Potential Geologic Host Media For
A High-Level Nuclear Waste Repository

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I. Introduction

Although several methods have been proposed for isolating high-level radioactive waste, burial in geologic repositories has received the most serious consideration. The U.S. Department of Energy is proceeding with plans to test and build a geologic repository which will begin operating between 1998 and 2003.

Over the past several years, the role that geologic materials are expected to play in containing nuclear waste has changed. As recently as 1978, many held the opinion that the host rock and surrounding rocks should provide essentially all of the containment for the waste, with the container required only for safe handling, transportation, and retrieval over a period of about five years (Cain, 1978). The immediate disposal formation was to be the primary barrier against waste migration, with the overlying geologic units providing additional containment. Since, in all probability, water would be the primary means for transporting the waste products to the environment, attention was focused on rock types of low permeability and water content which occurred in formations of large lateral and vertical extent and at considerable depth.

The medium that appeared to fulfill these requirements best was salt, salt mines were known to be dry and the continuing presence of large deposits of salt, a highly soluble mineral, millions of years after deposition provided evidence of the stability of the potential host environment. Since salt tends to flow under stress and heat, it was thought that openings made during the construction of a repository would gradually close and thus seal off the waste. Although the level of federal funding for research and development in all rock media was low, the available funds were allocated primarily to salt studies.

Under the Carter administration, a number of significant changes were made in the U.S. Nuclear Waste Management Program, including (NRC, 1980):

- expansion of the number of rock types under consideration;
- new criteria for the isolation of high-level waste in geologic repositories.

These policy changes have been accompanied by a greatly expanded research and development budget.

With the inclusion of rock types having properties different from those of salt, the important distinction between the characteristics of a generic rock and those of a rock mass becomes much more pronounced. For example, granite may theoretically exhibit all of the qualities desirable for waste isolation. In the dimensions required for a repository site, however, the total volume of rock in a formation may be composed of a matrix of granite blocks separated from one another by joint planes. The overall characteristics of this granite rock mass may be quite different from those attributed to granite, per se. The suitability of this granite rock mass for waste isolation will also depend upon its physical deposition (shallow or deep), the hydrologic regime and so on. In short, the amount of information that can be obtained on the basis of a generic rock type alone (granite, shale, basalt, tuff, etc.) is extremely limited. All of these generic rock types have certain advantages and certain disadvantages; however, their relative importance as part of the total containment picture can only be properly assessed on a site-specific basis.

II. BASIC GEOLOGIC CHARACTERIZATION OF THE ROCK MEDIA

The heat generated from nuclear waste, the impact of repository mining activities, and the criterion of retrievability are the aspects of repository siting that must be considered closely in geologic characterization of host rock media. The specific geologic characteristics that play a role in site selection can be listed readily, but it should be re-emphasized that no rock type exists which exemplifies all of the desirable characteristics.

The desirable characteristics used in the assessment of potential host rocks are (DOE, 1982):

1. The areal extent of the geologic formation should be sufficient to contain the necessary structures for a repository, and to ensure containment of the waste.

2. The formation thickness should be sufficient to ensure containment of the waste.

3. The depth below ground surface should be sufficient to isolate the formation from any externally imposed environmental changes such as surface water encroachment due to erosion, rising sea level, permafrost, etc.

4. The formation should be homogeneous.

5. Bedding in sedimentary rocks should be relatively flat.

6. The formation should have properties that would ensure a stable excavation.

7. The geologic host formations should be of extremely low permeability and be surrounded by formations that

permit no leaking to the biosphere. These conditions should be simple and determinable.

8. The chemical exchange characteristic of the formation should favor containment.

9. The thermal conductivity of the rock should be high.

10. The formation should be resistant to chemical or mechanical alterations.

11. The area should be located in a zone of low seismicity, removed from active or capable faults.

12. The rock should not be of any present or future need as a raw material for man or be associated with any such rock or mineral.

13. The formation should be of low solubility.

III. CHARACTERIZATION OF POTENTIAL HOST MEDIA

Table 1 summarizes the major types of geologic formations which various countries are considering for radioactive waste repositories. These formations include salt, crystalline rock (mostly granite, but also basalts and volcanics), and argillaceous rock (shales and clays). The U.S.S.R. is also investigating deeply confined porous strata (limestones and sandstones). These are also the primary rock types that have been under consideration in the United States. In 1981, the Department of Energy decided to discontinue its basic research on argillaceous rocks because of the complexity and cost of the project. However, the department is now investigating tuff as a repository medium.

Rock Salt

In the United States and a number of other countries, rock salt has long been a favored geologic medium for the containment of radioactive waste. The plastic behavior of salt promotes self-healing and otherwise makes the rock impermeable to circulating ground water. Other important advantages of salt include its wide distribution, ease of mining, and favorable heat dissipation characteristics.

