Role of Salt Domes in Energy Production

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ABSTRACT

Salt domes are potentially valuable elements in new developments to meet future energy needs. They offer an opportunity for cheaply developed safe underground space for construction of nuclear power plants. They should be considered as a type of salt mass suitable for the storage of radioactive wastes from nuclear power production. Peaking power needs can be alleviated by storing energy in solution cavities in salt domes using compressed air, electrolytically produced hydrogen, or underground pumped storage. The location of salt domes is often fortuitous for use in off-peak energy storage. Examples that can be cited are: the location of salt domes near proposed tidal power sites on the Bay of Fundy and offshore domes under suggested marine solar power plants.

INTRODUCTION

Domal salt represents an end product of deformation of bedded salt in response to tectonic stresses and buoyant forces operating in the earth's crust. These salt masses have in many instances risen by buoyancy from salt beds buried several miles beneath other sedimentary layers of higher density than salt. Varying thicknesses of sediments have been penetrated by this mobilized salt. The top of such salt may be thousands of feet deep or the salt may have reached the surface of the land. In some places such as Iran, it has been extruded on the surface itself producing salt glaciers.

There are four salt dome provinces in North America: one in the Maritime provinces of Canada; one in northeastern Mexico; and two in the United States. In the United States salt domes occur in the Paradox basin of Colorado and Utah, and the Gulf Coast province. There are 329 salt domes in the onshore and offshore areas of the Gulf Coast. The distribution of these domes and statistical data pertaining to them is given by Hawkins and Jirik (1966). Figures 1 and 2 show the relation of salt domes to cultural and topographic features in parts of south Louisiana as well as the typical size and variability of onshore domes. Thus it is seen that huge masses of salt exist commonly at very shallow depths beneath the land surface of the northern coastal region of the Gulf of Mexico and elsewhere. This has proven to be of great economic value because of oil, gas, and sulfur accumulations associated with these domes and because of the salt itself. The impervious nature of the salt and its high solubility combine to make these salt masses useful for huge storage caverns for gases and liquids. Cavities on the order of 12,000,000 cubic feet in volume have been dissolved in the course of solution mining in Gulf Coast salt domes. The same techniques used in solution mining are employed to develop very large storage reservoirs. This is sound economically inasmuch as such storage capacity costs about one-tenth that of mined out space in rocks and about one-hundredth of the cost of conventional storage in above ground steel tanks (Hawkins and Jirik, 1966). These authors reported that 57 million barrels of liquified petroleum gas were stored in nine salt domes in the Gulf Coast in 1965 and they have identified 130 onshore salt domes of potential value as underground storage sites.

Attention recently has been directed to the possibility of using these domal salt structures for waste disposal and other environmental purposes (Martinez, 1971). Their possible utility for the storage of radioactive wastes has been widely recognized but rejected by concerned governmental authority in the United States. The underlying reasons for this position are given by Gera (1972). The feasibility of the disposal of high-level radioactive wastes in bedded salt (tabular bodies) has been intensively investigated by the Union Carbide Corporation for the U.S. Atomic Energy Commission (Empson, et. al., 1970). It

