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SITE SELECTION FACTORS FOR THE BEDDED SALT PILOT PLANT

Staff of the ORNL Salt Mine Repository Project

MAY 73

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

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ABSTRACT

Because of the nature of radioactive waste disposal in geologic formations, the selection of suitable sites is a unique exercise totally different from that for any other type of facility. This compilation of the various factors which must be taken into consideration was assembled as an aid in the selection and confirmation of a site for the Bedded Salt Pilot Plant. As might be expected, most of these factors are related to geologic characteristics, which are discussed under the headings of: (1) stratigraphy, (2) structure, (3) hydrology, and (4) mineral resources. Other factors concerned with geography and facility design and operation are also included.

A. INTRODUCTION

The purpose of this document is to provide a guide for the selection of specific sites for the Bedded Salt Pilot Plant and a standard against which various individual sites can be compared and evaluated in order to identify the most suitable ones. It contains a compilation and brief discussion of the major technical factors bearing on site selection, arranged and grouped in a manner to best illustrate their interrelationships and interdependence. The discussions were intentionally formulated in completely general terms so that the considerations involved would be universally applicable to any bedded salt deposit.

The objective of the proposed Bedded Salt Pilot Plant project is to demonstrate all aspects of a typical fully operational waste disposal facility without actually committing the wastes to ultimate geologic disposal. This demonstration may require as much as 10 years of operation and testing. However, the facilities will be designed so that they can be expanded to a full-sized waste repository upon successful completion of the Pilot Plant phase. For these reasons, site selection, site confirmation studies and other evaluations of the long-term geologic containment for the Bedded Salt Pilot Plant will proceed as though an actual, full-scale waste disposal facility were being considered. Because of this assumption, the geological features of the site, especially those related to long-term containment and operational safety, are considered to be the most important and therefore are emphasized in this document, although other factors are included. In addition to the items discussed here, final site selection will take into consideration other site criteria based upon AEC Manual Chapters 6202 "Site Selection," 6203 "Site Development Planning" and their appendices. The most pertinent of these, Appendix 6202, Part I, "Guides for Establishing Site Selection Criteria," is attached to this report.

A number of other assumptions are implicit in the following discussion of site selection factors:

1. The waste disposal concept for both the Bedded Salt Pilot Plant and a full-scale repository consists of placing containers of solidified, high-level fission-product wastes in shallow holes drilled in the floor of rooms excavated in the salt formation deep underground.

2. A site area of approximately two square miles will be required.

3. The actual site area will be surrounded by a buffer zone in which it is possible to exercise control over future surface, and especially, subsurface activities so as to preclude unacceptable penetrations of the salt formation in the immediate vicinity of the Bedded Salt Pilot Plant. The required width of this buffer zone cannot be specified at this time and is somewhat site-dependent but will probably be in the range of 1 to 5 miles.

It must be emphasized that the various detailed selection factors and the numerical values attached to them, must be considered as tentative, and subject to revision as new knowledge becomes available. In a broad sense, there is only one criterion: the characteristics of the site must be such that thorough and rigorous analyses and evaluations confirm that a waste disposal facility can be operated safely, and that the wastes will remain totally isolated throughout their hazardous lifetime. All of the individual and detailed factors discussed below are merely an elaboration of this general criterion based upon current best knowledge.

