Use of Solution – Mined Salt Caverns for the Disposal of Hazardous and Industrial Waste Products

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1. INTRODUCTION

The overall growth in world population, and the resulting increase in industrial activity and the recognition of environmental and health impacts from indiscriminate disposal of waste products has led to the need for an alternative to traditional methods of land filling and high temperature combustion.

The use of geologic repositories (particularly in salt formations) for the storage of crude oil, natural gas, liquefied petroleum gases (LPG) and other petro-chemical products is well established throughout the world. This paper discusses the use of salt formations, particularly caverns within domal salt formations which are developed by modern solution-mining techniques, for the long term disposal and isolation of hazardous and industrial waste streams from the environment. This paper describes the specific requirements and design parameters used by Secured Environmental Management, Inc. of Houston, Texas (USA) in the development of the first project to be permitted and constructed by regulatory authorities in the US for hazardous waste management and briefly discusses other applications.

2. STATUTARY AND REGULATORY PROGRAMS

2.1 Statutory Citations

Historically, five different hazardous waste disposal projects have been proposed in Texas since the early 1980's. Two of the projects were abandoned relatively early because of legislative and political problems. Of the remaining projects, one project was denied it's permit; the fourth project initially received permits but were later denied the final operating permits and the fifth (an apparently successful project) is the subject of this paper.

Each project has had progressively more stringent regulations to meet prior to reaching the final public hearing stage of the project. The four primary Federal statutory programs on which the specific regulatory requirements are based include [1-4] :

1. The Safe Drinking Water Act (SDWA) as amended;
2. The Resource Conservation and Recovery Act (RCRA) of 1976 as amended;
3. The Clean Air Act (CAA) as amended;
4. The Clean Water Act (CWA) as amended.

The citations to these statutes and to the implementing regulations are found in the reference section to this paper. Texas is a state that has been granted authority to administer the federal (EPA) programs within the state. The specific regulations for the state programs are also cited [5,6].

2.2 Regulatory Requirements

The entire body of regulatory requirements are voluminous and very detailed. The reader is encouraged to obtain full text copies off the internet at: www.tnrcc.state.tx.gov (for Texas State regulation) and www.epa.gov/epahome/rules.html for Federal EPA regulations.

With reference to the above regulations, the following major considerations must be addressed to obtain a permit to construct a hazardous waste management facility in the US.

A. Considerations under the Safe Drinking Water ACT- Underground Injection Control Program (Cavern Development)
   1. Siting Considerations
   2. Geologic Requirements
   3. Cavern Development
   4. Cavern Operations
   5. Cavern Closure
   6. Financial Assurance

B Considerations under the Resource Conservation Recovery Act (Surface Facility Development)
   1. Siting Requirements

2. Waste Identification/Receipt Requirements
3. Process Requirements
4. Emergency Response Considerations
5. Tank Design/Storage Considerations
6. Financial Assurance
7. Considerations Under the Clean Air Act

C Considerations under the Clean Air Act (CAA)

1. Property line Emission Limit Requirements
2. Technology consideration
3. Testing and Monitoring requirements
4. Financial Assurance

D Considerations under the Clean Water Act (Waste water discharge)

1. Discharge Limitations
2. Technology Requirements
3. Financial Assurance

3. SPECIFIC SITING AND DESIGN CONSIDERATION SETTING

3.1 Siting Considerations

Texas has three major areas of domal salt formations – The East Texas Basin and the Coastal Salt Basin and the South Texas Basin. There are well over five hundred different on-shore and off-shore (Gulf of Mexico) domes ranging in depth from a few hundred feet to top of salt to deep seated domes where the top of salt is several thousand feet below ground surface. Deep seated domes are not considered suitable at this time for disposal.

Regulatory requirements depend on the geographical location of the site. Sites in the US have many different state regulations that may supercede federal regulations. Locations outside of the US may have simple basic requirements or have comprehensive complex regulations or no regulations at all. Although at first thought, the lack of regulatory guidelines may seem advisable, a basic and somewhat universal minimal standard of operations may have merit to avoid large inter jurisdictional transfer of waste.

Proper siting of a facility requires an evaluation of multiple factors including technical and regulatory items. Regulatory items were discussed above but certain other considerations are important. Technical factors include the location of the salt deposit relative to the source of waste to be disposed; depth of salt below ground surface; lateral and vertical extent of salt deposit; proximity to brine receptors (consumption or disposal); quality of salt; overburden materials including cap rock characteristics; topography and general construct ability issues such as surface soil types, rock types, water, etc.

