous, chemical-toxic and radioactive wastes in particular represent a serious threat to future generations without proper and safe disposal.

One possibility for the safe, long-term disposal of waste without subsequent treatment is the utilisation or dumping of wastes in suitable underground openings. In Germany, wastes which require monitoring and which can neither be treated by chemical, physical or biological methods nor disposed of through incineration may be stored in surface or underground disposal sites. However, surface disposal sites could become abandoned polluted sites İn the future since the sealing systems used only have a limited service life (Martens et al. 1993). Underground disposal offers the possibility of permanent and safe disposal, particularly for wastes with a high proportion of water-soluble materials and heavy metals. The underground openings produced by mining work represent an important potential for this disposal method for both technical and economic reasons.

Germany has developed into one of the world's leadmg nations in terms of underground disposal and utilisation of non-mining waste, with over 25 years of experience in this field. Three underground disposals (UTD) are already in operation for wastes designated as requiring special monitoring (hazardous wastes), with a total capacity of over 500,000 tons p/a. Two further underground disposals, one of which has already been approved and the other of which İs in the middle of the approval procedure, will ensure an additional annual capacity of around 250,000 tons. Moreover, around 1.9 million tons of non-mining waste is utilised underground (UTV) every year as backfill İn around 20 German mines. Around 850,000 tons p.a. is hazardous waste. This waste is classified as requiring special monitoring in Germany.

Germany is also one of the world's leading nations in the research and development of final waste disposal projects for radioactive wastes. Figure 1 provides an overview of the locations of underground waste disposal sites in Germany, including disposal and utilisation sites for non-radioactive wastes as well as final radioactive waste disposal project sites.

2 LEGAL BASES FOR THE UNDERGROUND DISPOSAL OF WASTES

The legal bases for the underground disposal of wastes İn Germany are shown in Figure 2. According to the principles of the German Cycle Economy and Waste Act (Krw-/AbfG), an act for

'promoting closed substance cycle waste management and ensuring environmentally compatible waste disposal' which came into force in 1996, unavoidable wastes should primarily be subjected to substance recycling or used to obtain energy. In the case of substance recycling, the main concern should be the utilisation of the waste properties and not the elimination of the pollutant potential. Wastes which cannot be recycled should be permanently removed from the closed substance cycle and disposed of with no effects on the well-being of the general public.

- Underground disposal sites in operation (3)
- Approved underground disposal sites (1)
- Planned underground disposal sites (I)
- Underground utilisation of waste as backfill (20)
- Final disposal projects for radioactive wastes (4)

Figure 1. Locations of underground waste disposal sites in Germany.

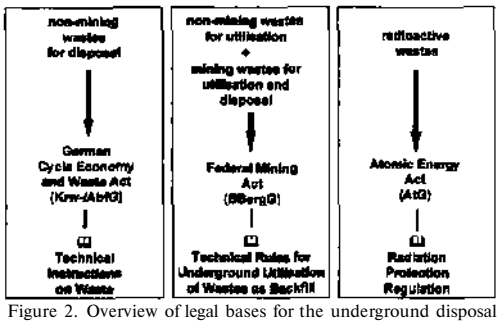


Figure 2. Overview of legal bases for the underground disposal of wastes in Germany.

The construction and operation of underground disposals for non-mining waste require a waste law plan or approval İn accordance with the 'KrW-/AbfG' act. The requirements of the administrative regulation "Technical Instructions on Waste" (TA Abfall) passed by the Federal Government in 1991 must be taken into account. The 'TA Abfall' only allows the construction and operation of underground disposals in salt rock (mines and caverns). These requirements are based on the fact that wastes dumped and sealed in salt rock are permanently kept away from the biosphere and no subsequent treatment is necessary (Schade 2000).

The utilisation of non-mining wastes in mines is allowed if it serves mining technology or safety purposes in accordance with the Federal Mining Act (BBergG), It requires approval by the mining authorities on the basis of a mining law plan of operation. The mining authorities and planning authorities, with the co-operation of all authorities and municipalities affected by the measures, check whemer the project can be approved in consideration of long-term safety. During the approval procedure, the regulations of the Federal Waste Act, Immission Control Act, Water Act, and Labour and Health Protection Act are taken into consideration alongside the Mining Act (Schade 2000). The utilisation and disposal of mining wastes is also the responsibility of the mining authorities in accordance with the Mining Act.

