Underground hazardous waste disposal: a dynamic alternative to current hazardous waste management

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Abstract

Current hazardous waste management in Europe is characterized by great differences from country to country. In the majority of EU and other European countries landfill or incineration are the main options, although in several Western European countries recovery of hazardous waste is also important.

European Directive 99/31 rises up the environmental standards for landfills and pushes hard for a big increase of the already high landfill tipping fees. Practically, this Directive acts as a market driver prohibiting new hazardous waste landfills. Taking into account that European Council Decision 2003/33 provides a concrete framework for the safe use of underground space, it seems that underground disposal in abandoned mines is a cheap and viable solution for hazardous waste.

The investigation on a suitable technology for that purpose was the main objective of the research project "Low Risk Disposal Technology". The paper presents the basic principles of the technology proposed and compares the latter with the surface landfilling.
Keywords: hazardous waste management, underground storage and disposal.

1 Introduction

The use of abandoned mines for hazardous waste disposal has already been tested in several cases as an alternative to typical landfills. Utilization of underground mines is believed to be an achievable, low-risk and relatively cheap solution for the disposal of hazardous waste. Underground mines, depending on

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the surrounding rock mass and the mining method applied, are usually "ready to use" areas as they provide an adequate space in a fairly safe environment. The necessary preparations for the construction of a waste repository are limited to its operational needs, like transportation and isolation of the waste. As a result, the construction cost of this venture is expected to be lower than that of any other underground repository that has to be designed from scratch. The concept of using, systematically, abandoned mines for hazardous waste disposal cannot be considered as a general and proven methodology, yet, but it may be, if the following questions are going to be answered:

- ❖ Does the current hazardous waste management system in Europe satisfy the environmental protection needs?
- ❖ Is underground disposal of hazardous waste a preferred option within the context of sustainable development and the current EU legislation?
- ❖ Are there abandoned mines that can be utilised in Europe?
- ❖ What are the minimum prerequisites that have to be met in order to use an abandoned underground mine?
- ❖ Are there low-cost disposal technologies under specific conditions and which is their environmental efficiency?

These questions were examined within the framework of the EC funded project "Low Risk Disposal Technology" (LRDT). Five parts have conducted this project, namely the Geodevelopment AB (Sweden), the DURTEC GmbH (Germany), the Computational Mechanics Center (UK), the Wessex Institute of Technology (UK) and the School of Mining and Metallurgical Engineering of the National Technical University of Athens (Greece).

2 Hazardous waste generation in Europe

Hazardous waste management in Europe has become one of the most important environmental issues within the context of sustainable development. Although hazardous waste consists less than 1% of all waste generated in Europe (around 36-40 millions tons per year), it presents a serious risk to the environment and human health, due to the dangerous substances it contains. The last 10 years are characterized by major changes in hazardous waste generation and management. Changes in generation rates are not uniform in European countries and they are strongly depended on the phase of economic development and the specific industrial sectors that characterize this phase.

Studies [1, 2] have shown that a large proportion of hazardous waste in most of the Western European countries consists of a relatively small number of waste types (typically 75% of hazardous waste consists of 20 principal types, a very small number compared to the 236 different hazardous list codes). The major types differ from one country to another, but in most of the EU countries hazardous waste generation is dominated by a relatively small number of sources. According to their percentage in the top 5 of the Hazardous Waste List (HWL) 6-digit codes, the main hazardous waste streams can be classified as follows:

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- Wastes from organic chemical processes
- Construction and demolition wastes
- Wastes from thermal processes
- Wastes from waste management facilities

3 Hazardous waste management in Europe

European Union has established the well-known concept of the waste hierarchy for waste management. According to this concept, waste prevention and minimization consist the only viable long-term solution for waste management, while recycling is the second preferred option. But these, undoubtedly right, options are practically translated into a need to design materials, goods and services in such a way that their manufacture, use, reuse, recycling and end-of-life disposal result in the least possible waste. Thus, this concept requires great changes in economy, market and social behaviors and such changes need time to be prepared and applied.