3. 1.1 Specific Site Characteristics

The site chosen for the SEM project is a domal salt deposit located in the Houston Salt Basin (See Figure 1). The specific dome is known as the Boling Dome and is located some fifty (50) miles southwest of Houston, Texas. The dome has plan dimensions of about 3 ½ by 4 ½ miles and an estimated depth of in excess of 35000 feet below ground surface.

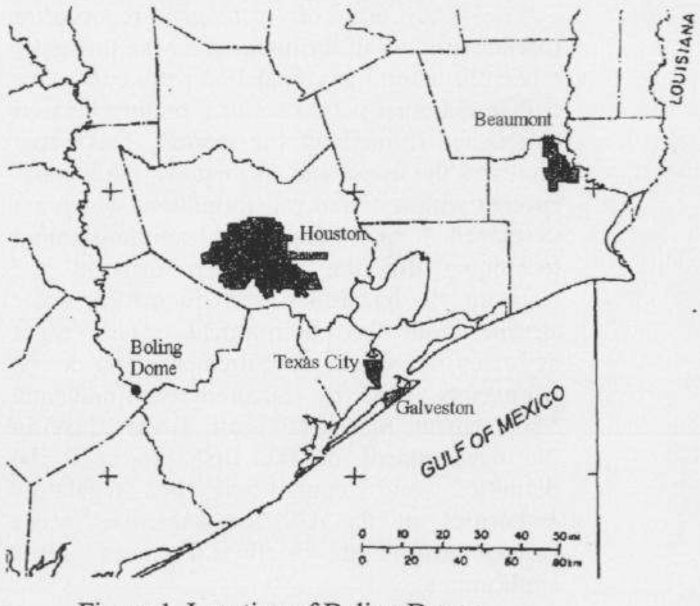

Figure 1. Location of Boling Dome, SEM Facility

The dome is located essentially equidistant between Beaumont / Port Arthur and Corpus Christi, Texas. These two industrial areas form the extreme ends of the Texas gulf coast industrial area. Approximately 85% of the industrial and hazardous waste production in Texas occur between these two areas and within 200 miles of the proposed facility. The site area is also predominantly rural with less than five residences within a mile of the facility and none within a half mile.

Beginning in the early 1930's, sulphur deposits in the cap rock formation over the salt stock were mined using the Frasch process. Mining stopped in 1993. The location of the mining area is about 2 ½ miles from the site. There is a natural gas storage facility located about ⅔ of a mile from the facility location. This natural gas facility is the only co-user of the salt stock at this time.

The location of the facility meets the basic siting criteria of: 1.) being reasonably close to waste sources; 2.) being a relatively large salt formation; 3.) being reasonably isolated from high population centers; and 4.) having few other co-users of the salt stock or cap rock formation near the facility.

3. 1.2 Design and Process Provisions

The basic design philosophy of the facility was one of having an enclosed facility, capturing nearly all emissions (water and air), and reducing exposure of the waste to personnel and environment.

The surface facilities consist of three large process/administrative maintenance buildings and two truck/container and tank storage areas. The facility/drive areas are all concreted and curbed to allow control of spills/leaks or storm water accumulations. Spills/ leaks are collected for treatment and disposal while storm water will be analyzed and discharged into a storm water retention area.

All incoming waste streams have first been subjected to strict pre-acceptance protocol that have been reviewed and accepted by the regulatory authorities. When arriving at the facility, the actual waste load is subjected to waste receipt analyses and compared to the pre-acceptance protocol. Differences must be rectified before further processing can proceed.

As the waste proceeds through the facility, it is either directly solidified, dried, crushed and then pneumatically conveyed into the cavern repository, (the cavern repository is described in a later section) or is first subjected to a hydrocarbon recovery process before the solid residue is sent over to a solidification unit for further processing.