B. DISCUSSION OF FACTORS

1. Geologic - Stratigraphic Factors

1.1 Thickness of Salt Formation

Two of the major advantageous properties of rock salt formations for waste disposal are (1) its relatively high thermal conductivity, which serves to rapidly conduct the heat away from the waste containers, thereby minimizing the peak temperatures; and (2) its plastic or creep deformational behavior which permits sizeable strains to be absorbed without fracture, while at the same time reducing the strain transmitted to the overlying rocks. In order to take full advantage of these desirable properties, a certain minimum thickness of salt is necessary. Thermal calculations indicate that for a 200-ft-thick salt formation and an economically acceptable waste disposal pattern, the temperatures at the disposal horizon will not be excessive and the maximum temperatures at the upper and lower formation boundaries will not exceed 120°C. This temperature is considered to be about the limit for excluding the possibility of drastic alterations of rocks containing significant quantities of hydrated minerals. For a thicker salt formation and the same waste disposal pattern, the temperatures at the disposal horizon are only slightly decreased. For a thinner salt formation, the temperatures in the disposal horizon are somewhat increased but the maximum temperature at the formation boundary will be significantly higher, because that boundary will be closer to the heat sources. As the waste disposal room closes, it will be surrounded by a high deformation zone involving crushing, fracturing and other failure modes. The very limited evidence available suggests that in salt mines, this zone is at most only a few tens of feet wide. In order to assure that the high deformation zone will be well contained within the salt formation, it would seem prudent to allow at least 100-ft thickness of salt above the mining horizon and at least 50-ft thickness below the disposal horizon.

These two considerations, taken together, establish the minimum thickness of the salt formation as greater than about 200 ft.

1.2 Thickness of Salt Formation Above Disposal Horizon

Obviously, the advantages described in item 1.1 would be largely negated with respect to the overlying material (which is more critical than the underlying) if the disposal horizon were very near the top of the salt formation. The thickness of salt above the disposal horizon must be sufficient to protect the overlying non-salt rocks from (1) excessively elevated temperatures which could lead to adverse thermal alteration of the minerals present and (2) excessive mechanical deformation which could result in fracturing of the more brittle rocks. As implied in the previous section, a thickness of about 100 ft above the disposal horizon should suffice to limit the potential for thermally induced mineralogical alterations. Based on practical experience in salt mining operations, a thickness of at least three times the maximum room width would preclude fracturing of the overlying rocks. Therefore, the thickness of the salt formation above the disposal horizon should be greater than about 150 ft.

1.3 Purity of the Salt Formation

Bedded salt formations frequently contain a significant percentage of insoluble foreign material, usually clays, shales, anhydrite, and other evaporite minerals, disseminated within and around the salt crystal matrix and/or as discrete beds, layers, partings, or laminae. Since these foreign materials dilute the desirable properties of the salt discussed in item 1.1, their quantity and distribution must be limited. In this case, it is not possible to specify an acceptable quantitative limit of the impurities since that would depend upon the actual thickness and other characteristics of the salt formation and the types, locations, dimensions and distribution of the impurities. In very general and qualitative terms, the overall salt formation should be largely halite over at least the required minimum thickness and the amount and nature of the impurities should not be such that the pertinent properties of the formation are seriously degraded.

1.4 Detailed Stratigraphy in Disposal Horizon

The salt immediately adjacent to the waste containers will be temporarily subjected to a significant increase in temperature which may serve to mobilize included and adsorbed moisture. Therefore, it is desirable to limit, as much as possible, the quantity of moisture available in the disposal horizon, which, for this purpose, can be defined as a 12- to 14-ft-thick zone encompassing the maximum length waste can (10 ft) plus 1 to 2 ft on both sides. Within this zone, the total amount of moisture available as free water, from both the small brine inclusions within the salt and the water of hydration (at temperatures up to 300°C, which is much greater than the maximum temperature in the bulk of the salt) of any other minerals present, should not exceed 2% (by volume). Preliminary estimates suggest that 2% moisture will limit can and liner corrosion and gas generation rates to acceptable values. For waste disposal operations, it will be necessary to drill a large number of disposal holes into this zone. Obviously, any stratigraphic feature which made these drilling operations difficult, such as a thin bed of hard anhydrite, would be most inconvenient. Once again, it is not possible to exactly specify the limits of acceptability in this regard. In general and qualitative terms, the mechanical properties of the disposal horizon, especially drillability, should be equivalent to commercial grade rock salt (95%).

