DISCLAIMER

Conference Paper

Disposal of Oil Field Wastes into Salt Caverns: Feasibility, Legality, Risk, and Costs

to be presented by:
John A. Veil
Argonne National Laboratory

to be presented at and published in the proceedings of:
4th International Petroleum Environmental Conference
San Antonio, TX
September 9-12, 1997

Disposal of Oil Field Wastes into Salt Caverns:

Feasibility, Legality, Risk, and Costs

John A. Veil
Manager, Water Policy Program
Argonne National Laboratory
Washington, DC, USA

ABSTRACT

Salt caverns can be formed through solution mining in the bedded or domal salt formations that are found in many states. Salt caverns have traditionally been used for hydrocarbon storage, but caverns have also been used to dispose of some types of wastes. This paper provides an overview of several years of research by Argonne National Laboratory on the feasibility and legality of using salt caverns for disposing of oil field wastes, the risks to human populations from this disposal method, and the cost of cavern disposal. Costs are compared between the four operating U.S. disposal caverns and other commercial disposal options located in the same geographic area as the caverns. Argonne's research indicates that disposal of oil field wastes into salt caverns is feasible and legal. The risk from cavern disposal of oil field wastes appears to be below accepted safe risk thresholds. Disposal caverns are economically competitive with other disposal options.

INTRODUCTION

Each year, the oil and gas exploration and production industry generates large volumes of oily and solid waste that are disposed of by various means, including underground injection (disposal wells, enhanced oil recovery wells, annular injection), on-site burial (pits, landfills), land treatment (land spreading, land farming, road spreading), evaporation, surface discharge, or recycling. In recent years, interest has grown concerning the use of solution-mined salt caverns for disposal of nonhazardous oil field wastes. The U.S. Department of Energy (DOE) has a continuing interest in exploring new and alternative waste disposal methods, especially those that are less costly or risky than existing disposal methods. DOE funded Argonne National Laboratory to conduct three studies that evaluated various aspects of using salt caverns to dispose oil field wastes.

The first Argonne study, a feasibility study, evaluated whether any federal or state laws or regulations prohibited or inhibited cavern disposal (1). The feasibility study also reviewed existing uses of caverns, the types of wastes suitable for cavern disposal, cavern design and siting parameters, the actual waste disposal process, and anticipated environmental impacts following cavern closure. The second study, a cost study, compiled a data base of available off-site commercial disposal facilities in 31 oil- and gas-producing states (2). Costs of cavern disposal were compared to costs of other, more conventional disposal methods. The third study, a risk study, still in the draft report stage when this paper was submitted, evaluated the human health effects that could result from exposure to contaminants released from caverns that had been used for disposal of oil field wastes (3). The risk study calculated cancer and noncancer risks attributable to releases of cavern contents into drinking water supplies. This paper describes the results of those three studies.

BACKGROUND ON SALT CAVERNS

Figure 1 (reprinted from reference 1) shows the location of the major U.S. subsurface salt deposits. There are two types of subsurface salt deposits in the United States: salt domes and bedded salt. Salt domes are large, generally homogeneous formations of salt that are formed when a column of salt migrates upward from a deep salt bed, passing through the overlying sediments. Salt dome deposits are found in the Gulf Coast region of Texas, Louisiana, Mississippi, and Alabama.

Bedded salt formations occur in layers bounded on the top and bottom by impermeable formations and are interspersed with nonsalt sedimentary materials having various levels of impermeability, such as anhydrite, shale, and dolomite. Unlike salt domes, which are large masses of relatively pure sodium chloride, bedded salt deposits are tabular deposits of sodium chloride that can contain significant quantities of impurities. Major bedded salt deposits occur in several parts of the United States.

Salt caverns are created by injecting fresh water into a salt formation and withdrawing the resulting brine solution. Figures 2 and 3 (reprinted from reference 1) show the idealized construction for caverns in domal salt and bedded salt, respectively. The petroleum industry has constructed many salt caverns to store hydrocarbons. To provide guidance for designing and operating hydrocarbon storage salt caverns, several organizations have developed standards documents (4-6). Details on the design, location, and construction of salt caverns are provided in those reports.