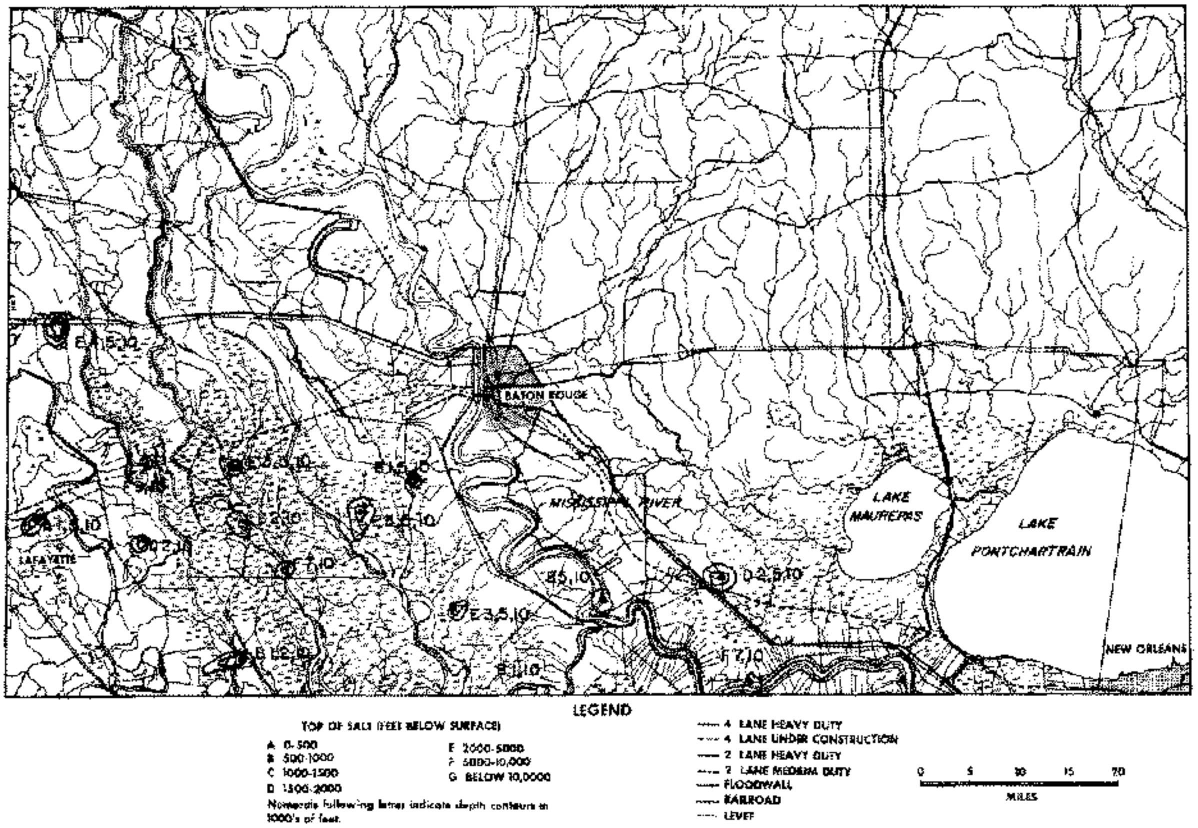

Figure 1. Relation of salt domes to cultural and topographic features in part of South Louisiana. Modified by Martinez (1971) from Wallace (1966).

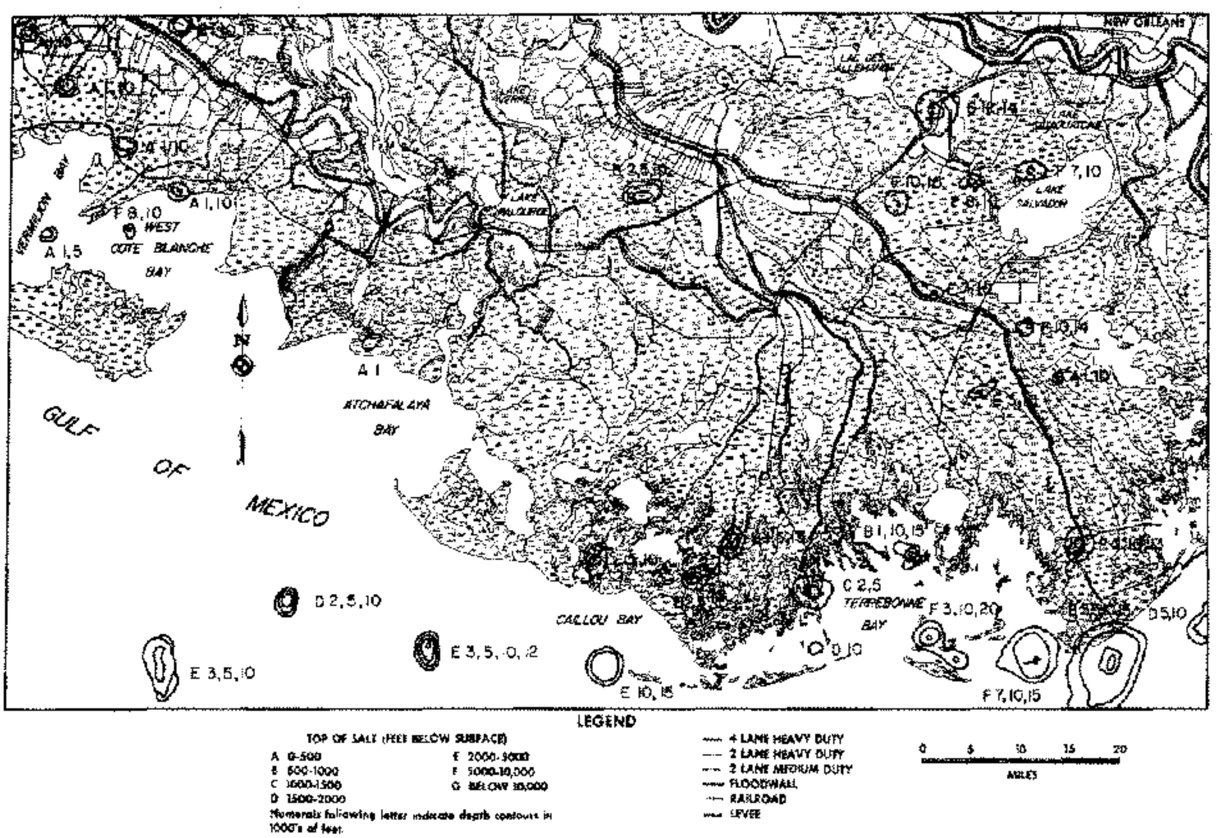

Figure 2. Relation of salt domes to cultural and topographic features in part of South Louisiana. Modified by Martinez (1971) from Wallace (1966).

apparently was concluded that this method of disposal in an inactive mine at Lyons, Kansas would be effective and safe. More recently, objections have been raised to this proposal and further studies are in progress. The use of salt domes rather than bedded salt for this purpose might have met with greater acceptance due to the much greater extent of the salt in a vertical direction, in spite of objections that have been raised. It would seem reasonable to reconsider the question.

