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UNDERGROUND STORAGE OF HAZARDOUS WASTE

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Summary

The use of underground space for the storage of hazardous waste is a little used option and is a viable candidate to supplement existing and developing technologies.

The use of underground storage for hazardous waste has been successfully demonstrated for 13 years at the Herfa-Neurode Mine Facility in West Germany [1]. There is an ongoing effort to clean up dioxin contaminated soil in Missouri, one of the proposed solutions is the use of mined space for the long-term storage of this contaminated soil. The magnitude of the problem, criteria for siting a mine facility and a brief description of a proposed facility are outlined [2]. The proposed use of solution mined space in salt offers the potential for large volume bulk storage of hazardous waste. Several design and operational concepts are illustrated and discussed.

Worldwide activities utilizing underground storage for hazardous waste containment, as described in the literature, are summarized and referenced.

Introduction

Underground storage of hazardous waste is a little used option at the present time. The presently accepted methods of treatment and disposal of hazardous waste are deep well disposal, RCRA designed landfills, land treatment and incineration.

Over the past 5 years, the magnitude of the hazardous waste problem in the United States has become more apparent and the public and Congress are pressing for solutions to the problem. The practice of moving the hazardous waste from a remedial action site to a permitted facility is now seen as counter productive. This has created a need for long-term storage capability for large volumes of contaminated materials.

Existing or new mines are technically and probably more important, economically, a feasible method for long-term storage of large volume waste or for permanent storage of the toxic end products of hazardous waste treatment.

The advantages of using mined space for storage of hazardous waste are:

- Mined space can be created economically in large volumes,
- In shallow mined space the waste would be contained above the ground water table,

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- In deep mined space the waste would be located below the potable aquifers,
- Isolation from the public and the surface ecology,
- If required, waste can be isolated from the hydrological environment by encapsulation or containerization,
- Security can be readily maintained,
- In a sealed mine, no continuing maintenance will be required, and
- If retrievability is desired, the mine could be used as a long-term underground warehouse.

Regulation and permitting

In the United States the regulation and permitting of a hazardous waste storage facility is governed by the Resource Conservation and Recovery Act (RCRA).

In May 1980, EPA published regulations which include provisions whereby a state agency may be authorized by EPA to administer a hazardous waste program in that state in lieu of a federally administered program. Many of the states have chosen to develop and manage their own hazardous waste programs under EPA regulatory guidelines [3]. A few states have not developed or are lagging in development of their hazardous waste management plans, and EPA is now administering their program. The result is that a reasonably uniform hazardous waste management program is being conducted throughout the United States.

At this time neither EPA nor any of the states have developed regulations specifically pertaining to hazardous waste storage in mined space. Therefore, initial mined hazardous waste facilities will have to be designed, sited and evaluated by interpretation of the intent in existing regulations, with ultimate legislation being developed if the feasibility of mined storage is demonstrated.

The EPA regulation governing permitting a of new hazardous waste facility requires preparation and submittal of a two-part application for approval of the proposed facilities [4].

Present permitting requirements do not include specific terms related to waste storage in mined space. The general format and requirements are, however, comprehensive enough to provide the basis for requisite information for a mined hazardous waste storage facility permit application.

In general, states administering their own program now have regulations and permitting practices which conform to EPA hazardous waste management regulations and administrative criteria. Differences in storage regulations and permitting procedures do not appear to be major. At this date, none of the authorized states have regulations which specifically relate to the storage of hazardous waste in subsurface mined space.

The 1976, RCRA does not prescribe requirements for the siting of new hazardous waste management facilities. Present policies consider this function to be the responsibility of each state. Consequently each state has developed its own criteria for siting and permitting a facility [5].

Technology evaluation

An evaluation of the technology of underground storage of hazardous waste consists of the description of: existing mines, new mined space and solution mined caverns in salt. The development of these methods ranges, from presently in use, to conceptual designs. The following summarizes the current development of each of these methods.

Existing mines

The Herfa-Neurode facility in West Germany is the only example presently in operation. This facility was established in 1972, and has been in continuous use since that time. The facility is located in a depleted portion of a potash mine. The mine is at a depth of approximately 700 m in horizontal sedimentary beds of salt and potash. The mine level is reached by a vertical shaft equipped with a mine type of hoist or elevator. The extraction plan of the mine was a checker board pattern called room and pillar. This pattern created a series of rooms alternating with supporting pillars. These rooms are used for the storage of the hazardous waste containers and when each room is filled it is sealed off from the active mine by concrete block walls. In the event a portion of the stored waste must be recovered for reprocessing or reuse; the walls can be removed and the waste returned to the surface. Administrative procedures have been developed so that a paper-trail for each container is maintained. Safety procedures have been established for this facility which include spill mitigation measures. This facility can be considered a state-of-the-art example of the use of an existing mine for hazardous waste storage.

