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A Strategy for Investigation of Fluid Migration in Evaporites (Waste Isolation Pilot Plant - WIPP)

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Sandia National Laboratories

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**A Strategy for Investigation
of Fluid Migration in Evaporites
(Waste Isolation Pilot Plant - WIPP)**

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ABSTRACT

The proposed strategy for WIPP project investigations of fluid migration in evaporites focuses upon a quantitative evaluation of each of several processes. Potential short- and long-term problems arising from fluid migration are complication of waste retrieval and mobilization of waste nuclides. The strategy will attempt to determine the degree to which these potentials are realized with respect to five hypothetical types of waste-rock interactions: movement of waste containers, migration of nuclides, formation of radioactive brine pocket, radiolytic generation of gas, and degradation of waste container. Of eight identified processes whose combinations could lead to the five types of interactions, only five are to be quantitatively investigated by the studies of fluid migration per se: presence of fluids, fluid mobilization toward heat-producing and contact-handled waste, encounter of fluids with influence of waste form, reversal of direction of fluid mobilization, and entrainment of nuclides in fluids. Methods of investigation entail an iterative combination of laboratory experimentation and mathematical modeling.

Introduction

Bedded deposits of Permian evaporites of the Ochoan epoch in southeastern New Mexico's portion of the Delaware Basin are known to contain small but finite amounts of liquids and gases. These fluid phases appear to be at present inert in their host environments, due to physical and at least partial chemical equilibrium with their host rocks. They have continued to be inert for the past 200 million years (Powers, *et al.*, 1978). However, there is evidence to indicate that this inertness may not persist as the host rock is subjected to such WIPP-induced perturbations as (1) mining a cavity and (2) experimentally emplacing heat-generating radioactive wastes. Examples of the first perturbation are observed in New Mexico potash mines. Small accumulations of liquid and gas are periodically intercepted by the mining operation, and give rise to short-lived seeps, usually encountered near mudstone beds. An example of the second perturbation was simulated in heater experiments of Project Salt Vault, in which fluids moved into the heated cavity (Bradshaw and McClain, 1971).

The mobilization of fluid has the potential for causing the following short-term and long-term problems for the WIPP:

- A. The mobilization of the fluid could hinder or complicate any retrieval of waste required during the operational phase of the repository by causing waste packages to move or corrode.
- B. The mobilization of the fluid could increase the risk that the radionuclides will reach the biosphere after the repository has been decommissioned.

The ultimate objective of the fluid migration program is to determine the degree to which the above concerns are realized. However, before this objective can be realized, a much better understanding of the mechanisms of fluid migrations must be acquired.

Figure 1 shows the five adverse interactions (ellipses) which could lead to the general concerns described above. Also, Figure 1 shows the processes (rectangles) that lead to those interactions. The remainder of this document will address the following topics: a brief background discussion of the nature of fluids in bedded salt, descriptions of the adverse interactions and the processes that cause them, a description of the objectives of the fluid migration program, and finally general descriptions of methods that will be employed in the WIPP program in the WIPP program to meet the objectives. A detailed description of the task of fluid migration as presently formulated is given by Shefelbine (1979).

Background

Evaporite rocks contain three different sources of fluids: (1) water of crystallization and hydroxyl in hydrous minerals, (2) intracrystalline fluid inclusions, and (3) intergranular fluids.

Water of crystallization and hydroxyl occur in certain minerals in definite proportions of the mineral bulk composition. The H_2O and OH groups (as H_2O) are liberated at discrete temperatures, depending upon the specific mineral. Some minerals display multiple episodes of water and/or OH loss at a variety of temperatures (Suzuoki and Epstein, 1976). The resultant less-hydrated new phases may exhibit more or less reactivity towards other phases present in or near the rock.

Intracrystalline fluid inclusions are sometimes erroneously called "negative crystals"; not all of them are bounded by crystal faces. Syngenetic fluid inclusions, for example, result from a local depletion from the mother liquor of the crystal components, resulting in the crystal lattice growing around the liquid, entrapping a quantity of it. Inclusion size can range from microns to centimeters. They can be mobilized upon rupture (resulting in some cases in decrepitation of the host grain) or in a temperature (or, less commonly, pressure) gradient through changes in the solubility of the host mineral in the fluid in one portion of the inclusion relative to that in another portion of the inclusion. The temperatures and pressures at which fluid inclusions are mobilized by rupture or imposition of gradient can be expected to vary considerably for different minerals and in situ conditions, and the mechanisms for movement are, in general, poorly understood. In addition, many fluid inclusions are known to contain both liquid and gaseous phases. Furthermore, different sizes and generations of fluid inclusions will probably exhibit different mobilization behavior, at different temperatures, as will inclusions with different proportions and compositions of liquid and gas.