A list of various uses for which salt domes might be employed for environmental purposes includes:

1. Space for ultimate disposal of noxious liquid and/or solid wastes.
2. Space for chemical or biological degradation of liquid and/or solid wastes.
3. Use of man-made solution cavities in salt domes as chemical reaction chambers for industrial operations.
4. Use of man-made solution cavities in salt domes for development of off-peak energy by air storage or pumped storage methods.
5. Sites for underground location of hazardous plants such as nuclear power plants.

Three items in this list directly relate to the current energy crisis. Salt domes may be useful in providing:

1. Safe space for nuclear power plants.
2. A means for conserving our energy resources through storage of off-peak power.
3. A safe method for disposing of high-level radioactive wastes.

UNDERGROUND SITING OF NUCLEAR POWER PLANTS IN SALT DOMES

It is possible that the various components of a nuclear power plant can be situated in separate cavities in a dome, thus isolating them in the event of reactor malfunction (Figs. 3 and 4). The high pressure containment normally provided by expensive pressure vessels at the surface would be furnished by the salt mass itself. Standby chambers could easily be incorporated into the overall design to

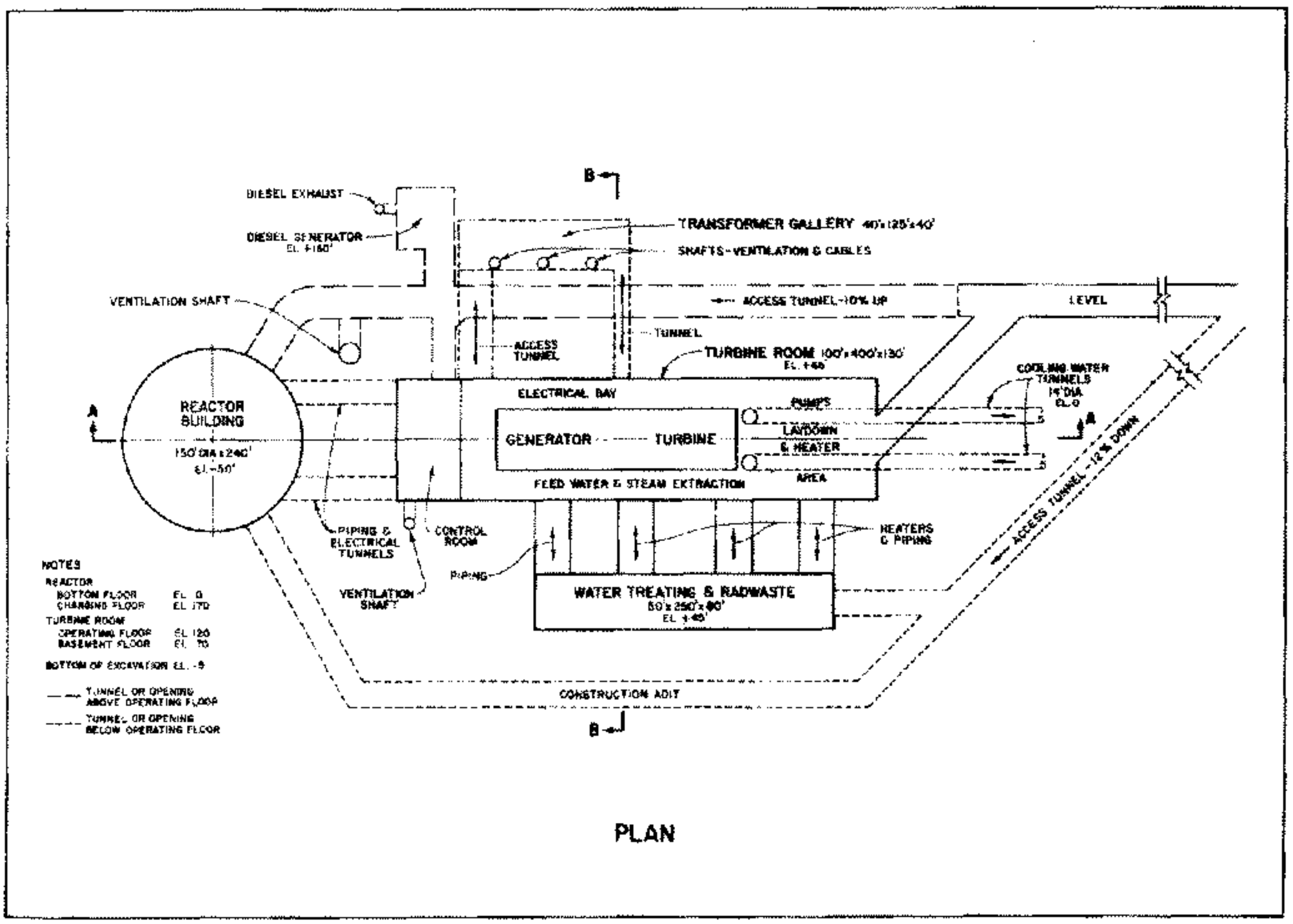

Figure 3. Plan view of a proposed underground nuclear power plant. From Swiger (1971).