New mined space

The concept of using new mined space for long-term storage of hazardous wastes allows the designer to select the best geological environment, locate the facility near transportation and design the best method of access to the facility (Incline, Shaft, etc.). It allows the engineer to construct the facility to the most efficient layout or pattern to meet the material handling, storage, environmental and personnel safety requirements and regulations. It allows the designer to more readily meet the regulations and procedures necessary to isolate the waste, protect the ground water, minimize soil erosion and reduce air contamination during recovery operations.

Solution mined caverns in salt

There are a number of methods which might be employed for utilizing solution mined caverns for the storage of hazardous wastes. Each possible technique is directly related to the type and character of the waste to be stored. None of these techniques have been permitted or used for commercial hazardous waste storage to our knowledge.

Brine balanced cavern

Nearly all of the existing storage for liquid hydrocarbons in the U.S. utilizes the brine balance method. The liquid hydrocarbon, being lighter than brine, floats on top of the brine and flows out under pressure when the product valve at the wellhead is opened. During product withdrawal, brine is added to the casing string hanging to the bottom of the cavern so that the cavern is maintained full of fluid at all times. When product is introduced into storage, it must be injected by means of a pump, displacing brine up the casing string and over to a brine holding pond. Caverns using this concept have a very long life because the range of stress change on the salt is small.

If the hazardous waste slurry was significantly lighter than saturated brine, the waste could be injected into the top of the cavern, displacing saturated brine up the casing string as shown in Fig. 1. The displaced brine could then be injected into the same disposal wells that were used for construction of the cavern.

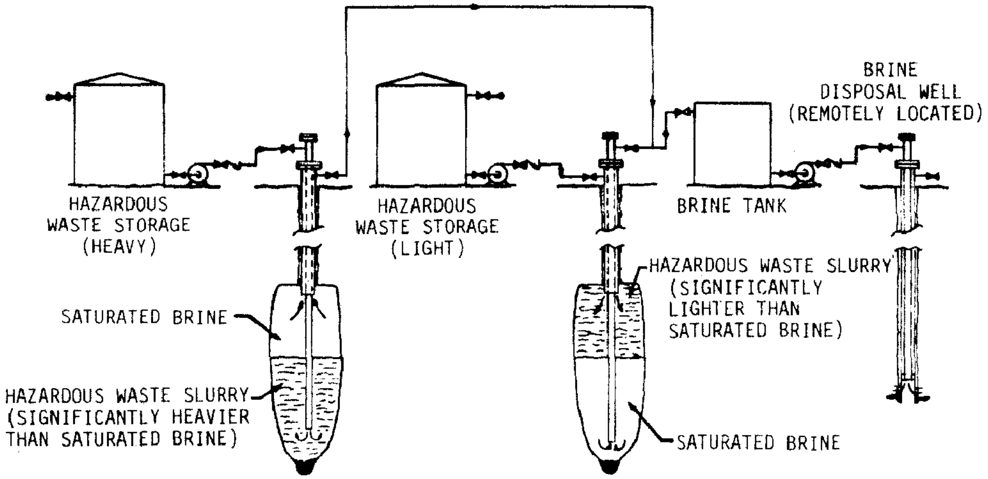

Fig. 1.Brine-balanced cavern with brine discharge during waste injection.

If the specific gravity of the waste was close to or greater than that of the saturated brine, the waste slurry would have to be weighted so that it would be significantly heavier than the brine causing it to remain in the bottom of the cavern as shown. The floating brine would be displaced from the top of this cavern and would be directed to disposal as before.

Although gravity separation of liquids is used extensively in solution mined caverns, the risk of contaminating the brine would increase as the specific gravity of the waste approaches that of the saturated brine. Brine contamination might also result from gases or vapors released by the hazardous waste in the cavern in the case of the heavy waste/floating brine cavern.

Gas-balanced cavern with zero discharge

In this method, after the cavern had been developed to capacity, the brine would be displaced by an inert gas and injected into a remote brine disposal well as shown in the cavern dewatering scheme of Figure 2. The cavern would be sealed at the minimum design pressure after which gaseous, liquid and slurry hazardous wastes would be injected into the cavern until the inert gas reached the maximum design pressure of the cavern as shown in the storage scheme of Fig. 2. Gas-balancing eliminates the possibility of contaminating the brine, and eliminates the need for a scrubber and flare, unless they were needed for the surface plant.