In the mean time, hazardous waste management in Europe is characterized by significant differences from country to country. In several Western European countries the main option is recovery of hazardous waste, but in the majority of EU and the other European countries landfill or incineration are widely used. In many countries, hazardous waste has to be stabilized before disposal, with the use of an appropriate physico-chemical treatment. However, treatment methods are often poorly defined, sometimes they are even undeclared, and this leads to difficulties in comparing practices and environmental impacts. Figure 1 presents current hazardous waste management in Europe.

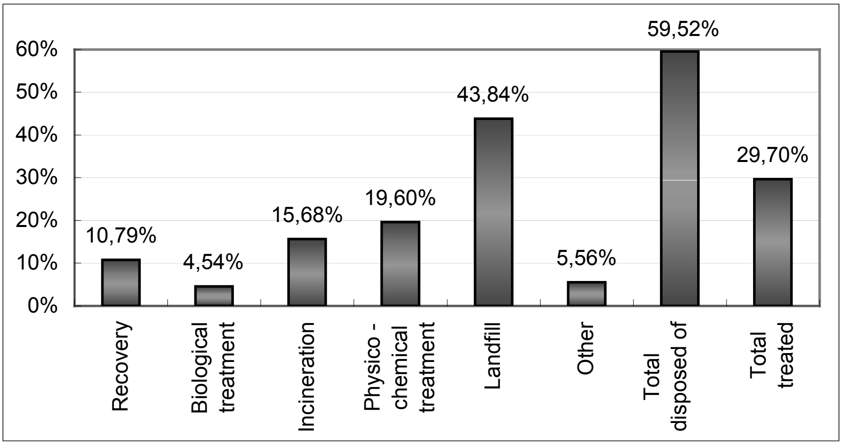

Figure 1: Current hazardous waste management practices in Europe.

It is obvious that almost 60% of the total hazardous waste is disposed of by means of landfill (almost 44%) and incineration (almost 16%), while only 11% is recovered.

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3.1 Incineration

Incineration of hazardous waste is a common used practice of disposal in a lot of countries. According to the latest year available data from EUROSTAT [3], at least 4,72 millions tons of hazardous waste is incinerated without energy recovery, an amount comparable with the 5,9 millions tons of hazardous waste that are treated with physical - chemical methods. Social acceptance of incineration is a frequent problem, especially in the cases that local conditions eventually prohibit the sustainability of operations of incineration plants (e.g. long transport routes). Although incineration can reduce the after-treatment residue of waste, not all hazardous waste are suitable for a safe incineration. Moreover, flue gas cleaning has become a very difficult and very expensive issue, especially for hazardous waste incinerators, after the related new EU directive for incinerators. An other important issue is that part of the residue (fly ash and bag - filters) is hazardous waste, which need, in any case, another disposal option. It should be noticed that slag and fly ash from waste incineration are two of the major hazardous waste streams in a lot of Western Europe countries.

3.2 Landfill

Landfilling of hazardous waste is officially considered as the lowest ranking waste management option, but it still is the dominated method of disposal in Europe. According to the latest year available data, more than 13,2 millions tons of hazardous waste is landfilled, an amount remarkably larger than the sum of all the other hazardous waste management techniques (11,8 millions tons). Environmental problems, as well as reluctance of public opinion to accept landfills as a safe technology, contribute to the creation of great difficulties for the establishment of new landfills. In most of the countries, hazardous waste landfill capacities are very limited or unavailable and thus hazardous waste is accumulating pending the availability of treatment and disposal options. Some countries (e.g. Estonia, Latvia) have demonstrated some success in this regard by establishing safe storage for large quantities of obsolete pesticides, nevertheless, this cannot be considered as a final solution. The need for an environmental sound alternative to landfill is more than urgent.