The most common use for salt caverns is to store hydrocarbons such as propane, butane, ethane, ethylene, fuel oil, gasoline, natural gas, and crude oil (7). In 1975, the U.S. Congress created the Strategic Petroleum Reserve (SPR) program to provide the country with sufficient petroleum reserves to reduce any impacts that might be caused by future interruptions in the oil supply. The SPR consists of 62 leached caverns in domal salt with a total capacity of 680 million bbl. DOE has prepared a plan for, but is not currently pursuing, the development of an additional 250 million bbl of storage capacity. Highly compressed air has also been stored in some caverns where it can later be withdrawn to generate electricity.

Another use for salt caverns is to dispose of various wastes. In the United States and other countries, only a limited number of salt caverns have been issued permits for waste disposal. The Railroad Commission of Texas (TRC) has issued permits for disposal of nonhazardous oil field waste to six caverns. Four of these are currently operating as disposal caverns. At least four caverns in Canada have been permitted for disposal of nonhazardous oil field waste. Reference 1 describes other types of cavern disposal activities in the United Kingdom, Germany, the Netherlands, and Mexico.

REGULATORY CONSIDERATIONS

On July 6, 1988, the U.S. Environmental Protection Agency (EPA) published a list of those oil field wastes that were exempt from regulation as hazardous wastes under Subtitle C of the Resource Conservation and Recovery Act (RCRA) (53 FR 25477). On March 22, 1993, EPA issued clarification of the 1988 determination, adding many other wastes that were uniquely associated with oil and gas exploration and production operations to the list of wastes exempt from RCRA Subtitle C requirements (58 FR 15284).

EPA's Underground Injection Control (UIC) regulations define Class II injection wells as wells that inject fluids that are brought to the surface in connection with natural gas storage operations or conventional oil or natural gas production. Most, but not all, of the wastes exempted by the 1988 RCRA regulatory determination would meet the UIC program's criterion to be "in connection with" oil and gas production. Some wastes (e.g., hydrocarbon-contaminated soil) would not meet the UIC criterion, but EPA's guidance on the subject allows states to have the discretion to determine whether such wastes may be injected into Class II wells.

At the state level, only the TRC has formally authorized disposal of oil field wastes into salt caverns. The TRC has issued permits for six facilities, but only four of these are active. In April 1996, the TRC released draft proposed amendments to TRC Rule 9, the regulation that governs injection into a formation not productive of oil, gas, or geothermal resources. As of July 1997, the TRC had not finalized those regulations. Ten other states were contacted about their interest in disposing of oil field waste in salt caverns. Although several states were interested, none had cavern disposal programs or had authorized any cavern disposal activities. In the past year, Argonne National Laboratory has been asked by oil and gas agencies in Mississippi, New Mexico, and Louisiana to provide assistance in developing cavern disposal programs. On the basis of a review of regulations and telephone interviews with state and EPA officials, there are no apparent regulatory barriers to the use of salt caverns for disposal of nonhazardous oil field wastes at either the federal level or in the 11 states contacted for this analysis.

TYPES OF WASTES TO BE ACCEPTED

The types of oil field waste proposed for disposal in salt caverns are those that are most troublesome to dispose of through regular Class II injection wells because they contain high levels of solids. Wastes containing water that is not fully saturated with salt may increase the size of caverns, because the unsaturated water will leach salt from the cavern walls. The presence of fresh water in wastes should not preclude their disposal in salt caverns, but the operator must account for the increased volume of the cavern and what effect it will have on such cavern siting parameters as distance to adjacent caverns and roof span or thickness. The solids-containing oil field wastes most likely to be disposed of in salt caverns include used drilling fluids, drill cuttings, completion and stimulation waste, produced sand, tank bottoms, and crude-oil- or salt-contaminated soil.