The existence of salt beds and domes hundreds of thousands of years old testifies to their isolation from water and to their stability. The strength of salt deposits is fair to good in the undisturbed state, and its plastic behavior has the positive advantage that creep tends to seal discontinuities; on the other hand it may be difficult to stabilize the openings created during the development of a repository. Although heat tends to reduce the strength of salt, its high thermal conductivity is conducive to heat dissipation. But a salt deposit may also contain moisture in interbedded material and small cavities; combined with heat, this mositure creates the potential for a loss of strength from solution action. The least desirable characteristics of salt are its high solubility in water, negligible sorption capacity and a potential for exploration as a raw material or storage medium.

In the United States, most attention has been directed to the large salt deposits. The bedded deposits in the Permian Basin, for example, extend from central Kansas through the Oklahoma Panhandle and into western Texas and eastern New Mexico covering a total area of about 120,000 square miles. Domal salt is generally homogeneous and extends to great vertical depths. Although more than 300 salt domes are known to exist in the Gulf Coast area, fewer than 50 of them are considered good candidates for further study. The large majority of domes are either offshore or too deep, or have ongoing petroleum or mineral operations (ONWI, 1982).

Argillaceous Rocks

Argillaceous formations display extreme variability in their physico-chemical properties. Plastic clays are usually young and highly porous, having a water content of 15% to 20%.

The implications of this high water content for the emplacement of heat-generating waste are not well understood. Further study will yield better information.

The advantages of argillaceous sediments are their plasticity, extremely low permeability, and high sorption capacity. In addition, clays are less corrosive to waste containers than salt. Their great abundance near the surface makes it very unlikely that in the future man will be motivated to drill through the specific deep clay formations where a repository is situated. On the other hand, values for the thermal conductivity properties of clay are rather low--two to four times less than for those of salt. Moreover, maintaining openings in argillaceous sediments can be difficult.

Shales are usually stratified or laminated, though they may show some layering and may break into small angular blocks. They may also have discontinuities consisting of bedding joints and fracture planes. The fine-grained clay minerals in the shale account for a high natural moisture content and porosity. Generally, however, the voids are not interconnected so that permeability is low. Moreover, the clay minerals have a high ion exchange potential.

Although shales are relatively weak rocks, stable openings have been constructed in them at fairly great depths. But they are very susceptible to air slaking, and wetting and drying may signficantly weaken the rock. On the positive side, many shales, due to their potential for plastic flow have the ability to accommodate large deformations (Gevantman, 1981).

Crystalline Rocks

Igneous rocks as a group may have similar physical characteristics, but they range in chemical and mineralogical composition from granite to granodiorite and related rock types. Their porosity is low, with little or no natural moisture content, their permeability between grains is extremely low, and their strength is considered very high. Most of the component minerals are hard and very durable, which guarantees little deformation under stress. Igneous rocks alter little under heat because of the high temperatures under which the rock was formed. However, the thermal expansion of particular minerals may be sufficient to cause rock spalling and related phenomena. The mineral components of granite are almost chemically inert under ambient pressure and temperature conditions.

Although granite as a rock mass has no bedding because of the way it was deposited, it may be jointed. The joints, which may range from sealed to partially opened, divide the rock mass into a series of blocks, and may be interconnected over great areas. Therefore, one of the concerns with siting a repository in igneous rock is joint permeability, which might provide a pathway to the surface.

The term "basalt" identifies a black to medium-gray extrusive volcanic rock. The major components of which are plagioclase and olivine. The texture of basalt may vary from glassy to angular; in general, it is a very dense, high strength material. Consequently, porosity and permeability are favorably low. Basalts remain relatively strong under elevated temperatures, but they may expand.

As a rock mass, basalt flows may cover a large area. They are layered and may be highly jointed; and these platy or columnar joints may be filled with various secondary minerals derived from weathering products of the rock. Thick and extensive in certain part of the U.S., flood basalts are composed of many superposed individual layers, each of which represents an eruptive event. The basalts in the pacific northwest average 1,000 m. in thickness over approximately 100,000 square km. These formations are currently under investigation at the Hanford Reservation Test Facility in Richland, Washington (Dames and Moore, 1979).

Other Rock Types

Tuff, a volcanic material, has begun to receive more attention as a waste repository medium. It has the favorable property of high ion-exchange capacity, but the disadvantage that it occurs in relatively small stretches and is relatively weak.

Limestone, dolomite, and chalk can be viewed as potential candidates for isolating nuclear waste in unique environments where they are overlain by thick sequences of dense, impermeable shales, the major problems with these rock types are their close association with aquifers, their brittleness and susceptibility to fracturing, and their potential for dissolution by circulating ground water.