The solidification process provides for a uniformity of treatment regardless of the source of the waste and provides a treatment that meets regulatory requirements prior to disposal. Four major processes are utilized at the site. One is the solvent extraction/hydrocarbon recovery process; the second is a pozzolan/cement based solidification process (which includes a dryer unit to surface dry the material); a pneumatic (air) system to convey the dried (and crushed) waste into the cavern; and a flameless thermal oxidizer to destroy organic emissions released from the raw waste while in storage tanks and during processing. All tanks are closed top and emissions are piped to the thermal oxidizer. Emissions from the hydrocarbon recovery unit and the solidification / dryer unit are directly piped to the thermal oxidizer.

The surface facility design meets the basic criteria of: addressing current and anticipated future regulations; having a minimal surface area footprint size; collecting and managing all emissions resulting from processing the waste including air and water; treating all waste received to meet the same end conditions so as to have as consistent as possible physical properties in the cavern repository.

4. CAVERN RESPOSITORY DESCRIPTION AND MODELING RESULTS

In addition to comprehensive surface treatment of the wastes, the second component of the waste management system is the placement (and long term isolation) of the dried waste in cavern repositories that are created by solution mining techniques in a large stable salt dome formation. The caverns proposed for the subject project will be solution – mined over a depth interval of 2000 feet to 3000 feet below ground surface (610 to 915 m) and will have diameters ranging from 100 feet (30m) at the top, to 165 feet (50m) at the bottom. Salt cover over the top of the caverns will be about 1000 feet (300 m) and pillar thickness between caverns well be 385 feet (117m).

Numerical models were designed to address issues raised by the Texas Natural Resource Conservation Commission (TNRCC) relative to SEM's application [7]. Two different computer programs, VISCOT and FLAC, were employed to demonstrate consistency of modeling results. Modeling included the "cavern history" for calculating the maximum extent of the "disturbed salt zone" (DSZ) around caverns, as well as the time dependent loss of cavern volume, compaction of fill material, and gas pressure build-up within sealed caverns. Other modeling involved analyzing the effects of anomalous temperature increases in the fill material within a cavern, and determining a conservative bound on surface subsidence over caverns. Results were compared to findings from other salt cavern modeling studies, and found to be generally consistent. The approach of this study could also be used for modeling caverns that are initially brine-filled, and are later back-filled with brine displacing granular media.

Described below are summaries of the various analytical models performed to characterize the caverns as waste repositories.

4.1 Extent of Disturbed Salt Around Caverns

Figure 2 illustrates the Disturbing Salt Potential (DSP) contour for C = 0.20 for both the VISCOT and FLAC models at the end of dewatering the SEM caverns, when DSP values would be the largest. The contours are obviously very similar, which demonstrates consistency of the related analyses. A significant finding from these analyses was that the DSZ did not extend more than one cavern radius into the salt.

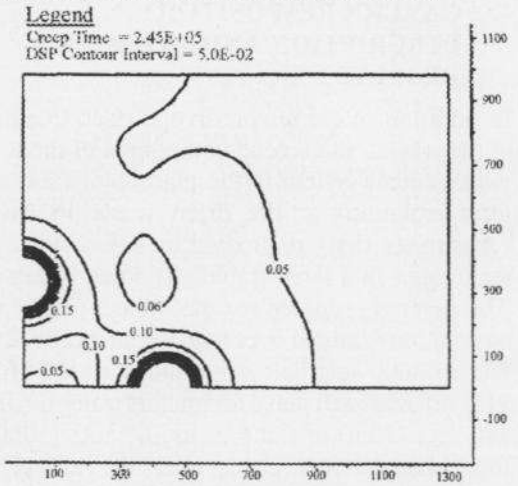

Figure 2. Disturbed Salt Potential Between Caverns

4.2 Effects of Fill Material

Fill materials in dry salt caverns are deformed primarily by compaction (volumetric strain) under pressure (isotropic stress) exerted by inward salt creep and weight of the material itself. This is similar to the state in back-filled mines, for which the compaction and propping effects of fill materials have been studied for some time. Laboratory tests of fill material yield results that are typically displayed as plots of pressure versus volumetric strain. Figure 3 depicts results from "confined compression" (CC) tests and "isotropic compression" (IC) tests, plotted together for convenience, that involved two different sets of example fill materials. The confined compression test is also called the "odometer" test.