The legal basis for the construction and operation of final waste disposal sites for radioactive wastes is the Atomic Energy Act (AtG). This specifies that the state is responsible for the construction of facilities for final waste disposal. The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) is responsible for the final waste disposal program.

3 UNDERGROUND DISPOSAL OF NON-RADIOACTIVE HAZARDOUS WASTES

3.1 *Properties-quantities-safety concepts*

Wastes for underground disposal must have special properties. The most important of these are (TA Abfall 1991):

- The wastes must not be explosive or self-igniting.
- The wastes must not be combustible under the storage conditions.
- The wastes must not release gases (may form neither explosive nor other pollutant gases).
- The components of the waste must not be able to react with each other or with the surrounding rock (e.g., salt rock).
- The wastes must not contain pathogens of contagious diseases.
- The wastes must not swell.

• The wastes must have sufficient strength or achieve this in their final condition.

Figure 3 shows an overview of the development of the quantities of hazardous wastes requiring special monitoring. Underground disposal is regarded as the safest disposal method for wastes with a high water-soluble share or with toxic pollutant contents (e.g., heavy metals, cyanide). As can be seen in the illustrations (Figs. 3-4), the proportion of wastes disposed of in underground disposals has risen over the past few years despite a drop in the quantities of hazardous wastes which require special monitoring.

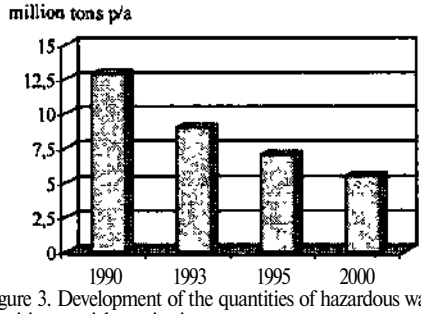


Figure 3. Development of the quantities of hazardous wastes requiring special monitoring.

Some of the wastes disposed of in underground disposals in Germany are from countries which do not have underground disposal systems that can ensure the necessary long-term safety. For example, 17.8 % of the total 2 million tons of hazardous wastes placed in the Herfa-Neurode disposal originated in neighbouring European countries (Wiedemann, 2000). Thus, German facilities perform important disposal functions within Europe.

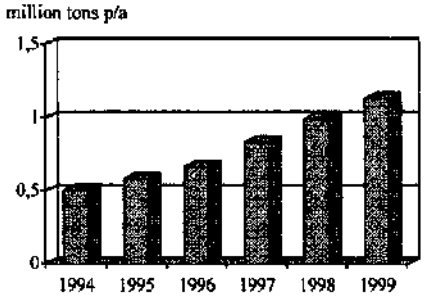


Figure 4. Development of the quantities of hazardous wastes disposed of in underground disposals.

Apart from the hazardous wastes, large quantities of 'non-mining wastes with a low pollutant content' (e.g., power station ash) are disposed of underground İn Germany. A large amount of mining waste produced during the extraction and treatment of mineral resources is also disposed of underground.

The openings in various underground German mines offer a great potential for the disposal of wastes. Table 1 shows the theoretically usable opening volume for underground disposal in various German mines.

Table !. Usable opening volume for waste disposal İn various underground mines (Bieter el ai., 1994).

Underground mines	Available opening volume (x 1000 m V
Potash mines	79 500
Rock salt mines	8 800
Ore mines	8SO0
Coal mines	11 100"*
Other mines***	4 400
Total	112 600

* theoreiically usable opening volume (Status 1994)
** opening volumes produced annually (without shafts and drifts)
*** other mines (e.g., limestone mines, spar mines)

The safety concepts of 'neutral immission' and 'complete enclosure' are applicable for underground disposal in consideration of both legal and technical aspects. In the case of 'neutral immission' disposal (Fig. 5), contact with ground water is possible but the pollutant release from the wastes must be insignificant for the ground water (prohibition of deterioration in quality). Wastes produced in large quantities but with a low water-soluble pollutant potential (e.g., power station ash) can thus be disposed of underground.

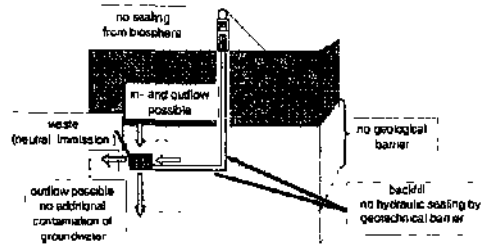


Figure 5. Safety concept of neutral immission.