1.5 Detailed Stratigraphy in Mining Horizon

The present design concept calls for the excavation of extensive rooms and corridors having a minimum height of 15 1/2 ft with the floor located about 8 ft (for shielding) above the tops of the waste containers. The material in this zone must therefore be such that it can be excavated without undue difficulty and that the material left in place as support pillars will adequately perform in that capacity. It is not possible to specify the detailed requirements in this case since they are highly dependent upon the mine design, mining methods and associated special procedures and the local situation. However, it is apparent that the stratigraphy and lithology of the mining horizon above the waste disposal section must be such that the rooms and corridors can be excavated using standard established salt mining techniques.

1.6 Vertical Isolation of the Wastes from Aquifers

It is necessary to assure that the waste materials are protected from circulating ground water throughout the very long time spans during which they are hazardous. With respect to dissolutioning of the salt deposit along its upper or lower surface, this protection can be provided in a number of possible ways, for example: (1) by showing that the salt formation is separated and isolated from flowing aquifers by suitable impermeable formations in such a way that water could not contact the salt, or (2) by showing that although the surface of the salt formation is in contact with an aquifer (regardless of whether the salt is currently being actively dissolved), the available thickness of salt between the wastes and the aquifer is more than adequate to assure the confinement of the wastes at the maximum potential dissolution rate.

1.7 Depth to Disposal Horizon

In choosing a depth to disposal horizon there are two important considerations - the limits of mining capability, and protection from surface phenomena.

With respect to mining capability, operations in salt become more costly and more difficult as the depth and overburden pressures increase. At some point these problems become so severe that mining is no longer practical. For example, salt is commonly produced from depths of about 2000 ft without undue difficulty, while potash (a more valuable material having very similar structural properties) is being economically mined at depths up to about 3500 ft, but with more difficulty. Based upon these indicators, it would seem inappropriate at this time to select a site where the depth to the disposal horizon was greater than about 2500 ft.

With respect to protection from surface phenomena, it is primarily the overlying geologic material which assures the long-term containment of the wastes buried in the salt. This overlying geologic material protects the disposal horizon from ordinary surface processes such as erosion and denudation. Of these processes, stream erosion (channel downcutting) could be the most damaging. Analysis of available data on the rates of this process suggests that, even in a semi-arid region of low relief, stream channel downcutting is possible and, under certain conditions, it could amount to a few hundred feet in a million years.

Consequently, it is felt that the depth to the disposal horizon should be at least 1000 ft but not greater than about 2500 ft.

2. Geologic - Structural Factors

2.1 Attitude of the Salt Formation

The principal consideration bearing on this factor is simply the obvious desirability of carrying out mining and, more importantly, waste disposal operations in a single, approximately horizontal, unit of the salt formation. Lesser considerations include recognition of the fact that appreciable differential gravity loads on the salt formation hold an increased potential for producing mass flowage, especially when the salt is heated; and that nonuniform design of room and pillar widths might be required to compensate for appreciable differences in overburden pressures. These potential problems can be eliminated and the desirable features preserved by limiting consideration to those areas where the salt formation at the mining horizon has dip or tilt of less than 100 ft per mile.

2.2 Incipient Diapirism

One mechanism by which it might be possible for wastes buried in salt formations to be disinterred is by the mass flowage of the salt into anticlines, ridges, or domes (diapirism). The conditions necessary to initiate and sustain this flowage are not known exactly, but there is general agreement that very thick formations buried to depths of tens of thousands of feet (or equivalent tectonic conditions of stress and temperature) and significant stress differentials seem to be the minimum required. For the purposes of site selection, it should be sufficient to demonstrate that the salt has never been subjected to the conditions necessary for mass flow by the absence of any diapiric structures throughout the region.

2.3 Regional Structural Framework

In general, the major salt deposits of the United States tend to be located in regions characterized by a history of marked tectonic stability, at least since the deposition of the salt. However, all aspects of the regional geologic structure should be examined for any features which would suggest that a proposed waste disposal site might be located where future deformations would be concentrated. These features would certainly include such things as zones of weakness, subsurface faults, and folding trends.