The curve labeled FLC/HIFI in Fig. 4 was obtained with the FLAC model and HIFI 2 material of Fig. 3. The HIFI material was considerably less stiff than the SEM material, and thus the effect of fill material stiffness could be ascertained by comparing results from the FLAC modeling. The SEM material tended to a limiting smaller value of cavern volume loss more quickly than the HIFI materials, as expected. At about 16 years the cavern volume loss was approximately 17% and 25%, for SEM and HIFI materials, respectively. The HIFI material also continued to exhibit compaction at a larger rate than the SEM material. In general, the predicted behavior of the SEM caverns for the two materials appeared reasonable and uneventful.

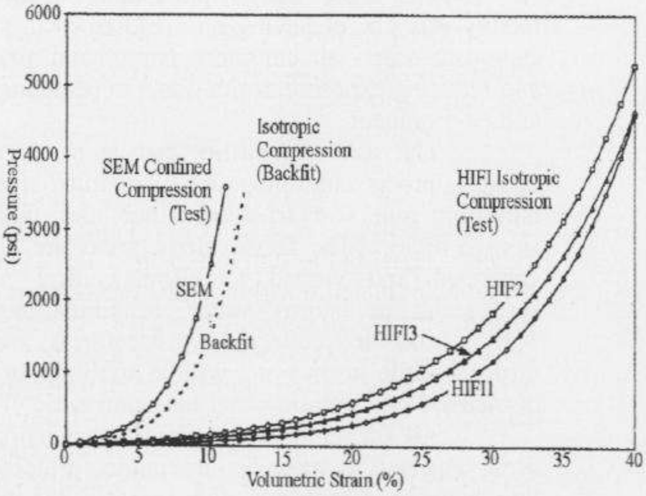

Figure 3. Fill Material Properties

Figure 4 depicts values of cavern volume loss (shrinkage) versus time for three modeled cases of SEM cavern history. The two curves labeled VISCOT/SEM and FLAC/SEM denote results obtained with the VISCOT and FLAC models, respectively, with the SEM (test) material of Fig. 3. (Use of the SEM test data, rather than the back-fit data, yielded the representation of a greater span of likely fill material behavior.) The predicted cavern volume losses at 16 years were 3.01 X 10^6 and 2.39 X 10^6 bbls (0.48 X 10^6 and 0.38 X 10^6 m^3), respectively, for the VISCOT and FLAC models. These losses represented about 22% and 17%, respectively, of the initial volume of a SEM cavern (14 X 10^6 bbls (2.23 X 10^6 m^3). The predictions of the two models for this same loading history were considered to be reasonably consistent, especially after taking into account the different approaches used in obtaining them.

4.3 Pressure Build-up

The familiar "gas law" was used to calculate pressure build up in the sealed SEM caverns. This calculation required values of gas

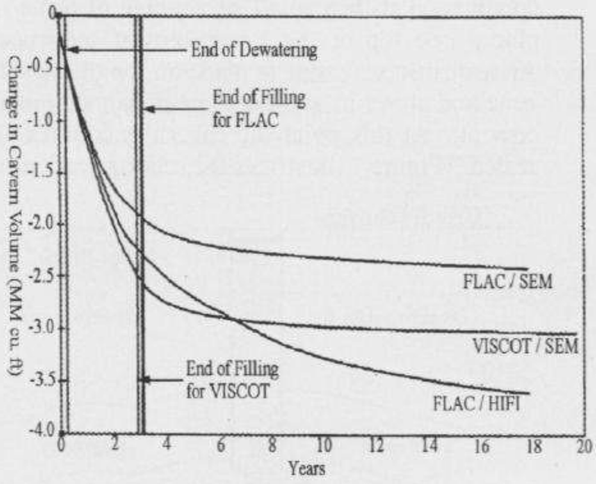

Figure 4. Cavern Volume Loss

"storage volume" remaining in the fill material at different times. The storage volume was assumed equal to the sum of the "pore space" in the granular material within the cavern. Material compaction was assumed due solely to reduction of pore space. This permitted calculation of storage volume lost by compaction, but not the complementary volume remaining. Volume remaining could be based on appropriate laboratory tests data, or estimated on the basis of another safe-side assumption. The latter approach was used by assuming that the pore space was reduced to zero when the material was subjected to maximum lithostatic stresses that could be applied in the cavern. This is a safe-side assumption, since there would likely be some pore space remaining at this point. The state of maximum lithostatic stress would occur at the bottom of the cavern in the long-term.

