

WASTE DISPOSAL IN UNDERGROUND MINES - A TECHNOLOGY PARTNERSHIP TO PROTECT THE ENVIRONMENT

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INTRODUCTION

Waste disposal in underground mines is not a revolutionary concept. "A Dictionary of Mining, Mineral, and Related Terms" (U.S. Bureau of Mines, 1968) actually defines backfill as "Waste sand or rock used to support the roof after removal of ore from stope." But many mines choose not to backfill with waste rock for a variety of technical and economic reasons. Much of the underground void volume resulting from mining can, therefore, be used for the disposal of waste generated by activities other than mining.

ISSUE

At the same time that more automated and efficient mining methods generate underground space at an ever increasing rate, near-surface landfills are being strangled by "environmental" regulations, and entire categories of waste suffer from the "Flying Dutchman" syndrome, i.e., they cannot find a final resting place. This situation is a clear paradox that cries for a resolution. The good news is that one already exists and that there is no valid scientific or technical reason why the U.S. cannot avail itself of the same elegant solution.

U.S. STATUS - DEEP GEOLOGIC DISPOSAL OF CHEMOTOXIC WASTE

The U.S. does not yet use its vast supply of mined underground openings for large-scale

waste disposal, in spite of a positive, technical assessment of the concept in a twenty year-old Environmental Protection Agency (EPA) report. Principal conclusions of EPA-600/2-75-040 "Evaluation of Hazardous Wastes Emplacement in Mined Openings" (December 1975) state:

- Storage in underground mines is an environmentally acceptable method of managing hazardous industrial wastes...
- The design and operation of an underground storage facility for hazardous industrial wastes is technically feasible.
- Environmentally suitable underground space for the storage of hazardous industrial wastes now (1975) exists within the United States.
- Room and pillar mines in salt, potash, and/or gypsum offer the most suitable containment...
- The first-level (*immediate*) chemical interaction of storable hazardous industrial wastes with each other or with the receiving geological formations will not create any uncontrollable situations.
- The potential for waste migration out of a properly selected mine is slight and can be controlled through proper treatment, containerization, and site selection.
- Locating regional waste storage facilities at existing mines is technically feasible.

In view of this positive technical assessment, the EPA commissioned an economic evaluation of deep geologic disposal. The resulting report, EPA-600/2-77-215 "Cost Assessment for the Emplacement of Hazardous Materials in a Salt Mine" (November 1977) demonstrated the economic attractiveness of the concept. This old study contains a surprisingly modern sounding statement:

In many parts of the country, finding a secured on-land disposal site for hazardous wastes is a very difficult problem (sic) and underground mine space can be very attractive for hazardous waste management. Underground mine space is a valuable resource...

The study concludes with a trip report (Appendix F) of a visit to the then only known underground hazardous waste disposal facility, the Herfa-Neurode repository, part of a still operating potash mine in then West Germany. Almost 20 years later, deep geologic disposal of hazardous waste remains a fragile hope in the U.S., while several active repositories in Germany have recently even started competing with each other. As a result of that competitive pressure, disposal fees charged per ton of waste have actually declined for some waste categories.

U.S. STATUS - DEEP GEOLOGIC DISPOSAL OF RADIOTOXIC WASTE

Under the strict definition of a mine as "An opening or excavation in the earth for the purpose of extracting minerals" (U.S. Bureau of Mines, 1968), the U.S. does not plan to dispose of radiotoxic waste in mines. But the Department of Energy (DOE) is proceeding with two mining-related projects that may and should result in the eventual deep geologic

disposal of radioactive waste in the U.S.

The Waste Isolation Pilot Plant (WIPP) is the project closest to achieving its goal, the disposal of transuranic (TRU) defense waste in bedded salt near Carlsbad, New Mexico. Surface and underground facilities have been technically ready since 1988 to receive the low-activity, long-half life, and alpha-particle emitting waste. The DOE expects to resolve further bureaucratic, regulatory, and judicial hurdles by 1997 or 1998.

The DOE is also investigating another site, the Yucca Mountain Project (YMP) in southern Nevada, for deep geologic disposal of spent nuclear fuel and high-level radioactive waste. The emplacement medium under study is welded volcanic ash (tuff). An exploratory drift is being excavated, but the site is not realistically expected to start receiving waste before 2010 at the earliest.