2.4 Tectonic Stability

In addition to the geologic indications discussed above (item 2.3), the tectonic stability of the region also can be estimated on the basis of the record of historical earthquakes. The details of that record should be examined for a large area surrounding any proposed site and, if possible, correlated with the regional structure. Also, earthquake resistance is a factor in the structural design of the various surface facilities.

3. Geologic - Hydrologic Factors

3.1 Ground Water

In general, a waste disposal facility should be located in an area of limited ground water. This provision contributes to the long-term geologic containment of the wastes in two significant ways: (1) the rate of dissolutioning of the salt (see items 1.6 and 3.3) is directly related to volumes and rates of ground-water flow, and (2) the ground water is by far the most available mechanism for widespread dispersal of the radionuclides should they ever escape from the salt formation. An additional factor in waste repository site selection would be the avoidance of any area underlain by large and extensive ground water aquifer systems having a potential for significant future development.

3.2 Surface Water

For the same reasons as discussed in item 3.1, a repository site should be remote from large surface water supplies, including rivers, large creeks, reservoirs, etc. A further consideration in this case would be the relationship between surface hydrology and potential rates of surface erosion.

3.3 Horizontal Extent of Salt Deposit

The potential for dissolutioning of the salt formation containing the radioactive wastes from its top and bottom surfaces was discussed in section 1.6. It is also possible for the salt formation to experience dissolutioning at the deposit boundaries. In actual fact, this is frequently the case because the bedded salts were nearly always initially deposited in broad basin-shaped structures. This means that the deposit boundaries are usually at a much shallower depth than the central portions and therefore much more likely to be exposed to circulating ground water. A repository site must be located so as to provide protection from these boundary dissolutioning processes by an adequate horizontal distance of salt. The required distance depends upon the analysis of a number of items: (1) the total thickness and shape of the salt formation; (2) the thickness of salt overlying the wastes; (3) the structure of the salt formation between the repository site and the deposit boundary; (4) the rate of dissolutioning if it is currently active; (5) potential rates of dissolutioning in the future; and (6) the nature and character of dissolutioning process and the regional hydrologic regime which controls it.

4. Geologic - Mineral Resources

4.1 Mineral Production History and Potential

Mineral production activities inevitably involve subsurface operations of some type which could have a bearing on the geologic containment of radioactive wastes. Therefore, areas of existing production or extensive exploration should be avoided as much as possible (see sections 4.2 and 4.3 for detailed discussions of two particularly important considerations).

4.2 Mining Operations

One factor of particular importance related to the mineral resources of the area is any previous production from within the evaporite sequence. This production could be mining of either salt or other evaporite minerals (especially potash) by either mechanical underground mines or hydraulic mining (including solution-mined storage cavities for LPG or other materials). These operations could represent a potential threat to the long-term geologic containment since current technology makes it difficult to predict what their eventual effects might be. Therefore, a repository site should be located so that existing subsurface operations would be outside the buffer zone, and the mineralogical and structural character of the rocks within the buffer zone would minimize the probability of any such future operations. The buffer zone should be designated so as to preserve the repository site against any deleterious effects from commercial operations associated with the resource but conducted beyond the buffer zone.

4.3 Existing Boreholes

Another factor of particular importance related to mineral resources is the number of existing boreholes in the area. These holes are important because they represent a potential hydraulic connection between the salt formations and both higher and lower aquifer systems. In a very few known cases, circulation of this type has become established and resulted in very rapid local dissolution of the salt. It is obvious that this type of dissolutioning at any proposed site or within the buffer zone could render it unacceptable. Consequently, all existing boreholes have to be located, evaluated as to their potential to form a hydraulic connection between the salt formation and both higher and lower aquifer systems, re-entered, cleaned out, and replugged in as permanent a manner as possible in order to protect the salt against the development of circulations of this type in the future. The advantage of selecting a site with a minimum number of existing holes is apparent.