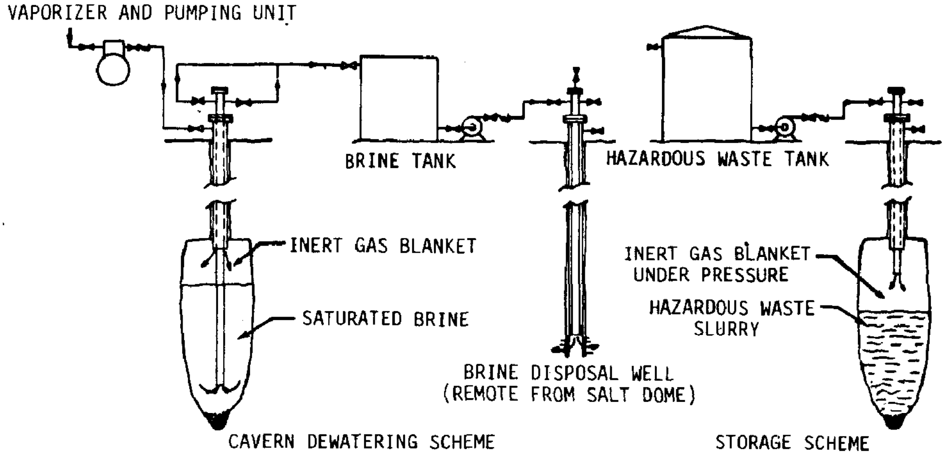

Fig. 2. Gas-balanced cavern with zero discharge.

Atmospheric cavern with controlled gas discharge

Following solutioning of the cavern to its design capacity, the brine could be pumped out of the cavern by means of a submersible pump and directed to disposal. Chemically compatible liquid and pumpable slurry wastes would then be injected into the cavern. Displaced vapors and/or gases would be collected and would be either sent through a scrubber or burned in an approved flare as shown in Fig. 3.

A cavern designed to be exposed to atmospheric pressure would be limited in size to maintain structural integrity. There would be no brine contamination, but a scrubber and a flare would be required.

In-situ-solidified waste disposal

Recently, officials of the state of Texas, who are responsible for permitting requirements for underground storage, have been considering a

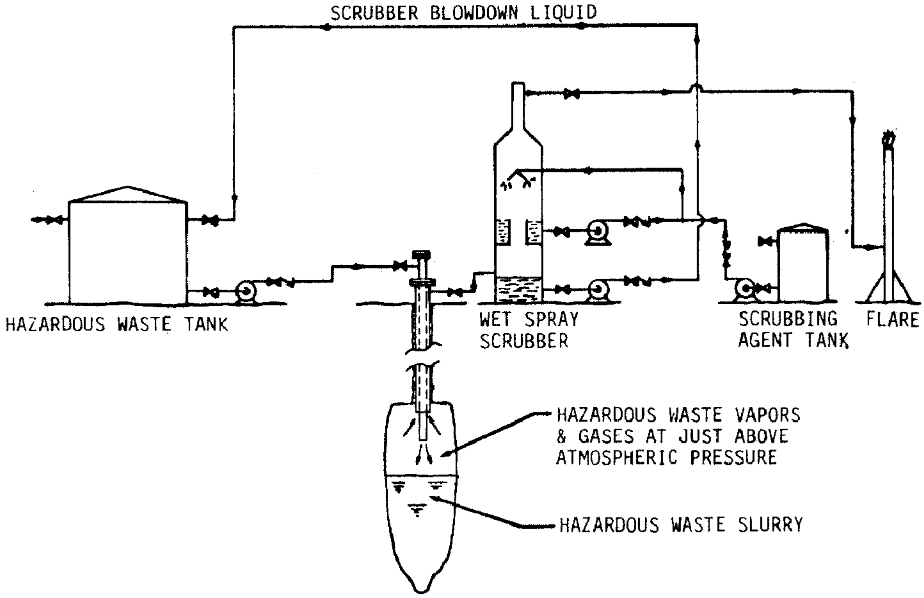

Fig. 3. Atmospheric cavern with controlled gas discharge during waste injection.

concept that would require that all hazardous waste be mixed with a cement of polymer slurry prior to injection into a cavern as shown in Fig. 4. This would provide a permanent disposal for liquid and slurry wastes and would reduce risks occasioned by earthquake or the inadvertant drilling into a hazardous waste cavern. This type of cavern would be limited in size in order to maintain structural integrity during the period it would be exposed to atmospheric pressure.