CAVERN DISPOSAL OPERATIONS

Initially, caverns are filled with clean brine. Wastes are introduced as a slurry of waste and a carrier fluid (brine or fresh water). A carrier fluid that is not fully saturated with salt will eventually leach salt from the cavern walls or roof. Expansion of cavern diameter is generally not a problem as long as the anticipated degree of expansion is accounted for in the cavern design and the actual degree of expansion is monitored throughout the waste emplacement cycle. To avoid excessive leaching of the cavern roof, operators may intentionally introduce a hydrocarbon pad that, by virtue of its lower density, will float to the top of the cavern and keep the unsaturated carrier fluid from coming in contact with the cavern roof.

As the waste slurry is injected, the cavern acts as an oil/water/solids separator. The heavier solids fall to the bottom of the cavern, forming a pile. Any free oils or hydrocarbons that are associated with the waste float to the top of the cavern. Clean brine displaced by the incoming slurry is removed from the cavern and either sold as a product or disposed of in an injection well. When the cavern is filled, the operator removes the hydrocarbon pad and plugs the cavern.

POST-CLOSURE IMPACTS

There is no actual field experience on the long-term impacts from disposing of oil field wastes in salt caverns. The literature contains theoretical studies that estimate what might happen after such a cavern is closed. Although several different authors agree that pressures will build in a closed cavern because of salt creep and geothermal heating, they do not specifically address caverns filled with oil field wastes. Several experienced researchers in the field, interviewed by the authors of reference 1, believe that caverns filled with oil field wastes would be much less likely to leak than would caverns filled with less dense liquids. However, other experienced researchers believe that until the pore space of the waste pile is reduced through creep-induced compaction, a solids-filled cavern will behave in the same way as a fluid-filled cavern.

Argonne National Laboratory has joined with Sandia National Laboratories, the University of Texas-Bureau of Economic Geology, and the Solution Mining Research Institute to form a salt cavern research partnership. The partners are coordinating their research efforts to answer key questions concerning salt caverns. One of the most important issues being studied by the partnership is a better understanding of post-closure processes and impacts.

DISPOSAL COSTS

Reference 2 contains several tables that list the off-site commercial disposal facilities from 31 oil- and gas-producing states that accept nonhazardous oil field wastes. The data from reference 2 were collected in two steps. First, representatives of state oil and gas regulatory agencies were contacted to determine if a list of permitted commercial disposal companies was available. Then, if such a list existed, each company on the list was contacted by telephone. If a state agency had no list of commercial disposal companies, state officials were asked to describe how operators in that state disposed of their nonhazardous oil field waste. Commercial disposal companies were asked what type of wastes they accepted, what type of disposal method they employed, and how much they charged for disposal, exclusive of transportation costs. The majority of companies surveyed willingly provided information. A few companies elected not to participate, primarily out of concern that the cost information might be used to their competitive disadvantage.

Because the types of waste that are most likely to be disposed of in caverns are those that contain a large percentage of solids or are oily, only the data for that type of waste from reference 2 are discussed here. These data are summarized in Table 1. Disposal facilities use any of three cost rates — dollars per barrel ($/bbl), dollars per cubic yard, and dollars per ton. Table 1 shows a composite of the reported rates for 85 disposal facilities. Overall the costs range from $0-$57/bbl, $4.20-$50/cubic yard, and $12-$100/ton.

The disposal options in Table 1 can be compared on a dollars per barrel cost basis. Land spreading operations have a significant share of the commercial disposal market, with costs ranging from $5.50-$57/bbl. Landfills and pits represent another important disposal option, with costs ranging from $0.50-$36/bbl. Only one landfill/pit facility charged less than $2.25/bbl. Two facilities evaporate the liquid fraction of the waste and send the solids to a landfill. They charge $2.50-$2.75/bbl. Several facilities treat the wastes before reusing or disposing of them. These facilities charge from $0-$12/bbl, although only one facility charges less than $3/bbl. Several facilities incinerate wastes, with costs ranging from $10.50-$38/bbl. Finally, the four cavern disposal facilities charge from $1.95-$6/bbl.