Values of compaction (volumetric strain) for SEM fill material over the cavern height were calculated using results from Stages 3 and 4 of the cavern history models. Figure 5 depicts values for two points in time, i.e., cavern filled (filled), and two years after filled (2YAF). The ultimate values of compaction that could occur for the SEM material over the cavern height were calculated directly by using lithostatic stress values in the compaction relationship for the SEM material. This was based on the safe-side assumption that the fill material would be subjected to lithostatic stress in the long term.

The long-term pressure in the cavern after sealing was calculated by multiplying the pressure at sealing by the ratio of sealing to long-term storage volumes in the fill material. Cavern temperatures were assumed constant since the fill material would be heated, and would be in place for some time prior to sealing. The ratios of gas pressure buildup for the VISCOT and FLAC models, respectively, were 6.67 and 7.28 for a cavern that was sealed 2 years after filling (2YAF) with SEM material. The 2YAF period corresponded to one example of a monitoring period, following cavern filling, that is part of the SEM proposal. The actual period of monitoring would be based on analyses of the behavior of the cavern after filling. These analyses would include modeling, with the benefit of site specific field data, until cavern behavior could be reliably predicted.

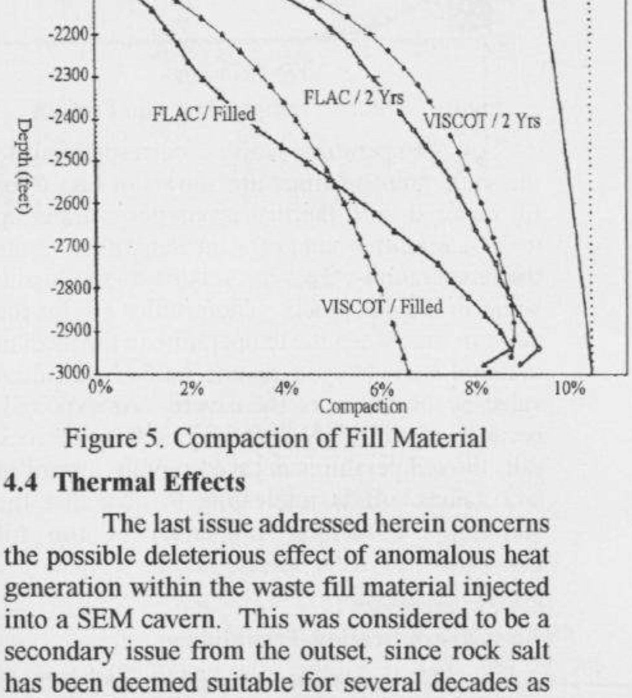

Figure 5. Compaction of Fill Material

4.4 Thermal Effects

The last issue addressed herein concerns the possible deleterious effect of anomalous heat generation within the waste fill material injected into a SEM cavern. This was considered to be a secondary issue from the outset, since rock salt has been deemed suitable for several decades as a host for radioactive waste disposal, where temperatures as high as 200°C (392°F) would be expected to occur around waste canisters.

The FLAC code was used in setting up a one-dimensional (1-D) model to demonstrate characteristics of transient temperature profiles in the filled material and surrounding salt. The initial and boundary conditions for the model were based on the assumption that the temperature throughout the fill material rose suddenly to 100°F above the in situ temperature in the salt, and then decayed without additional heat being generated. For simplicity, the in situ temperature in the salt stock was assumed constant over the cavern height, so that the 1-D model shown in the upper part of Fig. 6 could be implemented. Based on measurements in other Gulf Coast domes, the in situ temperature over the height of a SEM cavern would vary only about 20°F.