"String of pearls" waste storage caverns

By constructing a series of caverns, one above the other, from one deep solution well; the dome salt resource could be more effectively utilized for a given maximum cavern depth as proposed by Empak, Inc., of Houston, Texas [6]. Each cavern could be sealed by the installation of a cement plug in the top neck of the cavern, prior to starting construction of the next cavern above it as shown in Fig

The brine from the first (bottom) cavern could be removed by submersible pump and directed to the remote disposal wells. This cavern would remain structurally stable due to its small size and because it would be rapidly filled with waste, reducing the time that it would be exposed to near atmospheric pressure.

For maximum structural integrity into the future, all of the hazardous waste could be mixed with a cement slurry so that the entire small cavern would solidify as outlined in the preceding method. Then construction of the small middle cavern could proceed as shown [7].

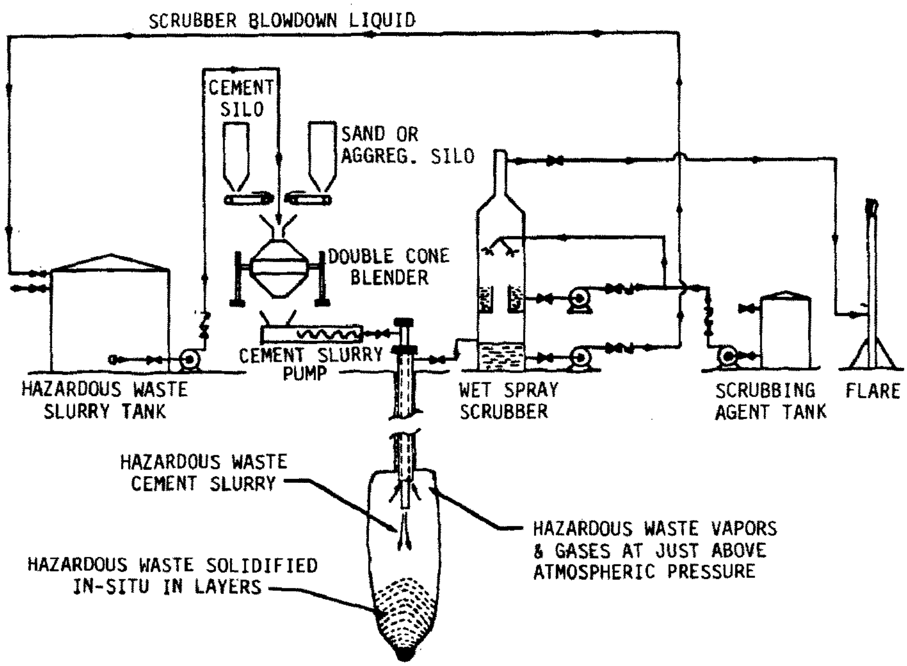

Fig. 4. In-situ-solidified hazardous waste storage.

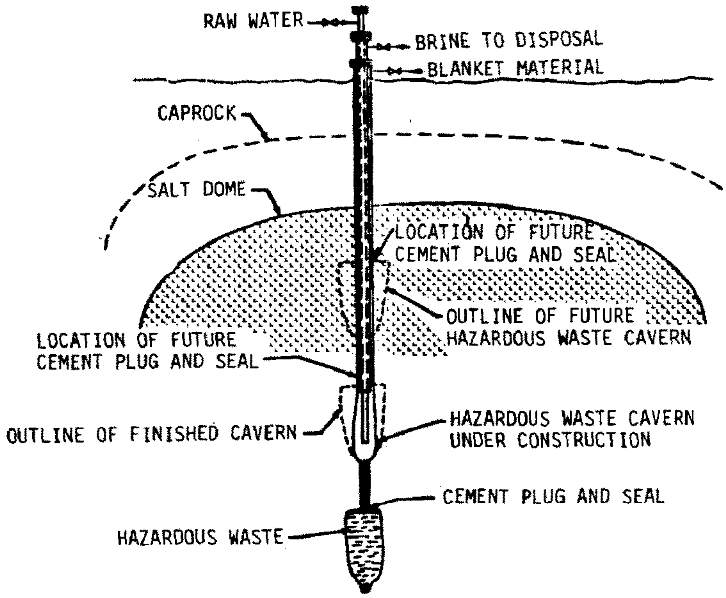

Fig. 5. "String-of-pearls" waste storage caverns.

Recent activity

Recent activities are listed alphabetically by country and by state in the United States. Solution cavern and mined cavern approaches to underground storage are intermixed as they were reported by the various authors in the literature.

Canada

Mercury compounds have been deposited in three solution mined salt caverns near a chlor-alkali plant in Saskatchewan; the mercury compounds take the form of clarifier sludge in one cavern and occur in suspension and in solution in the others.

