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E. J. Nowak

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ISSUES PERTINENT TO SEALING OF RADIOACTIVE WASTE REPOSITORIES IN BEDDED SALT FORMATIONS*

E. J. Nowak
Experimental Programs Division
Sandia National Laboratories
Albuquerque, New Mexico 87185
U.S.A.

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ABSTRACT

The following issues have been identified as pertinent to sealing of radioactive waste repositories in bedded salt formations:

- overall seal system functions and strategy for waste isolation;
- performance requirements for the seal system;
- need for redundancy;
- locations of long-term seals in excavations and boreholes;
- requirements for sealing interbeds and the disturbed rock zone (DRZ)
- seal stability for the required lifetime;
- need for short-term seals in addition to long-term seals

These issues are defined in general terms, and some principals that may be useful in addressing them are presented. Although this presentation derives from experience with bedded salt, it has applicability to domal salt as well.

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INTRODUCTION

Radioactive waste repositories are required by regulation to limit the release of radioactive waste species across specified boundaries. The repository site is usually placed in a geologic medium that provides a very large resistance to transport of radionuclides and that contains minimal quantities of transport fluids such as groundwater or brine. Bedded salt is a suitable geologic medium for that purpose, because it is characterized by very low hydraulic permeabilities and the absence of freely flowing groundwater or brine. To preserve these desirable properties and meet limited release requirements, man-made penetrations into the repository (e.g., boreholes, shafts, drifts) must be returned in a timely manner to a state of low hydraulic permeability that endures for the required lifetime of the repository. Plugs and seals are employed for that purpose.

Open boreholes, shafts, and drifts that invariably penetrate the repository boundaries and interconnect waste emplacements during the operational phase are potential paths for essentially unimpeded release of radioactive species. These excavations are created to provide physical access for site characterization; to carry out necessary research, development, and demonstration activities; and to emplace waste. In addition, a damaged or disturbed rock zone (DRZ) typically exists around any excavation in bedded salt and is also a potential release path. This disturbed zone can include the opening of fractures in the interbeds that typically appear in bedded salt.

Engineered structures in the form of seals and plugs must be designed and emplaced in penetrations to prevent radioactive release from exceeding the regulatory limits during the required lifetime of the repository. These structures must also be designed to take into account the special characteristics of bedded salt. Important characteristics include plastic flow (creep closure), the occurrence of interbeds (frequently clay or anhydritic materials), and the presence and movement of brine.

Specific sealing issues arise from the repository release limits and the characteristics of bedded salt. These issues include:

- overall seal system functions and strategy for waste isolation;
- performance requirements for the seal system;
- need for redundancy;
- locations of long-term seals in excavations and boreholes;
- requirements for sealing interbeds and the disturbed rock zone (DRZ)
- seal stability for the required lifetime;
- need for short-term seals in addition to long-term seals

The purpose of this paper is to define the issues in general terms and to discuss some principals that may be useful in addressing them. Although the presentation derives from experience with bedded salt, it has applicability to domal salt as well.

ISSUES

Overall Seal System Functions and Strategy for Waste Isolation

The primary overall function of the seal system is normally to minimize the escape of radioactive waste species in groundwater or brine from the repository through boreholes and shafts in the absence of human disturbance. Ideally, the seal system would be designed to exhibit longevity and flow resistance that are equal to or greater than that of the undisturbed host rock. In practice, the system is likely to be designed to meet repository safety criteria shown to be necessary by performance assessment calculations. The criteria are likely to include integrated radionuclide discharge or human dose limits over time periods during which release must be controlled. It is also important to define the boundaries of the repository at which release to the accessible human environment is assumed to have occurred. Such boundaries are usually defined by regulations.

Another overall function of the seal system can be to minimize fluid inflow from external sources. Minimizing water inflow minimizes the quantity of the primary medium (brine) for radioactive waste transport and release. Brine may also interfere with curing or other processes that create the final state of seals. This function may be particularly important if water-bearing strata overlie the repository.

An additional overall function may be to minimize the volume of interconnected waste that can communicate, by circulating fluid, with any single pathway created by human intrusion. Radionuclide release by human intrusion could be limited by isolating the penetrated waste volume from the rest of the waste. Isolating volumes of waste can also minimize the quantity of waste contacted by the brine that is admitted by a human intrusion.

The seal system design must be integrated with and support the overall strategy of waste isolation and performance assessment for the repository. Seals should sufficiently restore the effectiveness of strategic natural barriers in the repository site to satisfy the isolation requirements. Redundancy in the seal system should be considered in the overall strategy. Also, the seal system should be characterizable in sufficient detail to allow meaningful performance assessment calculations to be carried out. These calculations are likely to be necessary in order to show compliance with the long-term isolation regulations.

Performance Requirements for the Seal System

The seal system must be designed to limit fluid flow below rates that would threaten the isolation effectiveness of the repository. Allowable flow rates through the seal system can be established from calculated estimates of repository performance. This process of estimation is likely to be iterative, becoming more accurate as repository behavior becomes better understood. The complete elimination of fluid flow through the seal system is neither possible nor necessary.

Specific performance requirements for the seal system can be derived from maximum allowable fluid flow rates within and out of the repository. Measurements of host rock flow properties may provide bounds on the required flow resistances for the seals. Specification of performance requirements is likely to be an iterative process, evolving as repository performance calculations are refined and as test results become available. These requirements can be expressed in terms of seal flow resistances or effective permeabilities, in some cases as functions of time after emplacement. Materials development, initial materials choices, test designs, and modeling will be guided by the design requirements.