Both the WIPP and the YMP are, strictly speaking, not mines but specially excavated underground openings. These excavations do not yield marketable minerals and, being government projects, do not generate profits. Concerning particular repository engineering aspects, however, these projects may serve as models for commercial disposal operations in underground mines, after a fashion. Information and technology transfer between the government and private sectors in this field will, therefore, benefit both sides and the environment.

ADVANTAGES OF SALT

Any geologic formation, be it host to a repository or not, is subject to the natural rock cycle, "a sequence of events leading to the formation, alteration, destruction, and

reformation of rocks as a result of such processes as magmatism, erosion, transportation, deposition, lithification, and metamorphism" (American Geologic Institute, 1972). We can therefore not designate just one kind of rock as best or ideal for deep geologic disposal. That is why various countries are using and investigating a variety of rocks that are (potentially) suitable for waste disposal.

Nevertheless, salt (NaCl) has been considered for several decades (National Academy of Sciences, 1957) to have excellent potential for deep geologic waste isolation, and Germany already operates several repositories in salt. Salt is easy to mine, virtually impermeable, and contains very little fluid. Salt reacts to differential stress by viscoplastic deformation, closing and healing voids and fractures. In that respect, it behaves similar to ice in glaciers. Massive deep salt deposits are common and widespread. Salt has been mined for hundreds of years, and the behavior of the mined openings has been studied and documented extensively. Salt formations that are hundreds of millions of years old prove through their very existence that long-term isolation from the biosphere, especially from fresh ground water, is feasible and has been achieved.

FOREIGN OPERATING EXPERIENCE

One foreign country in particular has advanced well past domestic efforts at waste disposal in underground mines. Germany practices environmentally friendly deep geologic disposal in several repositories for chemotoxic and one repository for radiotoxic waste. All of these operating repositories are either former mines or the mined-out portions of still active mines. The longest-lived of them has been emplacing chemotoxic waste since 1972. Former East Germany started deep geologic disposal of low-to intermediate level

radioactive waste in 1978. The repository medium of choice is salt/potash. Over 35 years of combined operating experience have not identified any obstacle to the safe, long-term confinement of waste in underground mines. Thus, waste disposal in underground mines has been validated safe and effective, not just by theoretical performance assessments and virtual-reality computer models, but by real-life operating experience.

OPERATING MODEL I - HERFA

The Herfa repository is part of a still active potash mine in the bedded salt of the Werra-Fulda district in central Germany. Old room-and-pillar workings have been used since 1972 to dispose of highly toxic chemical waste, mostly from industrial processes. The parent company of the mine and repository operator, Kali und Salz GmbH (Potash and Salt, Ltd), is the German chemical giant BASF. The repository started by accepting waste generated by the parent company and gradually expanded its sources to other generators: first from its home state of Hessen, then from the rest of the Federal Republic, and finally even from a few other countries in the European Community.

The salt and potash seams at Herfa are of late Permian age (~ 250 million years). This host rock is naturally impermeable and remained so even in the vicinity of several Miocene (15 million years old) basalt intrusions. Mining frequently encounters pockets of associated carbon dioxide near the dikes. This gas has not migrated significantly in the last 15 millions years, proving that salt is indeed an excellent medium for permanent confinement.

The main potash ore at Herfa is Hartsalz, a kieserite ($\text{MgSO}_4 \cdot \text{H}_2\text{O}$) - bearing anhydritic (CaSO_4) sylvite (KCl) - halite (NaCl). The nature and combination of these minerals, the

mining pattern/extraction ratio (~ 60%), and the mining depth (~ 700 m) together account for the closure rate of the openings to decline below measurability about ten years after mining. Preparation of decades-old openings for safe waste emplacement therefore consists basically of removal of the disturbed rock zone around rooms and drifts, installation of roof support where needed, and grading/compacting of the floor.

Waste comes to the repository in a variety of containers: big plastic bags, steel bins, and, most commonly, 200-liter drums. Delivery is by truck and rail. For safety and health reasons, the repository operator insists on full disclosure, before authorizing shipment, of waste components, as well as physical, chemical, and toxicological properties for each waste lot. Repository personnel routinely visit the generator sites and independently examine waste categories, processing streams, and production records before approving shipment. Waste analysis methods may include differential thermal analysis, gas chromatography, and determination of partial pressure and flammability. In addition to this examination the repository employees apply strict acceptance controls before allowing the waste to be taken underground. They carefully verify transportation manifests and other relevant documentation. Then they take representative samples of each arriving waste lot and store them in an underground sample library for future reference. Regulatory agencies may take their own independent samples. One member of the waste acceptance control staff is a trained chemical laboratory technician who checks whether each set of documentation matches the appropriate waste lot. Such a lot could range from a single container to a truck or trainload, consisting of the same waste category.