A salt cavern in the Sarnia district of southwestern Ontario serves as a repository for heavy, chlorinated hydrocarbons which are injected down 3 disposal wells. Three other salt caverns contain waste purge gas from a gas processing plant.

Giant Yellowknife Mines Limited at Yellowknife (Yukon Territory) uses cemented backfill to replace reinforced concrete in the construction of pressure bulkheads for underground chambers. These chambers are designed to contain arsenic dust produced through the roasting of arsenopyrite. The disposal of arsenic dust is into 7 separate underground chambers, located in the permafrost zone at about 75 m below ground level. An amount of 170,000 tonnes of arsenic dust has accumulated in the chambers since 1951 when disposal was begun [8].

Germany

The Herfa-Neurode facility has operated for thirteen years after its startup in 1972. Approximately 270,000 tonnes of hazardous waste have been placed in the mine. The annual volume presently is running between 35,000 and 40,000 tonnes. Approximately 25% of this tonnage originates outside Germany. The reuse of stored waste is possible and over 1000 tonnes of waste have been retrieved and sent back to the generator [9].

Holland

In 1938, Akzo, a chemical manufacturing firm in the Netherlands, started disposing of wastes from brine purification units into existing salt caverns in the Henglo area. In 1965, they began using salt caverns for the disposal of salty drilling muds. In 1978, they began disposing of magnesium chloride under the salt brine. Akzo has developed the original "string of pearls" concept wherein a series of waste disposal caverns are leached, one above the other, from a single deep solution well [10].

India

Studies for storage of hazardous waste in mined space have been conducted for the central region of India by the Geological Survey of India.

These studies examined the use of existing and new caverns to reduce severe waste pollution in the central region [11].

United States

Kansas

The Carey Salt Company, a midwestern salt producer, has utilized worked-out solution caverns since the early 1950's to dispose of calcium sulfate waste slurry from the salt refining process. The carrier liquid is salt brine. As the slurry is circulated through the cavern, the calcium sulfate settles to the bottom and the brine is returned to the brine refining circuit [12].

Louisiana

In 1983, Empak, Inc. of Houston, Texas submitted an application to the Louisiana Department of Conservation for a permit to build a hazardous waste facility at the Vinton Salt Dome in Southwest Louisiana. This project envisioned using solution mined caverns in the salt dome as final storage for hazardous waste. After this project was announced, a state law was passed (in 1983) forbidding emplacement of hazardous waste in salt domes for a period of two years. This was intended to allow the state time to evaluate the proposed use prior to issuing a permit. The option for exclusive use of the Vinton Salt Dome was dropped and the application withdrawn due to regulatory and legislative delays [13].

Minnesota

The Minnesota Waste Management Board financed a study entitled "Subsurface Isolation of Hazardous Wastes" which was completed in 1982. This study was conducted by the University of Minnesota and was oriented to deep geologic disposal in crystalline bedrock within the state. Following preparation of the report, the Waste Management Board made a survey to locate specific sites. They identified 18 mine study sites and anticipated reducing these to five sites for further investigation. Further investigation was to consist of air and water surveys and core drilling to determine the rock quality. When the five sites were announced, public opposition was immediately apparently and vocal. The Minnesota Waste Management Board dropped the crystalline rock concept from further consideration, due to its high cost, during a meeting held on February 24, 1984 [14].

Missouri

The discovery of dioxin contaminated soil at Times Beach, Missouri and the subsequent detailed investigation of the State for other contaminated sites led to the identification of 42 contaminated sites throughout the State with others being suspected to exist. Twenty seven of these sites are located in the St. Louis area, with another sizeable contaminated area near Springfield. The EPA's Hazardous Waste Engineering Research Laboratory in Cincinnati, Ohio conducted a study of the use of mined space for permanent storage of the dioxin contaminated soil from each site. EPA was assisted by PEI Associates and the Missouri Department of Natural Resources, who provided valuable assistance and background in locating and evaluating existing mines, state geology and hydrology. The State of Missouri is well known for its utilization of mined space for warehouses, offices, manufacturing facalities and recreational facilities, thus, the use of mined space for this purpose is a natural extension of the existing technology and use.