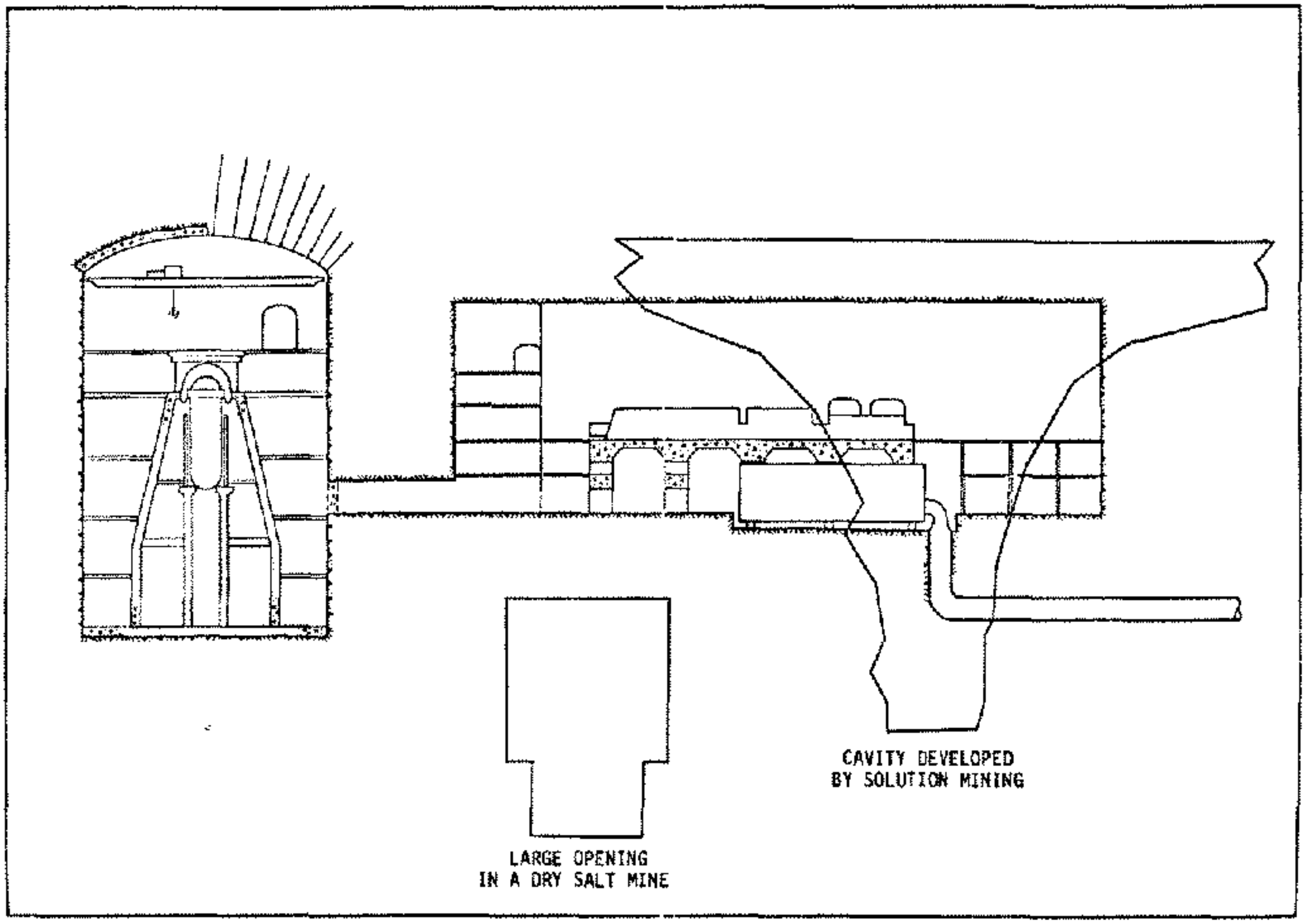

Figure 4. Size comparison in vertical section of components of an underground nuclear power plant with typically large mined out cavities in salt domes. Modified from Swiger (1971).

allow for automatic disposal of wastes in event of a major reactor malfunction. The cost of such a facility in a salt dome should be relatively low. However, since the normal lithostatic pressure tends to collapse a cavity, the effect of possible pressures in excess of lithostatic pressure must be carefully considered. Abnormal conditions of this kind might cause the salt to fail in tension, producing cracks. Close attention would also have to be given to proper measures to provide a fail-proof hydrostatic seal to the underground structure. The hazards due to leakage caused by salt dissolution must be thoroughly considered.