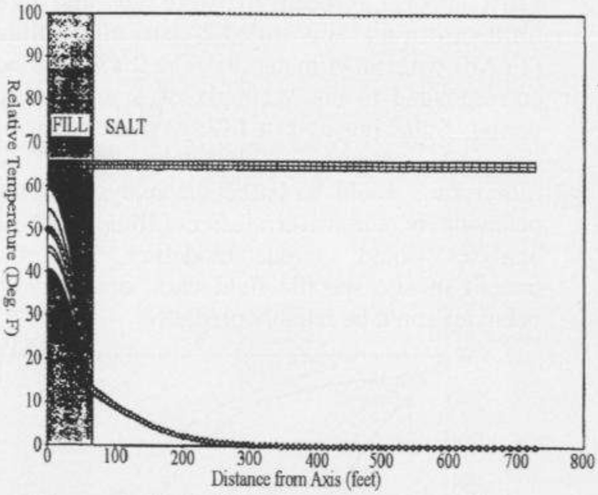

Figure 6. Model Temperature and Profiles

Temperature profiles, corresponding to the same point in time, are shown in Fig. 6 for fill material with thermal properties ranging up to 10% on either side of a median value. Note the temperature values are relative to the in situ value in the salt stock. The profiles are for the point in time when the temperature in the median material had decayed to one half of its initial value at the center of the cavern. As expected, because of the high heat conductivity of rock salt, the temperatures decayed rapidly toward in situ values. It is interesting to note that the variation in thermal properties of the fill materials had little effect on the temperature profiles in the salt.

4.5 Cavern Sealing Techniques

The cavern is entered using a multiple casing program. The waste is conveyed using suspended tubing into the finished dewatered cavern. After the cavern is filled, the cavern is monitored for a specified period of time to ascertain that certain regulatory requirements are met before sealing can commence. After the monitoring is complete, then the seal is placed on top of the waste and into the uncased portions of the borehole.

The seal consists of a multi-layered system of light weight concrete, salt saturated cement, crushed salt and asphaltic material. The sequence begins with a layer of light weight concrete placed directly on the waste and supports the subsequent layer of salt saturated cement. A larger zone of crushed salt conditioned with a small percentage of brine is placed one top of the lower cement sequence. An asphaltic seal zone is place on top of the salt zone and above it, another zone of salt saturated cement. At this point the cavern is completely sealed. Figure 7 illustrates the sealing sequence.

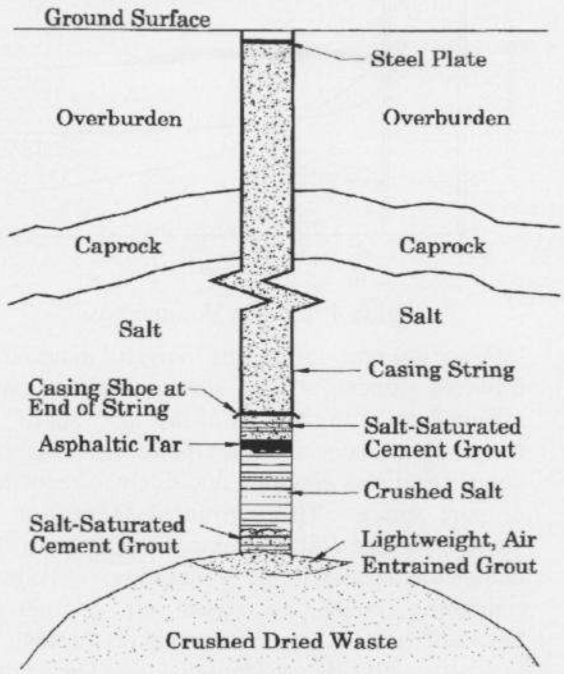

Figure 7. Cavern Seal

5. SUMMARY AND CONCLUSIONS

Comprehensive studies and modeling of proposed salt cavern repositions spanning a period of six (6) years of technical review by the regulatory authorities have demonstrated that cavern repositories offer a superior alternative to conventional methods of waste management. Repositories are cost effective and provide significant saving over combustion technologies. Wastes are permanently isolated from the environment after the caverns are sealed. Even though, this paper addresses solutions mined caverns, the technology may be applied to other circumstances such as bedded formations and dry mines.

6. REFERENCES

Federal Programs

1. Safe Drinking Water Act (SDWA) or amended; 42 USC 300f et seq. Regulations – 40 CFR 144-148

2. Resource Consternation and Recovery Act (RCRA) of 1976 as amended; 42 USC 6901 et seq Regulations 40 CFR 260-282
3. Clean Air Act of 1990 (CAA) as amended; 42 USC 7401 et seq Regulations 40 CFR 50-95
4. Federal Water Pollution Control Act (CWA); 33 USC 1251 et seq Regulations 40 CFR 104-143

State Programs

5. Texas Water Code; Title 2, Water Administration
6. Texas Health and Safety Code; Title 5, Sanitation and Environment Quality

Authors

7. R. Thoms, R. Gehle and C. Brassow, Analysis of Salt Cavarns with Granular Wastes, SMRI Spring Mtg (1999)