4 New EU landfill standards

At the same time European Directive 99/31 rise up the environmental standards for all types of landfills (municipal, inert and hazardous waste landfills). The directive imposes stringent operational and technical requirements on landfilling and requires a reduction in the quantity of various waste streams entering the landfills as well as treatment of all waste prior to landfill. The main scope of this directive is to eliminate landfills. Thus, the application of the Landfill Directive is usually accompanied by landfill taxes that significantly increase the cost of landfilling. The combination of the new Landfill Directive and the environmental

Waste Management and the Environment II, V. Popov, H. Itoh, C.A. Brebbia & S. Kungolos (Editors)

and social problems that characterize landfills has driven to a remarkable reduction of landfills, from a number of approximately 10.000 (1991, 12 countries of Central Europe) to a number of almost 5.000 (1999). From the above, it is obvious that landfill space has become much more limited, landfilling is politically driven to be much more expensive and landfill is considered as the less preferred option in European Union. Figure 2 presents the dramatic decrease in landfills in Europe [4, 5].

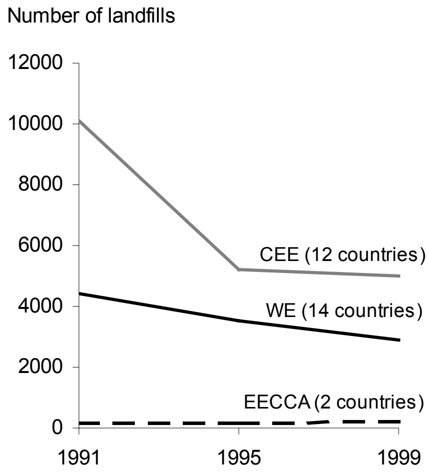

Figure 2: Reduction of landfills in Europe.

One very interesting issue is that Landfill Directive makes a distinction between underground storage and landfill. According to the Directive underground storage means a permanent waste storage facility in a deep geological cavity, as a salt or potassium mine. On the other hand landfill means a waste disposal site for the deposit of the waste onto or into land. Moreover, the Directive excludes underground storage facilities from: (a) the need for environmental monitoring and aftercare of landfill sites for about 20 years after closure and stop of their operation; (b) the obligation for leachate management in landfills (collection, treatment, protection of surface water) and (c) the undertaking of certain measures for protection of soil and water, as liners, gas handling and control etc. Finally, some other sections of the Directive (article 16 and annex 2) underline the need for development of specific waste acceptance criteria for underground storage.

The exclusion of underground storage from a lot of the strict obligations that should be applied for landfills results in a big advantage for underground disposal. While capital and operational cost of landfills are remarkably higher, in accordance with the new high technical and environmental standards, the construction and operational standards for underground disposal are much more easy to be achieved and the related costs are substantially cheaper compared to landfill costs.

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4.1 Safety assessment and waste accepted

European Council Decision 2003/33 (Appendix A) sets the basic philosophy for underground disposal. The main issue is the long-term protection of the water, utilizing the natural geological barriers of deep underground disposal facilities. The above Decision clearly mentions that waste acceptance criteria for underground storage are to be derived from the analysis of the host rock, taking into account all the local conditions. Consequently, a demonstration of the suitability of the strata for storage is necessary and thus a detailed risk assessment study should be implemented for all natural and artificial characteristics of the cavity.

The site-specific risk assessment of the installation must be carried out for both the operational and post operational phases. An integrated performance assessment analysis (geological, geomechanical, hydrogeological, geochemical, biosphere impact, impact on the surface facilities at the site etc.) should be prepared for each case.

Furthermore, a list of waste that should be excluded from underground storage is provided at Council Decision 2003/33, together with the obligation of Member States to produce lists of wastes acceptable in underground storage.

5 Low risk and the concept of underground disposal

In the following paragraphs, the basic results of the Low Risk Disposal Technology program are presented together with the authors' view of certain technical and economical issues.

5.1 Availability of mines for underground disposal

The economic growth that has been observed in all developed European countries ever since the industrial revolution relied largely on mining activity. As a result, there are a lot of abandoned underground mines, which, most of the time remain inactive and practically useless. In addition, due to the continuous decline of the mining industry, a large proportion of the remaining underground mines are expected to cease their operation in the near future [6]. These mines could also be considered as potential disposal sites.

During the study, an inventory of the used mines as hazardous waste repositories, as well as the abandoned underground mines in Europe has been conducted. There are 19 mines that have already been used for hazardous waste disposal in Europe. Additionally, more than 70 underground mines were registered and their main characteristics were recorded [7]. The majority of these mines are located in Germany, Sweden, Finland and the United Kingdom, as expected due to the intense mining activity in these countries [8].