PEAKING POWER NEEDS AND CURRENT SOLUTIONS

The current energy crisis has dramatically increased the need for peaking power. Daily and seasonal variations in the demand for electrical energy makes it imperative that an economical means of providing peaking power be incorporated into power generating systems. This is particularly true for the very large modern nuclear and fossil fuel plants in operation today. Tidal power and solar energy (possible power sources) could be used most effectively in conjunction with methods of storing excess power. This peaking power is currently provided in two ways. One means is the use of a number of large gas turbines (which can be easily placed in and removed from operation). Gas turbines are cheap to install although they are expensive to operate (Harboe, 1971). Even though these engines are operated with fossil fuel of the lowest pollution potential, this system does affect air quality. Furthermore, supplies of natural gas are already in very short supply and could best be used for other purposes. Another method presently used is pumped storage. This is a sound approach where topographic and hydrologic parameters make it practical. Two sets of basins capable of conversion into reservoirs must exist near each other but at substantially different elevations. One drawback to the use of conventional pumped storage, however, is its undesirable impact on environmental quality. Velz (1971) summarized the detrimental as well as the beneficial effects of pumped storage on the environment.

THE USE OF AIR STORAGE FOR PEAKING POWER

A third alternative currently under consideration is the use of air storage. The most widely accepted method of utilizing this concept is to use air that was compressed with surplus power to operate gas turbines for the production of peaking power. This approach was proposed by Professor Bozidar Djordjevitch of Yugoslavia and patented by him in Germany on March 22, 1956, under number 940683. The idea was further studied by the Deutsche Verbundgesellschaft e.v. and the Bundesanstalt für Bodenforshung (the Geological Survey, Federal Republic of Germany). This Geological Survey concluded that the proposal was technically and economically feasible and that the cheapest and safest possibility was to utilize abandoned salt or potash mines as air storage cavities (personal communications from Professor Dr. H. J. Martini and Deutsche Verbundgesellshaft e.v.). This method provides cheaper power than either pumped storage or conventional air storage gas turbines (which compress their own air supply). However, some gas will still be required whether the prime power is nuclear, water power, or coal. Another procedure (Fig. 5) has been suggested by Whitehouse, Council and Martinez (1968). Off-peak energy would be stored by compressing air in man-made cavities in salt domes. The energy would be reclaimed by exhausting the stored air through an expander. The same unit functions both as compressor and expander. The electrical unit also has a dual function, operating as a motor to drive the mechanical unit running as an expander. These writers

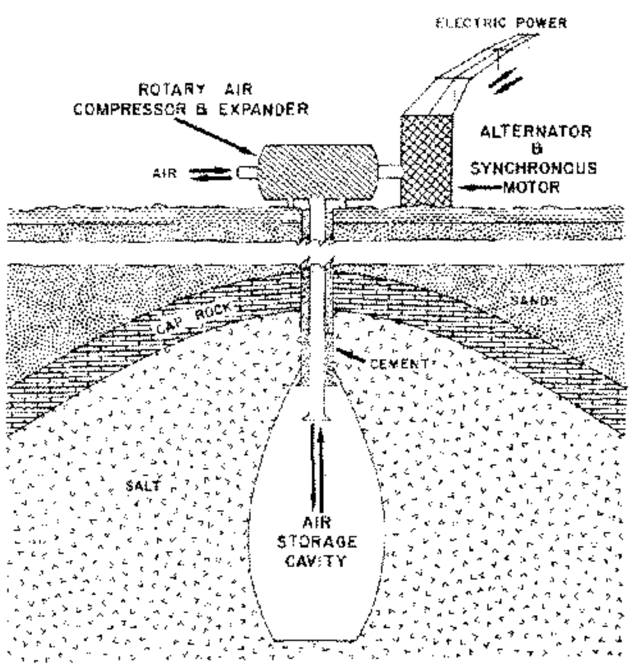

Figure 5. Storage of off-peak electrical energy using compressed air. Modified from Whitehouse, et al. (1968).

intended that pressure drawdown be limited by utilizing only a part of the stored air. An improved version of this scheme (Fig. 6) was patented by Lang in 1970 (filed about two months after publication of the Whitehouse, Council and Martinez paper). Lang added the concept of a water leg connecting the cavity to a surface reservoir which would serve to maintain a more nearly constant pressure in the cavity. This, of course, could also be done by using another cavity to replace the surface reservoir.

PUMPED STORAGE IN SALT DOMES

Salt domes could possibly be used in another way to provide peaking power. This method which was suggested to the writer several years ago by Professor Hawkins of L.S.U. is a variant of conventional pumped storage. The turbine would be located in a small cavity in the dome near a larger solution cavity deep in the dome which would serve as one of the required reservoirs. The other reservoir could be a surface body of saline water such as the Gulf itself, a man-made reservoir, or another solution cavity at a higher elevation in the dome. The latter possibility would be the most desirable because the water could be maintained in a saturated condition for NaCl. This would prevent further dissolution of the salt caverns. Of course, special non-corrosive equipment would have to be developed.