In the case of 'complete enclosure' (Fig. 6), a multi-barrier system permanently prevents contact between the wastes and the surrounding ground water. Wastes requiring special monitoring can thus be disposed of in accordance with this concept,

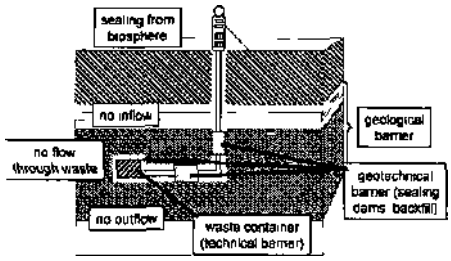


Figure 6 Safety concept of complete enclosure

3.2 *Waste disposal in underground disposal sites*

The openings in potash and rock salt mines in Germany offer ideal conditions for underground disposal. Waste disposal is only allowed according to the "complete enclosure" concept. These disposals have to fulfil special requirements. The most important requirements are (Kind 1991):

- The mme in which the wastes are to be disposed of must be dry and free of water.
- The openings in which the wastes are to be disposed must be protected against water-bearing layers.
- An abandoned and stopped-out working area must be available for disposal of the wastes.
- The disposal openings and access roads must be stable.
- The disposal operations must be separately ventilated.
- It must be disposal without retrieval.

Around 16 % of all hazardous waste types are disposed of in underground disposals (UTD) in Germany. The majority of wastes which are disposed of in these disposals are wastes 'of a mineral origin and from refinement products' and from 'conversion and synthesis processes'. The most important wastes İn terms of quantity per year are as follows (Prognos 1998):

- Solid reaction products from waste incineration plants (23,000 t/a).
- Mercury and residues containing mercury (11,000 t/a)
- Salts containing cyanide, nitrate and nitrite (11,000 t/a).
- Products and operating material containing PCB (14,000 t/a).
- Mixed waste from waste treatment plants (19,000 t/a).

Underground disposals have had a firm place in the German waste disposal infrastructure since the Herfa-Neurode underground waste disposal site was opened in 1972. They have become an irreplaceable final link in the disposal cham for certain types of waste. The quantities of hazardous waste which are disposed of in underground disposals are shown in Figure 7. The underground disposal site in Herfa-Neurode is the most famous m the world and is regarded a model plant by international experts. This facility is situated in an abandoned part of a potassium-producing mine in flat-lying strata. The mine workings form a room-and-pillar system and the disposal area is situated at a depth of about 700 m below the surface. In the past 28 years of operation, a total of 2 million tons of mostly drummed hazardous solid wastes have been placed m the abandoned parts of the mine (Wiedemann 2000).

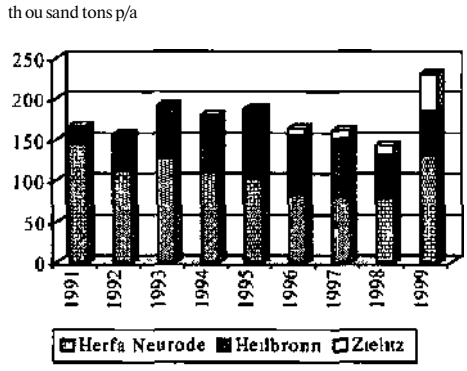


Figure 7. Quantities of hazardous waste which are disposed of in underground disposals

The prices for underground disposal in Germany are between EURO 200 and 300 per ton (plus taxes and fees). The prices for surface disposals are between EURO 100 and 350 per ton, depending on the type of waste (Prognos 1998).

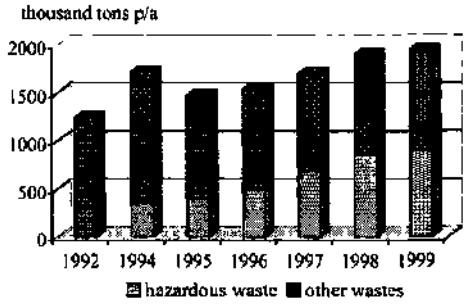
3.3 *The underground utilisation of wastes as backfill*

An increasing volume of non-mming waste can be used as backfill in Germany due to the development of new backfill technologies (Jahn 1998). The backfill should perform the following tasks:

- Protection of the surface.
- Optimum use of the deposit.
- Special safety and operating tasks (e.g., ventilation, fire fighting).