5. Geography

5.1 Land Values

Since a waste repository by law must be located on Federally owned land which is dedicated to that purpose in perpetuity, consideration should be given to its present value and ownership, and to land usage patterns in the general area, and to the potential for future development, especially for any purpose which would attract large numbers of people (such as recreational pursuits).

5.2 Isolation from Population Centers

In spite of the various engineered safeguards built into the proposed facility, efforts should be made to minimize the population requiring evacuation in the highly unlikely event of an accident or other emergency. This can be accomplished by the judicious location of the waste disposal facility in areas of low population density and as remote as practical from large concentrations of population (see also items 5.3, 6.4, and 6.5).

5.3 Existing Rights-of-Way

As far as is practical, proposed sites should avoid areas traversed by existing easements and rights-of-way, such as power lines, railroads, highways, and particularly oil, gas, and petroleum products transmission pipelines. This factor is simply a matter of avoiding the relocation costs if the easement would interfere with the operation of the facility.

6. Facility Design and Operation

6.1 Disposal of Excess Salt

The current waste disposal concept involves the excavation of a large number of long tunnels or "rooms" in the salt deposit. The containers of waste will be deposited in holes drilled into the floor of these rooms and the rooms backfilled with crushed salt obtained from the excavation of subsequent rooms. However, it is not possible to pack the same quantity of salt back into the rooms as was originally removed. The resulting surplus salt must be disposed of in an acceptable manner. It is estimated that excavations for the Bedded Salt Pilot Plant will result in about 250,000 tons of salt, none of which would be backfilled, while full-scale waste disposal operations with backfill would produce perhaps 6 to 8 million tons of excess salt over a 20-year operating lifetime. The method for disposal of this excess salt has not yet been determined but a number of possibilities exist. The best and most advantageous method would be to market it commercially.

Another method for the disposal of the excess salt would be to deposit it in a nearby existing underground mine. Such a practice would require certain salt handling facilities, both at the Pilot Plant and at the receiving mine, and the cost of the shipment between the mines and the disposal operations could be considerable.

The factors which relate to the disposal of excess salt (such as potential commercial grade, quantity, and type of associated insoluble material, proximity to usable existing underground mines, transportation facilities, etc.) should be considered in the selection of a site.

6.2 Waste Transportation

It is planned that waste deliveries to the Bedded Salt Pilot Plant will be initially by rail only. Therefore, a rail spur connection between the site and an existing serviceable rail line is an item of construction costs which could be influenced by judicious selection of the site and should, therefore, be taken into consideration.

6.3 Highway Communications

Another factor to be considered in the selection of a suitable site is its accessibility by road for freight and passengers. Furthermore, the possibility of future waste shipments by highway should not be overlooked.

6.4 Utility Services

The facility will require the usual utility services of electricity, water, sewage, fuel, etc. The ready availability of these services is a factor in site selection, since connections or independent, on-site provisions may have to be included in the construction costs.

6.5 Community Services

Similarly, from the point of view of normal operation of the facility, housing and services for employees, access to nearby services for equipment maintenance (such as machine shops, garages, etc.), ordinary hardware and other supplies, medical facilities, fire protection, etc., should be considered.

C. SUMMARY

The following table summarizes the various site selection factors discussed above, along with any numerical or quantitative values associated with them.