HYDROGEN STORAGE IN SALT DOMES FOR PEAKING POWER

Another variant on the use of salt domes for storage of energy envisions that peaking power generation be obtained by using off-peak energy to electrolytically dissociate hydrogen and oxygen as illustrated in Figures 7 and 8. The hydrogen and oxygen will then be stored separately in huge man-made cavities in salt domes. This hydrogen will then be pumped to the surface and burned (as a pollution free fuel) to furnish thermal energy for conventional use in generating electric power at times of high demand. The stored oxygen will be a valuable byproduct of the process. An alternative scheme is to use the hydrogen and oxygen for power generation in a fuel cell.

A CONTINENTAL SYSTEM FOR THE USE OF STORED ENERGY

The use of salt domes in storage of off-peak energy is not necessarily limited to conservation of energy on a local scale. Figure 9 demonstrates a concept by which localized sources of solar energy and tidal power could utilize the four salt dome provinces of North America for energy storage on a diurnal basis by the use of superconducting transmission lines. Although not all of these components are available today, they are technically feasible and will very likely be used in the future. The concept shown here

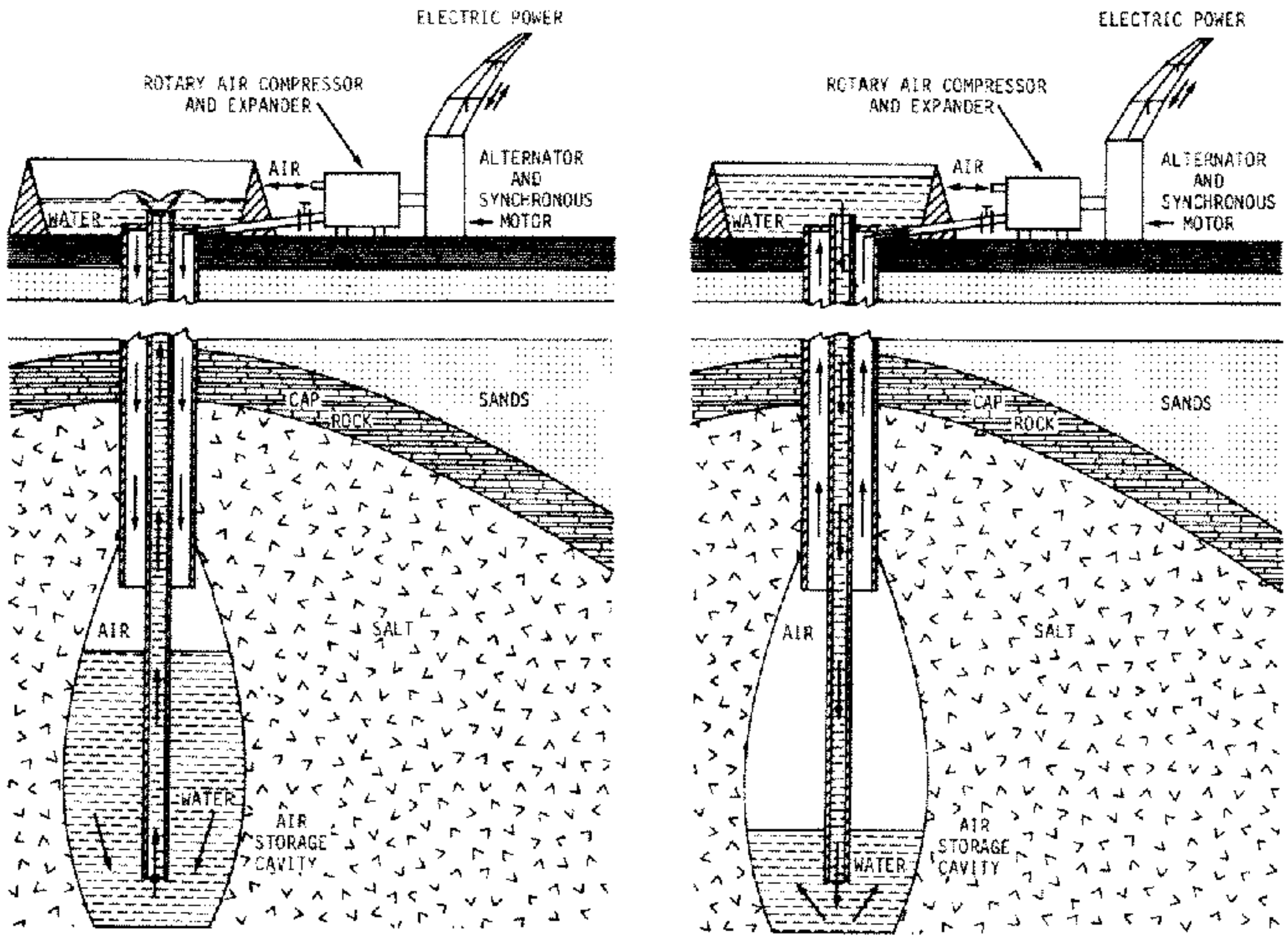

Figure 6. Use of compressed air for energy storage with hydrostatic pressure maintenance. Modified from Lang (1968).