Intergranular fluids occur in accumulations which vary in size from a thin film, as in the case of water absorbed on clay mineral surfaces, up to several hundred liters or more, as in the case of sporadically-occurring gas and brine pockets (aforementioned). Under some circumstances, these inclusions are isolated from one another much as intracrystalline inclusions. In other circumstances, the intergranular inclusions can form connected networks.

It is evident that fluid migration is a mineralogical, physio-chemical, and mechanical problem. Given the variations in mineralogy in and among evaporite environments and the necessity of using real rock for experimental and analytical studies, a geologically generic evaluation (not understanding) of the problem can be approached only through a geologically site-specific strategy. Results garnered from studies of rocks from one locality will in general not be applicable to rocks from another.

Whereas the liquid fluids have solutes which can be quantitatively reckoned, the contribution of gaseous fluids cannot be over emphasized. The presence of such gaseous components as volatile sulfur species and various organics could have consequences which far outweigh those of the presence only of water with or without solutes. The chemical reactivity of these is appreciable having the ability to enhance corrosion of container or mobility of contents. Thus, the obvious trap of reckoning all volatile constituents as "water" must be meticulously avoided in a study of fluid migration.

Related Work

The experimental aspect of fluid migration studies in evaporites has been pursued by other investigations prior to initiation of the WIPP program. Noteworthy among these are the experiments conducted in the Carey Salt mine near Lyons, Kansas, for Project Salt Vault from 1965 to 1967 (Bradshaw and McClain, 1971). Spent elements of nuclear reactor fuel and electric heaters designed to simulate them were placed in holes in the floors of room excavated in the bedded rock salt. Each heat source (about 1.6 kilowatts) was associated with an off-gas collection system for periodic measurement of quantities of liberated volatiles. During the heating phase, the temperature of salt near a heat source was about 200°C, and the calculated rate of brine inflow based on condensate recovered from a hole by purging with nitrogen, was 0.2 to 3.0 ml/day. Heating was stopped nineteen months after heating was started. From the most productive hole, as much as 35 liters of water was collected, 90% of which was liberated within two days following shutdown, prior to which the maximum cumulative collected condensate amounted to 3.1 liters. Most of this water was believed to have come from interbedded shale, not the evaporites themselves.

Laboratory studies of fluid inclusion migration have been concerned primarily with single crystals. Particularly significant are the efforts of Wilcox, Anthony and Clin, Roedder and Belkin, described by Powers et al. (1978).

Mathematical modeling of water released from one-kilogram blocks of rock salt was carried out by Hohlfelder and Hadley (1979). Measurement of volatiles recovered from an axially-heated 1800-kilogram cylindrical block of rock salt are reported by Hohlfelder (in preparation), and mineralogical aspects of fluid migration observed in the same experiment are discussed by Lambert (1979).

Potentially Adverse Interactions

The adverse fluid-salt-waste interactions (ellipses) that may occur and the process (rectangles) leading to them are summarized in Figure 1 and are discussed in more detail below. If one of these interactions were to occur, it cannot be assumed that it will result in either an unsurmountable operational problem or a certain release of radionuclides to the biosphere. More evaluation will be required to assess their impacts on either the operation of the facility or its integrity.

The Figure 1 ellipses are described as follows:

- A) The fluids, the evaporites, and possibly components derived from the corroded waste containers and/or the waste itself may combine in the vicinity of a waste canister to form a low-melting point mixture. The heat from the waste canister may make the mixture sufficiently less viscous to allow the waste to move. During the operational phase of the facility, such movement of waste canisters could hinder their retrieval. Also, there is a very remote probability that the waste containers would move closer together, creating a concern about reconcentration of heat sources and fissile nuclides.

- B) The fluids may corrode the waste canisters and leach radionuclides from the waste. The fluid with the entrained radionuclides may then migrate away from the original waste location. One mechanism has been identified which may cause this migration: fluid inclusions with a trapped vapor bubble have been observed to migrate away from a heat source through a single crystal (a phenomenon first described by Wilcox, 1969).
- C) Even if the fluid with its entrained radionuclides does not migrate away from the original waste location, it could cause a problem by creating a pocket of radioactive fluid under lithostatic pressure. These fluids could reach the biosphere if the pocket is balled into at some time in future.
- D) The fluid may corrode the canister and come in contact with the waste. Gas may be generated by either the corrosion process itself or by radiolysis of the fluids by the alpha-emitters in the waste. If sufficient gas of higher molar volumes than those of native fluids is generated, it may cause the surrounding salt to flow or crack breaching the physical integrity of the repository.
- E) The fluid plus salt can corrode the waste containers to a point where retrieval of these containers would be made more difficult. Unlike the interactions described above, this interaction is mainly applicable to the non-heat producing contact-handled waste, a portion of which may be stored in mild steel containers. Slight changes in the moisture content (such as raising the relative humidity from 50 to 75 or 80%) in the air in the vicinity of these containers can cause an increase in the corrosion rate.