The principal objectives of the mine study included:

- Establish preliminary criteria for selection of candidate mines.
- Determine the proximity of existing mines to the contaminated areas.
- Determine the size, volume and capacity of candidate mines.
- Evaluate the geological and hydrological conditions associated with each mine, with primary emphasis on wet/dry conditions and proximity to groundwater.
- Evaluate the concept of developing a new mine in lieu of using an existing mine.
- Determine the availability of selected mines.
- Identify front-end preparations and fail-safe backup systems necessary for full-scale implementation.
- Determine data requirements for implementation such as: detailed hydrological evaluation, risk assessment, transportation studies and engineering design of onsite facilities.
- Identify available transportation options.
- Estimate the cost of developing one or more facilities.
- Document the advantages and disadvantages of the concept.
- Identify constraints posed by Federal and State laws and regulations.
- Identify local organized opposition.

In general, this concept is a viable alternate to other treatment/disposal options and may be as cost effective or even more cost effective than some of the other technologies. The packaging and transporatation of the contaminated material will constitute the largest part of the cost of operating a facility. Because this proposed facility would have a single use (dioxin storage), the design can be simplified to a near surface room and pillar mine, located in a massive sandstone or limestone formation above the water table. A new mine facility possibly on state owned land may be required due to the long term liability problems by the dioxin contaminated soil [15].

New York

The International Salt Company at Watkins Glen, New York began placing the residual natural wastes from their salt production operation into three interconnected solution wells in 1971, these wastes consist primarily of calcium sulfate solids and trace minerals such as iron, copper, cobalt, sulphur, etc., used in the manufacture of cattle feeds and salt blocks. The heavy metals were allowed to settle out in a solution cavern displacing the lighter brine to the surface for injection into a subsurface contaminated aquifer called the "black water" horizon and also known as the Cherry Valley formation. This formation contains hydrogen sulfide and other organic contaminates. The disposal well was permitted by the Department of Environmental Conservation of the State of New York [16].

Ohio

The proposed conversion of the PPG Industries, Inc. (Barberton, Ohio) limestone mine to a waste storage facility in 1981/82 has been dropped. This facility was proposed as a general hazardous waste repository with all types of waste being acceptable. Waste would arrive at the facility by rail and truck and be transported underground. A public information program was started and the local residents were invited to tour the mine to see for themselves the integrity and containment potential. Subsequently, public opposition was organized and pledged to fight the establishment of a hazardous waste facility at this site.

The project did not reach the permit application stage. A public notice discontinuing the project was issued by PPG Industries, Inc. on July 12, 1982. PPG cited U.S. economic conditions as the reason for discontinuing plans for this facility. However, based upon review of the public hearing documents, the organized public opposition to the proposed facility had a significant effect upon this decision [17].

Texas

United Resource Recovery, Inc. of Houston, Texas submitted an application to the Texas Department of Water Resources for a permit to store hazardous waste in the Boling Salt Dome. This application was returned to the company for further elaboration and information and has subsequently been resubmitted and is still pending. This request, in turn, triggered a two-phase geological study to evaluate the acceptability of using salt domes in Texas for waste disposal and to recommend guidelines for waste storage on salt domes. This study was performed by the Texas Bureau of Economic Geology (BEG) and was funded through October 1984. The study addressed the following factors:

- Domal Geologic System
  - Salt Stock
  - Cavern Stability
  - Cap Rock
  - Surrounding Strata
- Dome Geohydrology
  - Aquifer Pressures
  - Direction and Velocity of Ground Water Flow
  - Permeability
  - Aquifer Heterogeneities
  - Aquifer Chemistry
  - Age of the Ground Water

Engineering Considerations
Casing Seals
Casing Corrosion
Differential Salt Mass Flow
Engineered Barriers
Solidifying of Chemical Waste

Reports issued as a result of the study have defined the geological and technical issues involved with salt dome cavern hazardous waste storage. BEG concluded that the first year of study did not answer all critical questions, but that results did not disqualify salt domes as potential hosts for permanent isolation of toxic wastes. [18].

A second year of study (Phase III) was authorized and research covered the following subjects:
Subsidence and Collapse
Structural Patterns Around Texas Salt Domes
Cap Rock
Cap Rock Hydrology

The contents of the report consisted of five individual research reports covering various factors for the Boling, Barbers Hill and Damon Mound Domes. A summary of the results of the various studies as they applied to the overall problem was written by S.J. Seni. Conclusions reached were:

1. Salt domes may be suitable hosts for permanent isolation of some types of toxic waste in solution-mined caverns in salt.
2. Not all domes are appropriate sites for toxic waste disposal owing to uncertainties about dome size, shape, depth, salt heterogenities, cap-rock lost-circulation zones, hydrologic and structural stability, growth history and effects of resource exploration and development.
3. The large number of negative aspects associated with the Boling Dome over ride the positive aspects and the conclusion was reached that the use of the Boling Dome as the first site for toxic chemical waste disposal should be discouraged.
4. Methods for slurry transport and disposal of solidified toxic waste in solution-mined caverns are needed. No specific studies of the waste or in-situ solidification within solution-mined caverns are available.