Table 1

Summary of Site Selection Factors

Item No.	Factor	Value
1.	Geologic - Stratigraphic	
1.1	Thickness of Salt Formation	>200 ft
1.2	Thickness of Salt Formation Above Disposal Horizon	>150 ft
1.3	Purity of the Salt Formation	largely halite
1.4	Detailed Stratigraphy of Disposal Horizon	available water <2%; easily drillable
1.5	Detailed Stratigraphy of Mining Horizon	easily minable
1.6	Vertical Isolation of the Wastes from Aquifers	adequate to assure confinement of wastes
1.7	Depth to Disposal Horizon	<2500 ft; >1000 ft
2.	Geologic - Structural	
2.1	Attitude of the Salt Formation	dip <100 ft/mi
2.2	Incipient Diapirism	no diapiric structures in region
2.3	Regional Structural Framework	minimal
2.4	Tectonic Stability	low historical seismicity

Table 1 (continued)

Item No.	Factor	Value
3.	Geologic - Hydrologic	
3.1	Ground Water	minimal
3.2	Surface Water	remote
3.3	Horizontal Extent of Salt Deposit	sufficient to protect against dissolutioning
4.	Geologic - Mineral Resources	
4.1	Mineral Production History and Potential	minimal
4.2	Mining Operations	remote
4.3	Existing Boreholes	minimum number
5.	Geography	
5.1	Land Values	
5.2	Isolation from Population Centers	
5.3	Existing Rights-of-Way	
6.	Facility Design and Operation	
6.1	Disposal of Excess Salt	
6.2	Waste Transportation	
6.3	Highway Communications	
6.4	Utility Services	
6.5	Community Services	

Attachment 1

PART I

GUIDES FOR ESTABLISHING SITE SELECTION CRITERIA

A. CRITERIA DEVELOPMENT

Basic site selection criteria will be developed for the selection of each new site or a plant area within an existing AEC site. The criteria will encompass all the pertinent factors in each case and will necessarily vary to some extent. The factors set forth in the Code of Federal Regulations pertaining to reactor site criteria guides, 10 CFR 100, will be included in the basic site selection criteria for power and test reactors. Specific criteria developed by the responsible program divisions under Chapter 0540, "Safety of AEC-Owned Reactors," shall be followed in surveys for reactor sites.

B. FACTORS TO BE CONSIDERED

1. General Site Location

   a. Relation to other AEC sites or to defense installations and to other facilities and industrial complexes to avoid concentrations of important facilities in one potential target area.

   b. Requirements for site defensibility if applicable.

   c. Recognition of requirements for program continuity.

   d. Recognition of the requirement of the Agricultural Act of 1970 to locate new Federal offices and other facilities in areas or communities of lower population density in preference to areas of higher population density wherever practicable.

2. Isolation

Limitations with respect to current and projected population densities in the surrounding area.

3. Areas Required

Total number, size, purpose, and spacing or dispersal within the site of separate plant groups.

4. Waste Disposal

Requirements for disposition of solid, liquid, and gaseous wastes and limitations imposed by State and local standards, codes, and requirements.

5. Availability of Manpower

Total by types required for support of construction and operation of the facility.

6. Open Housing

As it relates to manpower (see chapter 0208).

7. Water

a. Availability of quantity and quality to meet all plant demands.
b. Consideration of alternate schemes of water use, such as "once-through," cooling towers, etc.
c. Limitations in acceptable amount of chlorides, dissolved solids, suspended solids, temperature, etc.
d. Effects of proposed water use (contamination, temperature, etc.) on other private or public uses.

8. Power

Availability of quantity and quality to meet all plant demands, and power services reliability.

9. Fuel

Types available and suitable for conforming with applicable pollution control standards.

10. Transportation

Rail, highway, air, and water.

11. Meteorology and Climatology

As they may affect design, construction, and operation of plant facilities, including an evaluation of the capacity of the atmosphere to receive and disperse plant gases safely, including their effect on the dispersion and distribution of potential airborne effluents.

12. Geology, Hydrology, and Topography

a. The relationships of the geology, hydrology, and topography on the safety and engineering requirements of the proposed facilities.

b. Desirable geological structure and character, load supporting capacity of soils, permeability, nature and extent of ground water and flows, including depth and direction, and earthquake probability and intensity.

13. Economic Analysis

Differentials in construction and operating costs between sites being considered.

14. Environmental Analysis

Consideration of the environmental impact of the proposed activity upon site and adjacent area.

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