Figure 8 shows that the utilisation of non-mining wastes as backfill has risen steadily over the past few years. In particular, the amount of hazardous waste utilised as backfill has risen, with an upwards trend.

Hazardous waste can only be used in accordance with the 'complete enclosure' concept and with proof of its long-term safety. Other wastes can also be disposed of in accordance with the 'neutral immission' concept - provided they are suitable for this.



Figure? Quantities of non-mming-wastes which are utilised as backfill m underground mines

Wastes from coal-fired power stations and thermal waste treatment plants are preferably used in these systems. These are ashes which can develop self-hardening properties on their own or in a mixture and thus meet the requirements for the production of a bearing backfill. The most important types of waste in terms of quantity are as follows (Prognosl998):

- Filter dusts and solid reaction products from waste incineration plants (96,000 t/a).
- Slags and filter dusts from hazardous waste incineration plants (43,000 t/a).
- Slags from non-ferrous metal smelters (13,000 t/a).
- Soil, building rubble and excavated earth with noxious pollutants (191,000 t/a).
- Filter dusts and ashes from coal-firing plants.

The disposal pnees in underground backfill systems are around EURO 25-110 per ton (Prognos 1998), and are thus far below those of other disposal methods.

Depending on the type of waste, and its composition and quantity, bulk matenal backfill, stack backfill in 'Big-Bags' or hydraulic backfill are used in underground utilisation plants.

4 FINAL UNDERGROUND DISPOSAL OF RADIOACTrVE WASTES

Even at the beginning of the sixties, there was a preference in Germany for using deep geological formations for the final disposal of long-lived radioactive waste (Lempert 1999).

Final disposal of radioactive wastes commenced in 1967 with the storage of low-level and medium-level wastes in the now non-productive 'Asse' salt mine in Lower Saxony. The disposal of radioactive wastes continued up to 1978, when the licence expired and was not renewed. Around 25000 m^3 of waste has been placed in this mine (Wiedemann 2000). The mine is currently open for R&D purposes. Wastes placed there are accessible and under constant control.

In the former German Democratic Republic (East Germany), disposal of low-level and medium-level radioactive wastes in the non-productive 'Morsleben' salt mine in Saxe-Anhalt started in 1981. During the time of the reunification of Germany, disposal was interrupted for three years, but resumed in 1994 Up to 1998, over 35000 m had been placed in this mine (Wiedemann 2000). As it appears the license will expire, the mine will be closed (Lempert 1999).

At present, no radioactive waste is being placed İn underground mine openings, but is instead stored at special surface plants. However, the federal government is pursuing two projects for the final waste disposal of radioactive wastes. One is the licensing of 'K.onrad\ a non-operational accessible and dry iron ore mine in Lower Saxony, which will offer a disposal capacity of approximately 650000 m^3 of low-level and medium-level radioactive wastes at levels between 800 and 1300 m below the surface. The other is the 'Gorleben' project in eastern Lower Saxony, which has been under investigation since 1979. A shaft was excavated and the host rock is being studied for its suitability for the placement of radioactive waste of all categories, including high-level, heat-generating wastes. If the geological structure proves suitable, disposal openings will be mined at a depth of 850 to 1 !00 m

5 THE FUTURE OF UNDERGROUND WASTE DISPOSAL IN GERMANY

Underground waste disposal is an important disposal method in the waste management system in Germany. German underground disposal plants also perform important disposal functions for neighbouring European countries. Despite falling quantities of hazardous waste, the amounts of waste which have been disposed of underground have risen over the past few years. Nevertheless, excess capacities have arisen İn underground waste disposal sites due to an overestimation of the amounts of waste planned for underground disposal.

There have also been legal problems due to imprecisely formulated statutory regulations, which have led to differences of political and social opinions in both Germany and the European Union (EU). Similar problems have also arisen in the final disposal of radioactive wastes. Although underground waste disposal is the best long-term solution for suitably hazardous wastes from a technical point of view, political and social questions still have to be settled. For this reason, the future of underground waste disposal will not be dominated so much by technical progress but by political and social opinions.

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