These data show that disposal caverns can be cost-competitive with other disposal methods. In the oil fields of western Texas and eastern New Mexico, numerous competing commercial disposal facilities are competing. Three of the four operating disposal caverns are located in this area. They have rates that are comparable to or less costly than facilities using other disposal methods.

HUMAN HEALTH RISKS FROM DISPOSAL CAVERNS

Whenever wastes are placed in the environment, some potential exists for waste-borne contaminants to migrate from the disposal facility and enter pathways for human contamination. Argonne's risk study (3) identified several scenarios under which a disposal cavern could leak or fail. These include

- Cavern intrusion, in which a new well is inadvertently drilled into the cavern;
- Failure of the cavern seal at the wellbore plug or casing seat;
- Loss horizontally through cracks in the salt or in anhydrite layers; and
- Collapse of the cavern roof.

The estimated probability of these releases ranges from 10^{-3} to 10^{-7}. The modeling focused on four pollutants of concern — arsenic, benzene, cadmium, and chromium — and evaluated the fate and transport of pollutants as they move from the site of the leak to the human receptor, in this case, through a drinking water supply.

The estimated cancer and noncancer risks were calculated and are shown in Tables 2 and 3 (reprinted from reference 3). Cancer risks range from 1.1×10^{-8} to 1.7×10^{-12}. The acceptable threshold for excess cancer risk is 10^{-6}. Noncancer risks range from 7×10^{-4} to 7×10^{-9}. The acceptable noncancer risk threshold is 1.0. At the time this paper was submitted, reference 3 was still a draft report, so these findings were preliminary, and the values may change.

CONCLUSIONS

Argonne National Laboratory has extensively studied the practice of disposing of nonhazardous oil field wastes in salt caverns. The following conclusions result from our investigations:

- Cavern disposal is clearly feasible, as several U.S. and Canadian companies are already using the practice. Cavern disposal can be a valuable disposal option where salt formations are of sufficient size and quality to safely support caverns.

- There are no apparent regulatory barriers that would keep states from establishing cavern disposal programs. Several states are considering authorizing cavern disposal.

- Disposal caverns are cost-competitive with other more conventional disposal methods in the same geographical area.

- Post-closure behavior of caverns is not well-understood. Salt creep and geothermal heating will cause internal cavern pressure to increase and potentially lead to cavern leaks, although many experts believe that the rate of pressure increase will be sufficiently slow that leakage will not occur.

- Even if caverns do leak, the risks to human health through drinking water contamination appear to be very low.

ACKNOWLEDGMENTS

The author wishes to acknowledge the efforts and contributions of the other Argonne salt cavern team members: David Tomasko, Deborah Elcock, Mary Raivel, Dan Caudle, Robert C. Ayers, Jr., and Ben Grunewald. This work was sponsored by the U.S. Department of Energy, Office of Fossil Energy, under Contract W-31-109-ENG-38.

REFERENCES

1. Veil, J. et al., 1996, *Preliminary Technical and Legal Evaluation of Disposing of Nonhazardous Oil Field Waste into Salt Caverns*, prepared by Argonne National Laboratory, Washington, D.C., for the U.S. Department of Energy, June.

2. Veil, J.A., 1997, *Costs for Off-Site Disposal of Nonhazardous Oil Field Wastes: Salt Caverns versus Other Disposal Methods*, prepared by Argonne National Laboratory, Washington, D.C., for U.S. Department of Energy, April.

3. Tomasko, D. et al., 1997, *Risk Analyses for Disposing of Nonhazardous Oil Field Wastes in Salt Caverns*, prepared by Argonne National Laboratory, Argonne, IL, for U.S. Department of Energy, draft May 15.

4. Canadian Standards Association (CSA), 1993, *Storage of Hydrocarbons in Underground Formations - Oil and Gas Industry Systems and Materials*, Standard Z341-93, Canadian Standards Association, Rexdale, Ontario, Canada, July.

5. American Petroleum Institute (API), 1994, *Design of Solution-Mined Underground Storage Practices*, Recommended Practice 1114, American Petroleum Institute, Washington, D.C., June.