Processes of Importance to Assessment of Consequence of Fluid Migration

The rectangles in Figure 1 represent processes which lead to the terminal events which in turn are to be assessed for their consequences. The quantitative evaluation of these processes form the crux of the numerical assessment (mathematical modeling) of the consequences.

The fluid migration program will address only the following processes: presence of the fluids (#1 in Figure 1), mobilization of the fluids toward the waste (#2), encounter of fluids with the influence of the waste form (#3), reversal of direction of fluid mobilization (#7), and entrainment of nuclides in fluids (#8). The other processes are being addressed by other programs. The fluid migration program will provide inputs to these other programs in some cases and require output from them in others. A description of each of the processes follows:

1. Presence of fluids. This is in effect a source term. As discussed in the "Background" section, the nature, distribution, amount and phase constituency of fluids in the rock salt are dependent upon the texture and mineralogy of the host rock. For example, the volatile constituents in potash zone rock salt cannot be assumed to be identical to that of WIPP horizons. Such fundamental differences are to be taken into account in interpreting results of fluid migration experiments involving potash

zone versus WIPP horizon material. Table 1 lists many of the potential sources of volatiles to be found in evaporites, in the "fluid source" column.

2. Fluid mobilization toward the waste. The mechanisms of fluid mobilization towards stored waste can be generalized as a three component system: a source of fluid, a conduit between this source and the waste location, and a force that drives fluid toward the waste (Table 1). This general mechanism applies to the two basic waste type storage configurations: heat-producing waste placed in holes drilled in the floor of the drift, and contact-handled (CH) waste stacked in open drifts. However, the fluid source, conduit, and driving force applicable to the two waste configurations are different (Figure 2). Also, four of the adverse interactions discussed above are applicable to heat-producing waste and the fifth is applicable to CH waste. The two waste configurations are discussed below.

Fluid Mobilization Toward Heat-producing Waste. The migration of fluids toward heat-producing waste is a poorly understood process. There are a number of candidates for each of the three components with little to indicate which ones are the most important. The three candidates shown in Figure 2 are examples of each component. There are certainly others that cannot be totally discounted (see Table 1).

Almost certainly the source of fluid migrating toward heat-producing waste is fluid trapped in the evaporites as intragranular fluid inclusions, as fluid associated with grain boundaries, or as water in hydrous minerals. Although it is known that all three forms exist, the relative importance of each form is not known. In fact, the variations in total volatile content of evaporites are not well known.

The most commonly cited conduit-force combination for fluid migration is the migration of fluid inclusions up a temperature gradient. Since the solubility of evaporites typically increases with temperature, salts will be dissolved from the hot side of an inclusion and deposited on the cold side. This phenomenon has been observed for fluid inclusions in single crystals, but there is evidence that the smaller inclusions are trapped when they encounter a grain boundary.

Another mechanism is to assume that the evaporite rock is permeable and that fluids can be forced toward the waste by such mechanisms as the vapor pressure of the fluid or the stress gradient in salt. Since relatively larger pockets of fluids and/or gases are occasionally encountered in salt deposits, it is evident that undisturbed salt rock under lithostatic pressure has little or no permeability. However, it is possible that the stresses generated by mining the repository, thermal expansion of the heated salt or the vapor pressure of the heated fluids could fracture the salt to the point that it becomes permeable.

Fluid Mobilization Toward Contact-handled Waste. The mechanism for water mobilization toward contact-handled waste stacked in open drifts is almost certainly driven by the hygroscopic nature of many evaporites. If the humidity in the air around the waste stacks exceeds certain critical

values, a relative humidity of about 75 percent for pure NaCl, the salt will absorb water from the air to the point that a brine is formed. If this brine forms on the mild steel waste containers, they will corrode relatively quickly.

As shown in Figure 2, there are at least three potential sources for water: release of trapped water during the excavation of the repository, water vapor introduced with inlet ventilated air, and water vapor introduced during the operation of repository. It will be very difficult to quantify many of these sources. Also, the interaction between the water vapor and the evaporation will be complex because of the complex mineralogy of the evaporites.