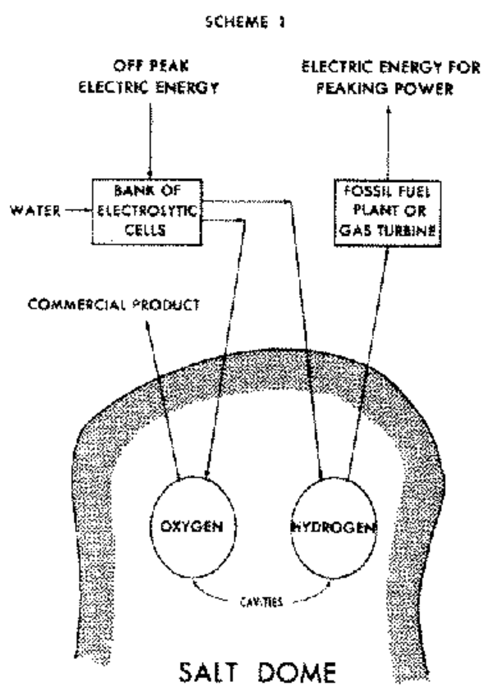

Figure 7. Energy storage in a salt dome using electrolytically dissociated hydrogen as a fuel in conventional power plants.

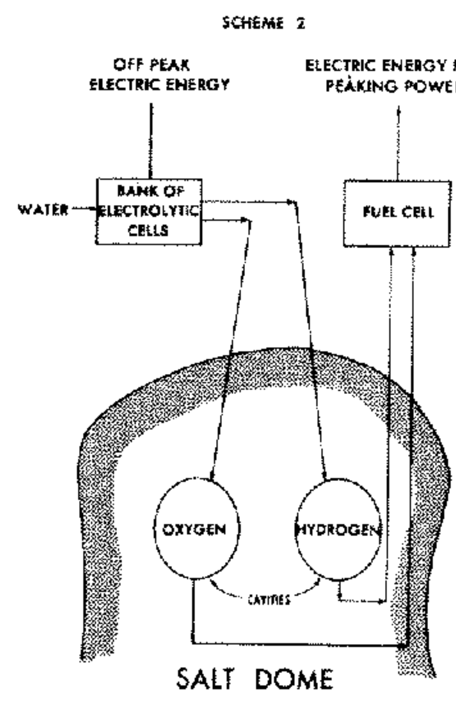

Figure 8. Energy storage in a salt dome using electrolytically dissociated hydrogen and oxygen in a fuel cell.