The following recommendations were made:

1. All waste caverns are to be initiated with large diameter cores (approximately 6 in. (0.15 m) in diameter) from the surface to 500 ft. (152 m) below the projected cavern depth to assure that adequate data are available to determine necessary geotechnical parameters. The core must be stored in perpetuity, preferably by the appropriate state or government agency.
2. Extra casing strings are to be set through the surface strata and cap rock. If lost-circulation zones are encountered, they must be filled with cement to prevent collapse and fluid migration. Cement shall be circulated until cement returns to the surface.

3. If major discontinuities are encountered within the salt in the form of drill holes, faults, significant bodies of incorporated terrigenous clastics, or significant bodies of other non-salt material, then the position of the waste cavern shall be adjusted so that a minimum distance of 500 ft. (152 m) separates the anomalous zone from the nearest cavern wall.
4. Waste material within the cavern must be solidified and have strength and density equivalent to or greater than salt [19].

Research activity

The U.S. Environmental Protection Agency has sponsored studies and development projects in recent years covering the fields of encapsulation, storage and fixation technologies. The developments from these and related projects have provided valuable background information on containment which did not previously exist and would apply directly to the use of mined space for storage of hazardous waste [20].

In addition to the EPA projects, the U.S. Department of Energy (DOE) and its predecessor agencies, have sponsored research and testing for siting, designing, constructing and maintenance of facilities for storing radioactive wastes in mined spaces. This research, administered by the Office of Nuclear Waste Isolation (ONWI) via various national laboratories and their contractors, was initially directed at storage of such wastes in salt deposits. Research has since been broadened to include other types of geological settings. Present studies, tests, and demonstrations for nuclear waste storage are continuing in salt, basalt, tuff, and crystalline rock geologic formations [21].

The American Society for Testing Materials (ASTM), through its Committee D-34, has been working on a "Guide for Determing the Compatibility of Hazardous Waste". Once an acceptable methodology for determining the compatibility of hazardous waste has been established, it could be expanded to include the compatibility of the waste to a particular geological environment. This evaluation would be needed in the event of a hazardous waste coming in direct contact with the rock of a mine storage facility due to a spill or rupture of a container. The potential for adverse reactions must be known so that appropriate safety procedures can be planned.

Conclusions

Three types of underground storage facilities which have been or are being proposed for the use of hazardous waste storage have been reviewed and described. These were, in order of technological development.

1. Existing mines — Salt, potash, gypsum and limestone mines which have been mined by the room and pillar method and have relatively flat lying geology, i.e., bedded deposits. A primary requirement is for the mines to be dry without water leakage from the surface or overlying aquifers. Water seepage in the access shafts must be controllable.

2. New mined caverns — New mined caverns can be sited in the best geological formations. The design of the facility can be tailored to the specific needs of a hazardous waste facility. The choice of geological formations is much broader for a new facility and can include structurally competent shales and sandstones as well as the minerals previously mentioned. The mining interval must be dry.

3. Solution mined caverns in salt — Solution mined caverns in salt could provide secure containment for hazardous wastes and complete isolation from the environment. Large salt deposits are located near a number of hazardous waste generating areas in the United States. This proximity would minimize the transportation hazards and the associated costs. Solution caverns have a long history of effective containment of hydrocarbon products in the petroleum refining business. This may be one of the most economical methods of providing permanent retention of hazardous waste [22].

New Mined Caverns and Solution Mined Caverns will require more research and development prior to their use.

References

1 A.A. Boraiko, Hazardous waste, National Geographic Magazine, Published by the National Geographic Society Washington, DC, 167 (3) (March 1985) 336—337, 346.

2 M.P. Esposito, W.E. Thompson, J.S. Gerber and J.C. Ponder, Mined space — A viable alternative to landfilling for the long-term retention of contaminated soils and other hazardous wastes in Missouri. In Proc. 6th National Conference on Management of Uncontrolled Hazardous Waste Sites, November 4—6, 1985, Hazardous Materials Control Research Institute, Washington, D.C., pp. 387—392.

3 Resource Conservation and Recovery Act of 1976, Subtitle C, Regulations published in the Federal Register in May, 1980.

4 Code of Federal Regulations, Section 40, Paragraph 270.

5 R. Stone, Update: Storage of hazardous waste in mined space, Proc. 11th Annual Research Symposium on Land Disposal of Hazardous Waste, sponsored by the U.S. Environmental Protection Agency, Office of Research and Development, Hazardous Waste Engineering Research Laboratory, Cincinnati, Ohio, 1985, pp. 341—342, 344—350.