5.2 Engineering barriers and disposal techniques

Different barriers should be used in underground disposal according to: (a) the mine characteristics (as specified by the reference types), (b) the type of waste disposed and (c) the estimated environmental risk.

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Regarding the latter issue, the barrier should be designed in a way that no major effects could be detected at the nearest aquifer that may be affected. Practically, that means that pollutants of interest should be always below certain quality limits specified according the current or potential use of the aquifer.

Alternatively to typical isolation techniques, two different disposal techniques were studied. If the geometry is suitable, the filling of the gap between the block assembly and the rock with clay slurry can be omitted. Expansion of the blocks consolidates the slurry that ultimately becomes as dense as the blocks, which can have an initial dry density of 1500 - 2000 kg/m^3. The compacted clay packages form a very effective engineering barrier.

A possible technique for backfilling of the drifts and tunnels that has been tried in practice is to blow in pellets. The net dry density is too low (800-1200 kg/m^3) for providing effective isolation of the waste but the technique can be used as an alternative to the slurry injection of the gap between block masonries and the rock. Backfilling of tunnels by using blocks requires very rational procedures and since no large-scale application of block filling has been made so far, the optimum technique is not yet known. A combination of several techniques may turn out to be at optimum.

The second technique is to prepare clay / ballast / waste mixtures. The technique for preparing and applying such mixtures may well be the same as for backfills with no waste and both applications in horizontal and inclined layers are possible.

5.3 Modeling results

According to the mine type, the hazardous waste stream and the barriers applied, a modeling procedure has been implemented in order to evaluate the environmental risk, in terms of water pollution.

The model developed in this study includes the continuum approach for the near-field rock. In the continuum approach, representative values for the continuum parameters have to be used. The numerical technique, that is used to solve the partial differential equations defined by the models, is the dual reciprocity method – multi domain (DRM–MD). The model resulted in a time scale of at least 400 – 800 years of safe disposal, with no major influence on the quality of water, if the hydraulic conductivity of the artificial barrier is below E-10 m/s.

5.4 Construction and operational issues

Underground hazardous waste disposal facilities have some significant advantages compared to the respective surface installations [9]. More specifically, as far as construction issues are concerned:

- The use of a 5 m artificial barrier or equivalent barrier (99/31 EC) below the waste body is not necessary. Even if it is needed, the use of artificial barriers is limited depending on risk assessment.
- The development of a leachate collection system (LCS), constituted of extended piping and drainage layer, is not required.

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- Wastewater treatment is negligible. In the cases it is required, safe storage of wastewater and transfer to wastewater treatment facilities is an indicated solution contrary to surface installations, where the treatment depends on local conditions and potential impacts at water tables and most of the times should be a 3rd level one.
- Storm water management is not always needed, as in the case of surface installations.

As far as operation issues are concerned:

- The environmental impacts from possible major accidents to water and ground/soil system are limited if not inexistent. Although toxic gas emissions may create problems to workers, they are not considered as a high level hazard.
- Environmental monitoring is limited, most of the times, to air quality within the working area.
- Long-term and after care monitoring is not necessary, since the main protection is provided by the underground space itself (the deepest the better). On the contrary, in the surface hazardous waste disposal facilities the protection measures that are needed have limited life – time. Thus, the landfill should be always monitored for possible leaks, even after the end of operation.

Table 1: Typical sealing cost in surface and underground hazardous waste disposal facilities.