6. Interstate Oil and Gas Compact Commission (IOGCC), 1995, *Natural Gas Storage in Salt Caverns - A Guide for State Regulators*, Interstate Oil and Gas Compact Commission, Oklahoma City, Okla., October.

7. Querio, C.W., 1980, *Design and Construction of Solution-Mined Caverns for LPG Storage*, presented at Solution Mining Research Institute's fall meeting, Minneapolis, Minn., October 12-15.

Table 1. Disposal Costs for Oily and Solid Wastes (based on reference 2)

Method	**$/bbl**	**$/cubic yard**	**$/ton**
land spread	5.50 - 57	14 - 40	20 - 95
landfill/pit	0.50 - 36	6.50 - 37.50	17 - 150
evaporation	2.50 - 2.75	4.20 - 18.90	
treatment then reuse or disposal	0 - 12	12.50 - 28.50	12 - 45
incineration	10.50 - 38		20 - 100
salt cavern	1.95 - 6	50	

Note: Costs were provided by disposal companies from June 1996 to March 1997 and may not reflect current costs. Costs do not include transportation expenses.

Table 2. Estimated Cancer Risks for Contaminants of Concern for Salt Cavern Disposal (reprinted from reference 3)

Contaminant of Concern	Release to Surface	Release to Shallow Aquifer		Release to Deep Aquifer	
	Intrusion	Cavern seal failure with casing failure at shallow depth	Cavern collapse with cavern seal failure and casing failure at shallow depth	Cavern seal failure with casing failure at depth of cavern	Cracks, leaky interbeds; cavern collapse with intact cavern seal; cavern collapse with cavern seal failure at depth of cavern
Arsenic	4.0×10^{-9}	1.1×10^{-9}	1.1×10^{-12}	1.1×10^{-8}	1.1×10^{-11}
Benzene	9.3 x 10-[10]	6.8×10^{-10}	6.8×10^{-13}	6.8×10^{-10}	6.8×10^{-13}
Cadmium	NA	NA	NA	NA	NA
Chromium	NA	NA	NA	NA	NA
Total	4.9×10^{-9}	1.7×10^{-9}	1.7×10^{-12}	1.1×10^{-8}	1.1×10^{-11}

NA - Slope factors not available.

Notes: 1. Acceptable cancer risk threshold is 10^{-6}.
2. These risk calculations were considered preliminary at the time the paper was submitted.

Table 3. Estimated Noncancer Health Risks for Contaminants of Concern for Salt Cavern Disposal (reprinted from reference 3)

Contaminant of Concern	Release to Surface	Release to Shallow Aquifer		Release to Deep Aquifer	
	Intrusion	Cavern seal failure with casing failure at shallow depth	Cavern collapse with cavern seal failure and casing failure at shallow depth	Cavern seal failure with casing failure at depth of cavern	Cracks, leaky interbeds; cavern collapse with intact cavern seal; cavern collapse with cavern seal failure at depth of cavern
Arsenic	6.2×10^{-4}	5.5×10^{-6}	5.5×10^{-9}	5.5×10^{-5}	5.5×10^{-8}
Benzene	NA	NA	NA	NA	NA
Cadmium	6.4×10^{-5}	1.6×10^{-6}	1.6×10^{-9}	1.6×10^{-5}	1.6×10^{-8}
Chromium III	9.3×10^{-8}	2.7×10^{-10}	2.7×10^{-13}	2.3×10^{-9}	2.3×10^{-12}
Chromium VI	1.9×10^{-5}	5.5×10^{-8}	5.5×10^{-11}	4.7×10^{-7}	4.7×10^{-10}
Total	7.0×10^{-4}	7.2×10^{-6}	7.2×10^{-9}	7.2×10^{-5}	7.2×10^{-8}

NA - RfDs not available for benzene; benzene is treated as a carcinogen.

Notes: 1. Acceptable noncancer risk threshold is 1.0.
2. These risk calculations were considered preliminary at the time the paper was submitted.