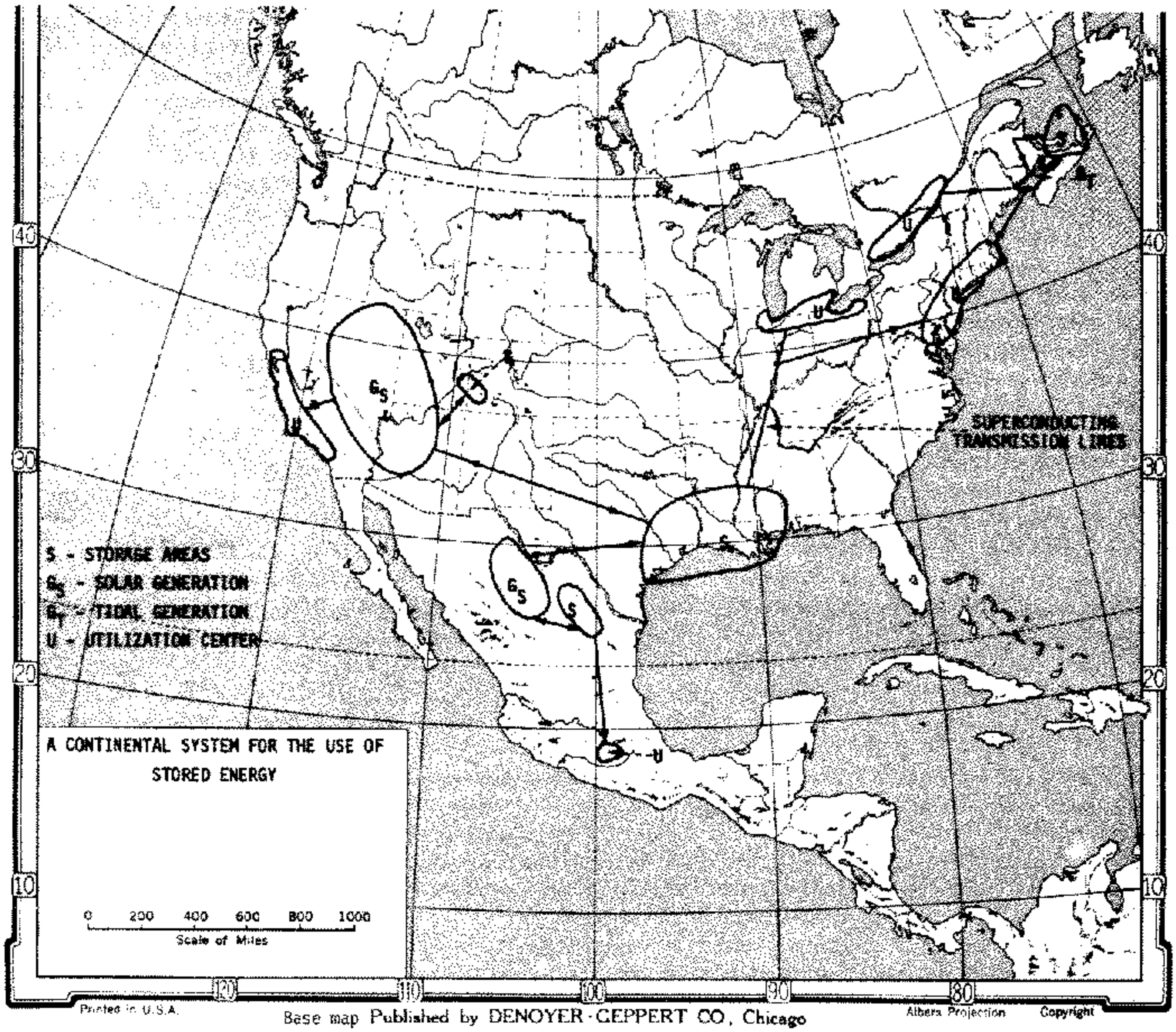

Figure 9. A continental system for the use of stored energy.

represents a total system of continental proportions which would enhance the value of their use.

REQUIRED STUDIES

In spite of the low cost of construction of cavities in salt domes and their general acceptance for gas storage, studies are required to demonstrate their practical utility for power storage using any of the suggested methods. A detailed economic analysis of each of these systems is also required. Problems include: structural stability of the cavern under tension created by high internal pressures, dissolution of the salt by water introduced into cavities in the salt, and possibilities of leakage of gases to be stored in the cavity.

Structural stability of underground salt cavities has been studied by Serata and Gloyna (1960). Martinez, Thoms and Jindal (1970) have used physical models to determine the effects of closure of solution caverns in salt domes. These earlier studies have been concerned with the strength of unpressured solution cavities in salt. It is possible that the storage of air or other gases at very high pressures in these cavities may cause the salt to fail under tension causing fractures which could result in release of the air or gas. This possibility may be enhanced if the pressure is periodically lowered and raised which would be inherent in peaking power operation. Further investigations are needed to evaluate such effects.

Dissolution of salt which may occur during operation of several of the proposed systems could cause severe leakage of stored air or gas and make the system inoperative. The severity of the problem varies with the system selected for storage of off-peak power. For example: the most severe problem of dissolution would be experienced in the development of a pumped storage system within a salt dome. The transfer of water from a surface body of saline water, which is undersaturated with respect to NaCl, back and forth into a cavity in the salt would tend to continue to enlarge the cavity. Transfer from one cavity to another using a saturated brine should not create a problem of dissolution but would constitute a less practical and more expensive system. An effective solution to this problem must be found and tested. The use of a water leg, as described in the Lang patent, will also result in much dissolution of salt unless some steps are taken to prevent it. A method to overcome this problem must be found and tested to make this system viable. The storage of hydrogen and oxygen in cavities can be effected without the use of water in operating the system. Therefore dissolution problems are not anticipated for the "electrolytic" system.

STORAGE OF RADIOACTIVE WASTES IN SALT DOMES

The advantages of disposing of radioactive waste in large bodies of rock salt in the earth's crust are well known. The work of the Union Carbide Corporation for the U.S. Atomic Energy Commission has already been mentioned. Their work focused, however, on disposal in bedded salt. Such deposits while laterally extensive are restricted vertically generally to relatively thin deposits. Their endorsement of a disposal site in bedded salt has recently met with objections leading to further studies.

There would appear to be some advantages to the use of domal salt for disposal of particularly noxious wastes of this kind. Richter-Bernburg, former president of the Geological Survey, Federal Republic of Germany, has contrasted the difference in failure response of caverns in bedded salt (he uses the term salt tables) and domal salt. These differences would seem to favor the use of domal salt. This would be specially true if the cavities were to be constructed by solution mining rather than by dry salt mining. Any loss of control would be much more serious in a body of salt of limited vertical dimensions than in a huge mass of domal salt.

Much of the basic data obtained in the Union Carbide study can be applied to a consideration of disposal in salt domes. Additional information, however, must be developed. No abandoned dry salt mines that are suitable are available in Gulf Coast domal salt or for that matter in any salt domes in the United States. Therefore, caverns would have to be constructed by solution mining. Feasibility studies must be made of techniques which could be employed to safely introduce the wastes into this kind of opening and to consider any special problems which might be encountered with domal salt. For example, the possibility of triggering movement of the dome from heat caused by radioactive decay must be investigated.

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