The partnership between waste generator and repository continues for at least three years after disposal, because emplaced waste remains the legal property of the generator during

that time; then the waste becomes the property of Kali und Salz GmbH. Although disposal at Herfa is in principle final and permanent, waste can be retrieved and returned to the generator for recycling, reprocessing, or other uses even after three years, but the cost for such retrieval may be substantial.

A system of four engineered barriers isolates the waste permanently from the biosphere, in addition to the principal natural barrier, the salt itself.

1. Packaging - is chemically and mechanically stable.
2. Brick walls - isolate different waste categories from each other; reduce volume to be ventilated and confine odors.
3. Anhydrite dams - isolate repository sections encompassing about five years worth of waste; are designed to be explosion-proof.
4. Shaft seals and concrete dams - are designed to withstand hydrostatic pressure.

Rooms are selectively backfilled with mined salt. Acceptable waste categories consist for the most part of solid, inorganic, and water-soluble materials with no significant gas generation potential. German waste disposal regulations start from the premise that organic waste forms can be minimized/neutralized by incineration or other conditioning, and that water-insoluble waste forms can be disposed of in near-surface landfills. Since 1972, Herfa has accommodated over 1.5 million tons of waste. Disposal fees per ton

have increased from DM 123 in 1976 to DM 440 (\$ 315) in 1993. Charges for acceptance checks/analyses, construction of walls and dams, and state disposal taxes are additional. The repository has been a steady source of moderate profits throughout its life, smoothing the ups and downs of the potash market. Repository capacity increases each year as mining generates new openings.

OPERATING MODEL 2 - MORSLEBEN

The Morsleben repository emplaces short-lived low- and intermediate-level radioactive waste from the civilian sector (power plants, research, medical, and technical applications, etc.) in a former potash and salt mine in a salt dome. Mined openings at the disposal level (500 m) are up to 150 m long and up to 30 m wide and high. Situated in former East Germany, the repository operated for 12 years before German reunification and resumed operations after a three-year hiatus in early 1994. The East German government invested about 100 million marks into the conversion from mine to repository, and the current operating license is valid until the year 2000. That license limits the amount of waste which may be disposed to about 54 000 m³. Until 1990, both liquid and solid waste forms were disposed of, with in-situ solidification of the liquids. Liquid waste disposal is no longer practiced.

Solid waste arrives at the plant in drums, with capacities ranging from 200 l to 400 l. Spent sealed radiation sources are also accepted. Spaces between and above the waste containers are backfilled with mined salt. A few small and declining inflows of saturated brine (ca. 570 l/month) that have been monitored for many decades do not present a hazard to the long-term integrity of the repository. Measured convergence rates are 1

mm/year or less. The safety analysis for the repository is based on the standards and recommendations of the International Atomic Energy Agency (IAEA) and was independently confirmed by the German federal secretary for environmental protection.

Operation of the Morsleben facility costs about DM 33 million (\$ 23 million) per year.

Generators are charged DM 12 500 (\$ 8 600) per m³.

LESSONS AND CONCLUSIONS

Environmentally compatible disposal sites must be found despite all efforts to avoid and reduce the generation of dangerous waste. Deep geologic disposal provides the logical solution as ever more categories of waste are barred from long-term disposal in near-surface sites through regulation and litigation. The German experience proves that it is possible to safely and permanently dispose of chemotoxic and radiotoxic wastes in underground mines. That example has blazed a trail which the U.S. mining industry must follow. Past mining in the U.S. has left in its wake large volumes of suitable underground space. EPA studies and foreign practice have demonstrated deep geologic disposal in mines to be rational and viable. In the U.S., where much^{of} the mined underground space is located on public lands, disposal in mines would also serve the goal of multiple use. It is only logical to return the residues of materials mined from the underground to their origin. Therefore, disposal of dangerous wastes in mined underground openings constitutes a perfect match between mining and the protection and enhancement of our environment.

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