Dry openings in calcareous rocks have been excavated for petroleum storage in the stable interior portion of the U.S.A., where limestone is protected by shale and the depositional sequence is continuous (Gevantman, 1981).

IV. SUMMARY AND CONCLUSIONS

Tables 2 and 3 show the results of two attempts to summarize various characteristics of the major rock types under consideration as waste isolation media (IAEA, 1981).

It is clear from these characterizations that, in the final analysis, each rock type has certain disadvantages when considered with regard to mining waste, containment and retrievability. Thus, these comparisons prove inadequate for identifying a "most favorable" or "least favorable" rock type for isolating nuclear waste. These weaknesses must be minimized through careful site selection and good engineering of the barriers for containing the waste.

As was pointed out before, there can be a vast difference between the acknowledged characteristics of a generic rock type, such as granite, and a rock mass composed of granite. After final analysis, a specific rock mass X may be considered far superior to a specific rock mass Y for waste isolation, even though the properties of generic rock Y appear superior to those of generic rock X. In the end, only site-specific studies can determine the suitability of a rock mass for hosting a high-level waste repository.

Table 1

Types of Geologic Formations Under Consideration As Host Media For A Nuclear Waste Repository (DOE 1982)

Rock Type	Countries Considering Rock Type*
Salt	Denmark, East Germany, France, Italy, the Netherlands, Spain, U.S.S.R., West Germany
Crystalline rock	Austria, Canada, Finland, France, India, Japan, Spain, Sweden, Switzerland, U.K., U.S.S.R., West Germany
Argillaceous rock	Belgium, France, Italy, Japan, Spain, Switzerland, U.K.

*Pilot plant testing by the middle to late 1980's is planned in Belgium, France, Italy, Spain, and Sweden; demonstration testing is planned in Canada after 1991, in West Germany by 1995, and in the U.K. by the year 2000.

Table 2

Properties of Potential Host Media For Deep Underground Nuclear Waste Repositories

(DOE, 1982)

Basic Properties	**Salt**	**Basalt or Granite**	**Shale**	**Tuff**
Plasticity	High	None	Variable	Variable
Solubility	High	Very low	Very low	Very low
Sorptive capacity	Low (depends on impurities)	Fair	High	Variable
Compressive strength	Moderate	High	Moderate	Moderate
Thermal diffusivity	High	Low	Low	Low
Thermal stability against chemical decomposition	High	High; potential dewatering of clay in basalt	High; potential dewatering of clay	High
In Situ Properties				
Porosity	0.5%; interstitial	1%; cracks	5–30%; cracks	15–25%; interstitial
Permeability	Essentially none	Decreases with depth	Very low	Low to moderate
Water presence	Isolated from flowing ground water	Present, open to flowing ground water	Present, open to flowing ground water	Present, open to flowing ground water
Corrosiveness of indigenous fluid	High	Low to moderate	Low to moderate	Low
Tectonic stability	Very stable	Very stable areas can be found	Very stable areas can be found	Very stable areas can be found
Geologic structure	Relatively simple areas can be found	Fracture systems often complex	Relatively simple areas can be found	Variable, may contain tight fractures
Geohydrology	Moderately difficult to characterize	Difficult to characterize	Difficult to characterize	Moderately difficult to characterize

Table 3

The Implications of Some Rock Properties For Deep Burial of Radioactive Wastes (DOE 1982)

Characteristic	Impact	Crystalline Rock	Argillaceous Rock	Salt	Tuff
Thermal conductivity	Allowable power density of waste	High to low 0	Low −	High +	Low −
Permeability	Radioactive nuclide transport velocity	High to very low, through fractures 0	High to very low, through fractures 0	Very low +	High to very low 0
Solubility	Long-term stability	Low +	Low +	High −	Low +
Strength	Mine stability	High +	Low −	Low −	Low −
Plasticity	Mine stability	Low +	High −	High −	High −
	"Self-sealing"	−	+	+	+
Ion exchange	Ability to absorb radionuclides	Usually none −	High +	None −	High +
Density	Long-term gravitational stability when deeply buried	Usually high +	Low to high 0	Low −	Low −
Volatile content	Shattering on heating, radiolytic gas formation	Low +	High −	Low to high 0	Low +
Generalized geologic environment of large continuous bodies	Location	In continental shields, mountain ranges, volcanic plateaus	In sedimentary basins	In sedimentary basins	In volcanic regions
	Association with gas, oil, water-bearing beds	+	−	−	+
	Proximity to seismic zones	0	+	+	0
Generalized distribution of large continuous bodies in U.S.	Availability in arid zones & zones of low population density	West, north, east +	East, central, west 0	Central, east −	West (small areas) −

Rating scale: + = favorable to waste storage
− = unfavorable to waste storage
0 = not clearly favorable or unfavorable because of intermediate value or wide range of values

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