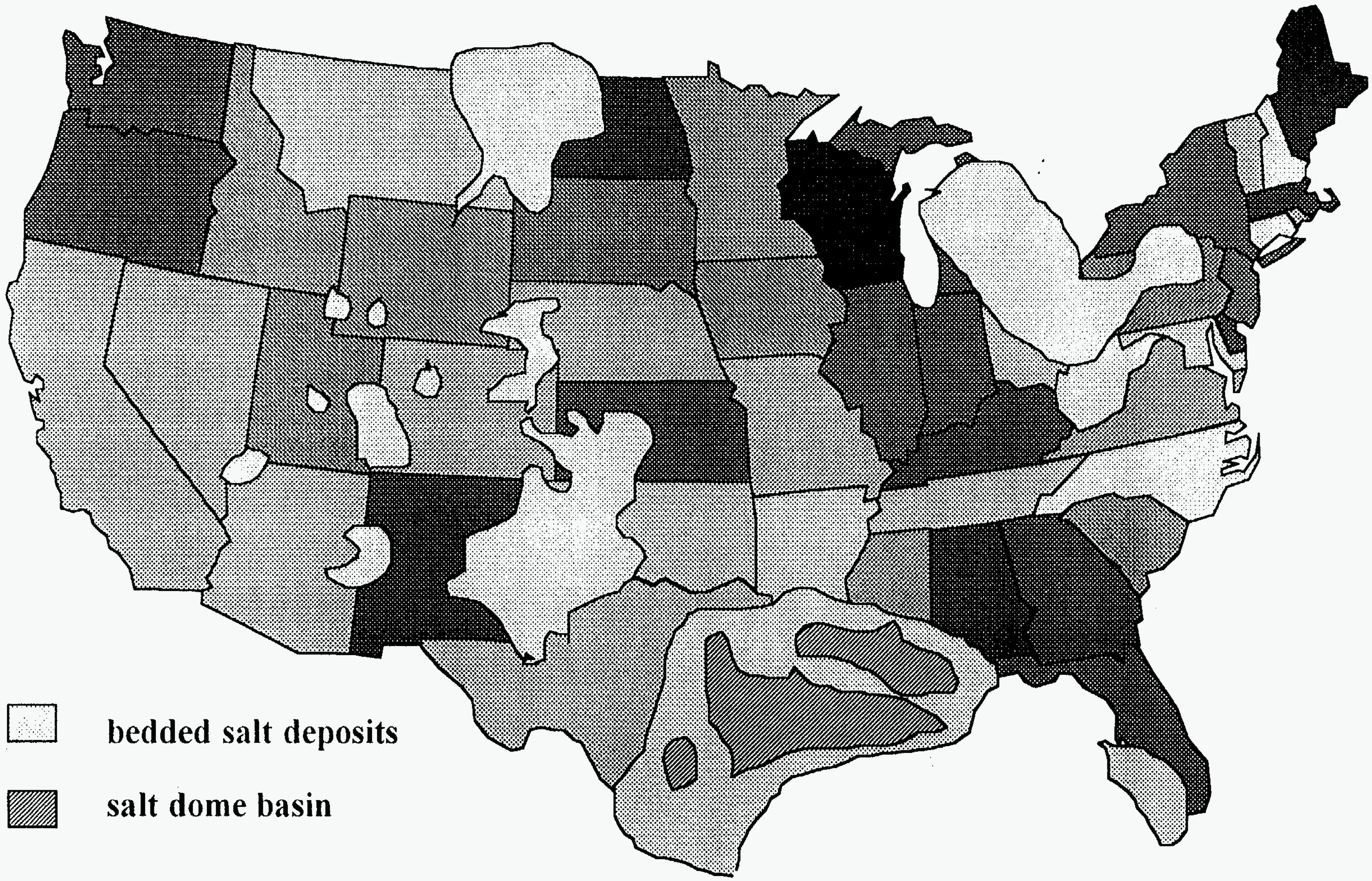

Figure 1. Major U.S. Subsurface Salt Deposits (reprinted from reference 1)

Figure 3 . Idealized Cavern in a Bedded Salt Formation (reprinted from reference 1)