Laboratory measurements of material properties and in situ tests can be designed to quantify the seal material properties and the flow resistance of seal emplacements. These data can be analyzed using models of seal behavior. The analyzed data are inputs for performance predictions calculated with seal system models.

Need for Redundancy

Redundancy requirements can arise from the overall strategy for waste isolation that is chosen. Redundancy can add considerably to the predicted reliability for the isolation system. Multiple seals can be used to reduce the probability that brine escape to the repository boundaries will exceed the regulatory limits. For example, panel or drift seals at the repository horizon may be redundant with respect to shaft seals if these two types of seals are in series along the same potential flow path.

Choice of Long-Term Seal Locations in Excavations and Boreholes

Seal locations will be influenced by the stratigraphy and overall design of the repository. Stratigraphic variations in bedded salt can result in inhomogeneous closure around and loading of seal structures. Closure data and models are needed to predict the mechanical response of the host rock salt to the excavation and seal emplacement. If reconsolidation of crushed or disturbed salt is desirable for sealing, locations of maximum closure rate (e.g., in lower strata where lithostatic pressure is higher) may be chosen for some shaft and borehole seals and plugs. Seal emplacements may also be most effective in host rock strata with the lowest permeability and highest mechanical integrity. In situ permeability measurements provide key data for seal locations. Overall repository design should reflect considerations of seal location. Decreased drift size at strategically located points may be desirable to minimize seal sizes and to reduce emplacement difficulties. Seals may also be located to reduce brine circulation within the repository by isolating groups of disposal volumes from each other.

Requirements for Sealing Interbeds and the Disturbed Rock Zone (DRZ)

Parting and fracturing of interbeds and general fracturing or porosity in the host rock salt develop around excavations in bedded salt, and these features may introduce potential pathways for brine flow and radionuclide escape. Creep closure may lead, ultimately, to the return of some of these disturbed regions to states of low permeability that characterize undisturbed host rock salt. This healing process has been observed in laboratory tests and may occur due to the plastic behavior of rock salt. Fractures in interbeds with large quantities of brittle, non-plastic rocks such as anhydrite may resist healing and require an appropriate sealing procedure. Laboratory and in situ tests can be utilized to quantify flow resistance in these regions and assess the need for sealing them. Both gas and brine flow measurements may be useful for this purpose.

The sealing of fractured interbeds and otherwise disturbed zones in the host rock salt is likely to require the introduction and flow of grout materials. It may be necessary to provide for continuous flow of grout material while appreciable deformation of the host rock persists, that is, until creep closure of repository excavation is nearly complete. Grout that contains primarily crushed host rock salt and possibly clay may be suitable for this purpose. Such a grout may flow plastically over long periods of time while remaining compatible chemically with the host rock and brine. Another obvious candidate material is bitumen, a material that flows and has been stable underground for geologic timescales.

Seal Stability for the Required Lifetime

The seal system must be stable and function acceptably during the required lifetime of the repository, and the lifetime requirement may be as long as thousands of years. The long-term seals and seal materials must be stable during that time. Good mechanical and, perhaps most importantly, geochemical stability will be required of the seal materials and shapes to meet that requirement. Among potential threats to stability are gas pressures generated from the waste or introduced from other sources, lithostatic pressure applied by the creeping host rock salt, and chemical reactions with brine.

Host rock salt mined during the creation of the repository excavations is one material that is very likely to be geochemically and mechanically stable in the repository environment. Crushed rock salt is a form of material that could be used. Crushed salt will be consolidated by creep closure of the excavation in which it is emplaced. Tests to measure consolidation rates, effects of interstitial brine on consolidation, and permeability as a function of density in the consolidated crushed salt mass are necessary to establish the viability of this material for long-term seals.

Bentonite is a geologically stable material with the desirable plastic properties and low permeabilities for brine that characterize good candidate seal materials. Studies have shown bentonite to be potentially very stable in brines. Physical containment of the bentonite where it is needed and control of swelling pressures are concerns that must be addressed if it is to be effective in seal systems.

Cementitious materials in the form of grouts and concretes are not thermodynamically stable in salt, but chemical studies can be conducted to determine whether the expected chemical reactions in the underground are sufficiently deleterious to be of concern for repository lifetimes. It is likely that cementitious materials will suffice as stable short-term seal materials to provide sealing functions until long-term seals can take over (e.g., after crushed salt has been sufficiently reconsolidated). Cementitious materials, possibly in combination with clays such as bentonite, may also serve to protect curing or reconsolidating long-term seal materials from effects of inflowing brine or flowing gas until they have reached stable states of density and composition.

<u>Needs for Short-Term Seals in Addition to Long-Term Seals</u>

Short-term seals may be necessary to contain and protect long-term seal materials until they become stable enough for long-term waste isolation. Brine entering from the host rock salt or from water-bearing zones in other rock types may have to be controlled in order to allow long-term seal materials to cure, consolidate, or otherwise achieve their final state of sealing effectiveness. Gas moving through the repository excavations may also generate transient pressure gradients that must be controlled. Multiple temporary seals may be utilized to distribute such pressure gradients over long distances, thus limiting the applied forces on any one seal.

The performance of proposed short-term seals can be assessed with calculations using mathematical models of system behavior. Models that couple brine flow, closure, and crushed salt consolidation, for example, can demonstrate the usefulness of temporary seals against brine and quantify the performance requirements for those seals. Gas flow calculations can demonstrate the attenuation of pressure gradients across seal emplacements due to other temporary upstream and downstream seals.