6 M. Hooper, J. Geiselman, T. Noel and J. Piskura of Empak, Inc., Houston, Texas, Vinton Salt Dome Project Descriptions, Section III, November, 1983.

7 R. Stone, K. Covell and L. Weynand, Using Mined Space for Long-Term Retention of Nonradioactive Hazardous Waste, Vol. 2, Solution Mined Salt Caverns, Contract No. 68-03-3191, for the Land Pollution Control Division, Hazardous Waste Engineering Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1984, pp. 37 and 41.

8 F. Simpson, Potential for deep, underground storage in Canada, In M. Bergman (Ed.), Storage in Excavated Rock Caverns, Proc. International Symposium — ROCKSTORE 77, Stockholm, Sweden, June 1977, Pergamon Press, New York, pp. 37—41.

9 A. Finkenwirth and G. Johnsson, Subsurface waste disposal facility Herfa-Neurode near Heringen on the Werra, In Proc. 5th Symposium on Salt, Vol. 1, Northern Ohio Geological Society, Cleveland, Ohio, 1979, p. 239.

10 H. Wassmann, Cavity utilization in the Netherlands, Akzo Zout Chemie Nederland, Postbox 25, 7550 GC Henglo, The Netherlands, 1983, 20 pp.

11 D. Ghosh, Natural cavern and underground space for controlling environmental hazards in central India, In M. Bergman (Ed.) Subsurface Space: Environmental Protection, Low Cost Storage Energy Savings, Proc. International Symposium — ROCKSTORE 80, Stockholm, Sweden, June 1980, Pergamon Press, New York, 1981, pp. 285—294.
12 R. Stone, K. Covell and L. Weyand, Using Mined Space for Long-Term Retention of Nonradioactive Hazardous Waste, Vol. 2, Solution Mined Salt Caverns, Contract No. 68-03-3191, for the Land Pollution Control Division, Hazardous Waste Engineering Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1984, p. 6.
13 M. Hooper, J. Geiselman, T. Noel, J. Piskura and F. Gentry, Vinton Salt Dome Project, Empak, Inc., Houston, Texas, 1983.
14 R. Stone, T. Moran, L. Weyand and C. Sparkman, Using Mined Space for Long-Term Retention of Nonradioactive Hazardous Waste, Vol. 1, Conventional Mines, Contract No. 68-03-3191, for the Land Pollution Control Division, Hazardous Waste Engineering Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1984, pp. 10—12.
15 P. Esposito, W. Thompson, P. Fairbank, T. Ponder, D. Sappington and J. McArdle, DRAFT REPORT, Feasibility of Utilizing Mined Space in Missouri for Long-Term Placement of Dioxin Contaminated Soils, PEI Associates, Inc., Cincinnati, Ohio, for EPA, Hazardous Waste Engineering Research Laboratory, Cincinnati, Ohio, 1985.
16 C. Jacoby, Underground mining, mine storage, and other attendant uses, In English, Foundation Conference on Need for National Policy for the Use of Underground Space, Proceedings, Papers, and Summaries, American Society of Civil Engineers, New York, 1983.
17 Disposal of Hazardous Wastes in Mines; A Case at Norton, Ohio, hearing before the Subcommittee on Commerce, Transportation and Tourism of the Committee on Energy and Commerce, House of Representatives, 97th Congress, 2nd Session, Washington, D.C., Government Printing Office, 1982.
18 S. Seni, H. Hamlin and W. Mullican III, Technical issues for chemical waste isolation in solution-mined caverns in salt domes, Contract No. IAC (84-85)-1019 for the Texas Department of Water Resources, by the Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas, 1984.
19 S. Seni, E. Collins, H. Hamlin, W. Mullican III and D. Smith, Phase III: Examination of Texas salt domes as potential sites for permanent storage of toxic chemical waste, Contract No. IAC (84-85)-2203 for the Texas Department of Water Resources, by the Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas, November 1985.
20 J. Jones, M. Bricka, T.E. Hayes and D. Thompson, Stabilization/solidification of hazardous waste, Proc. 11th Annual Research Symposium, EPA/600/9-85/013, Sponsored by the U.S. EPA, Office of Research and Development, Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, April 29—30, May 1, 1985.
21 Office of Nuclear Waste Isolation (ONWI), Battelle Memorial Institute, Columbus, OH, A list of publications may be obtained from the above office.
22 North American Storage Capacity for Light Hydrocarbons and LP-Gas Import Terminals — 1983, Published by Gas Processors Association, 1812 First Place, Tulsa, OK, U.S.A.