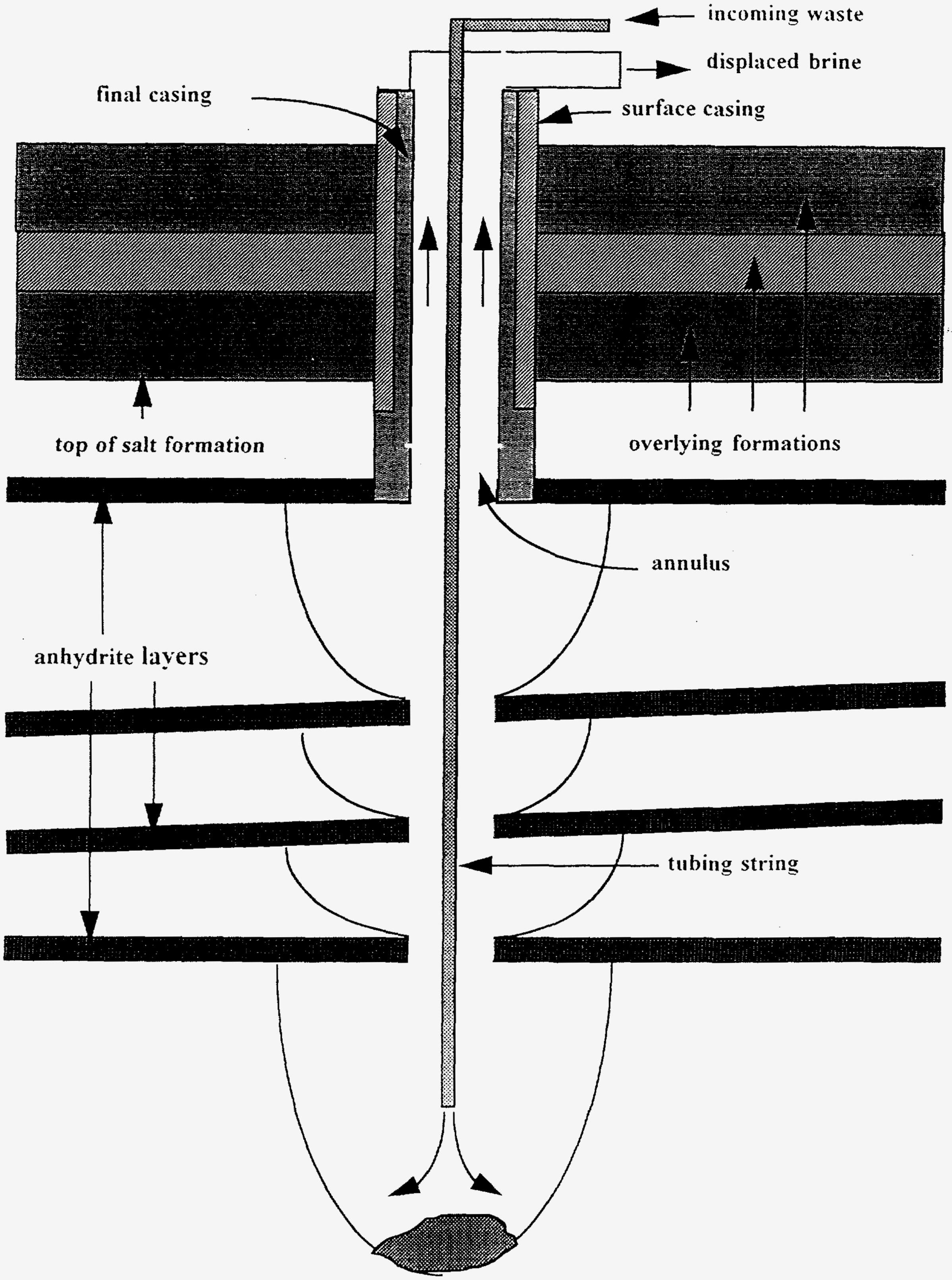

Figure 2. Idealized Cavern in a Salt Dome Formation (reprinted from reference 1)