Bottom layer for surface installations					
	Thickness	Quantity	Unit	Cost per unit (Euros)	Cost per m^2 (Euros)
Clay barrier (Hydraulic conductivity < 10^{-9} m/sec)	5 m	8,5	m^3	10	85
Geotextile	-	1	m^2	2	2
HDPE geomembrane (Hydraulic conductivity < 10^{-9} m/s)	2 mm	1	m^2	6	6
Geotextile	-	1	m^2	2	2
Drainage layer	0,5 m	0,5	m^3	5	2,5
Total cost					97,5
Sealing for underground facilities					
	Thickness	Quantity	Unit	Cost per unit (Euros)	Cost per m^2 (Euros)
HDPE geomembrane	2 mm	1	m^2	15	15
Shotcrete	10 cm	1	m^2	32	32
Total cost					47

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5.5 Cost issues

As far as the financial cost is concerned:

- Given the utilization of the already available space and the limited water inflow, the components that are needed during the construction phase have lower cost. In this case, sealing cost is the most important factor that determines the difference in the total cost of construction phase between surface and underground hazardous waste disposal. In Table 1 an indicative sealing for a surface installation cost is given, as well as the respective cost for an underground hazardous waste disposal facility.
- Monitoring, wastewater treatment and financial insurance, are the main cost drivers for operational cost. According to the operation issues mentioned above, operational cost is expected to be lower in the case of underground hazardous waste disposal.

The above-mentioned parameters reinforce the possibility of utilizing underground mines as hazardous waste repositories. The only difficulty occurring in this case is in the treatment procedures, which should be restrained due to space limitations.

It should be noticed that with the use of Low Risk techniques presented in paragraph 5.2 the above mentioned difference between surface and underground disposal of hazardous waste would increase.

6 Conclusions

Hazardous waste generation and management in Europe are in front of a necessary transformation for economical and environmental reasons. New EU landfill standards consist, actually, a market driver for the development of cheap underground disposal techniques as a dynamic alternative to current hazardous waste management system. Underground disposal in abandoned mines provides remarkable technical, financial and operational advantages.

There are a significant number (more than 70) of abandoned mines in Europe, most of which are located at the developed European countries that have the most extended industrial activities and consequently the largest hazardous waste production.

The selection of the disposal technique seems to be of particular interest, since it should be based on the physical state of waste streams, the mine layout and the hydrogeology of the surrounding area. At the same time the selected technique will significantly affect the disposal cost and the environmental efficiency, which will be in any case cheaper than the current one.

The modeling procedures prove that underground mines, with the use of the appropriate barriers, can provide hundreds of years of safe storage or disposal, with low cost. This is due to the fact that:

- Deep underground disposal provides natural protection with very slow groundwater flow and very long transport paths for pollutants.
- Isolation materials based on clay have proven been to be efficient barriers in both techniques (clay/ ballast/ waste mixtures and high-density clay blocks).

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References

[1] European Environment Agency (EEA). Hazardous waste generation in selected European countries - Comparability of classification systems and quantities, Topic report No 14/1999.
[2] European Environment Agency (EEA). Hazardous waste generation in EEA member countries -Comparability of classification systems and quantities, Topic report No 14/2001.
[3] EUROSTAT, New Cronos database 2002
[4] Austrian Federal Waste Management Plans. Federal Waste Management Plan, Federal Waste Management Report, Federal Ministry of Agriculture and Forestry, Environment and Water Management, Vienna, 2001
[5] European Environment Agency (EEA). Europe's environment: The second assessment, Copenhagen, 1998
[6] Kaliampakos D., Mavropoulos A. & Damigos D., Reducing risk of exposure from hazardous waste repositories, presented at the Environmental Health 2003 Conference, Catania, Italy, 2003
[7] National Technical University of Athens (NTUA), Survey of underground mines in Europe. Low Risk Disposal Technology Research project (E.E. EVGI – CT –2000 - 00020), Deliverable D1.1, 2000.
[8] Kaliampakos D., Mavropoulos A. & Prousiotis J., Abandoned mines as hazardous waste repositories in Europe. Proceedings of the 18th International Conference on Solid Waste Technology and Management, Philadelphia, PA U.S.A., 23 - 26 March 2003.
[9] Kaliampakos D. & Menegaki M., Hazardous waste repositories in underground mines. A possible solution to an ever-pressing problem. Proceedings of the 1st Conference on Sustainable Development & Management of the Subsurface, Utrecht, Netherlands, 5- 7 November 2003.

Waste Management and the Environment II, V. Popov, H. Itoh, C.A. Brebbia & S. Kungolos (Editors)