3. Encounter of fluids with influence of waste form. In this process, the fluids approach the waste form closely enough to experience effects in addition to that of simple mobilization. The influences of increased temperature and radiation flux near the waste form may give rise to changes in the properties of the fluid and perhaps even the rock. The heat might spawn new phases such as a vapor, or simply rearrange existing phases to give rise to local recrystallization, change in brine sulfate content, or different gaseous species from those native. An "encounter" of fluids with influence of waste form does not necessarily imply physical contact and subsequent physiochemical interactions.
4. Corrosion of waste container. One of the obvious consequences of interaction between fluids and waste container is the possible corrosion and degradation of the waste container itself. The contribution of these fluid migration studies will be to specify the fluids and native minerals available for such interactions. Studies of corrosion of waste containers will not be addressed here.
5. Release of nuclides from waste form. If the container is corroded to expose nuclides to the rock, new phases of varying mobility might form from the interaction of rock, fluids, container and nuclides and their matrix. Again, the contribution of these studies will be to specify the natural materials available for such interactions.
6. Formation of mixtures with lower melting points than those of native materials. Processes 3, 4 and 5 above could contribute to the formation of new phases (such as melts and solutions) by addition of components so to produce a mixture of lower viscosity than that of the original host rock. The waste form could then move in this lower viscosity medium. The amounts of various components necessary to enable this will vary with the mineralogy and texture of the rock in the immediate vicinity of the waste form. The nature of the bedded evaporites is not 1000 meters of pure sodium chloride containing unlimited quantities of fluid inclusions. The proposed repository horizons are rock salt between beds of less soluble components such as anhydrite and clays. Thus, the movement of a waste form in a locally developed medium of low viscosity is expected to be finite.

7. Reversal of direction of fluid mobilization. The WIPP Geological Characterization Report (Powers, et al., 1978) contains numerous references to investigation of fluid inclusion migration, mostly in single crystals. It has been found that under certain circumstances, fluid inclusions moving up a temperature gradient disproportionate to form a vapor and a liquid, which moves down the temperature gradient until the vapor condenses. (Fluid is evaporated on the hot side of the inclusion depositing its dissolved solids, and the vapor condenses on the cold side dissolving the salt.)

The existence of mechanisms other than vapor/fluid inclusion migration cannot be discounted. For instance, if the major mechanism responsible for fluid migration toward the heat-source is the permeability caused by the stress gradient fractures, this permeability may allow the fluid contaminated with radionuclides to migrate away from the original waste location.

8. Entrainment of nuclides in fluids. A consequence of Processes 5 and 7 is for nuclides released from the waste form to be entrained with migrating fluids. The degree of migration of nuclides varies with the mobility of released nuclide species, the carrying capacity of migrating fluid (if any), and the sorptive properties of rock with which nuclides come in contact.

If this process can cause radionuclide migration, several processes must occur:

- a. significant quantities of radionuclides must be leached by the fluids (Process #5)
- b. the fluids with the dissolved radionuclides must form vapor/liquid inclusions in the evaporites, or must be otherwise mobilized (Process #7)
- c. these inclusions are capable of migrating through the polycrystalline evaporites
- d. the radionuclides remain with the fluid during the migration

To a large extent, these processes must be considered hypothetical because there is little or no experimental evidence of their existence.

Overriding Concerns and Technical Objectives

The prime directive of this endeavor to understand fluid migration shall be to conduct only those studies which ultimately provide numerical results which directly support the assessment of consequences of fluid migration to the safety of conversion of WIPP to a repository. The validity and usefulness of the results will naturally have their roots in the experimental design.

An equally important directive for experimental design is to achieve as realistic a simulation of anticipated in situ conditions as practicable and allowed by the state of our understanding. This precludes the familiar "worst-case" approach. "Worst-case" treatments can be misleading if results of such are applied without a commensurate fundamental understanding of the underlying assumptions. The apparent discovery of a "worst case" might supplant consideration of an equally "bad" (unmitigated or unmitigateable) case.

The ultimate directive is this: to provide the data necessary for confidence in a consequence assessment of geological processes stemming from an understanding of the processes, not from engineering for the "worst case." Thus, the technical objectives of the fluid migration study are to gain an understanding of the phenomena. This will require addressing the following topics.

- a. the quantities and habitats of fluids in the evaporites
- b. identification of the major mechanisms that cause the fluids to migrate toward heat-producing waste
- c. determination of the parameters that influence the rate and quantity of fluid influx
- d. determination of the chemical constituents of the migrating fluid
- e. determination of the parameters that influence the relative humidity of the air in the repository storage rooms
- f. identification of any mechanisms that might cause fluid with dissolved radionuclides to migrate away from the original location
- g. determination of the parameters that influence this radionuclide migration

Methods of Research

This section will describe generalized strategies which might be employed in order to arrive at the requisite level of understanding of each of the processes enumerated and described above. Experimental details will have to be formulated and modified as the program develops.

1. Characterization of the nature and distribution of fluids. The WIPP Geological Characterization Report (Powers, et al., 1978) contains a broad survey of the amounts and kind of volatiles found in the Ochoan evaporites. Relatively few data are available for the geochemistry of the volatiles in general, but very respectable investigations have been conducted to determine the size, shape, distribution and behavior of fluid inclusions, less than 1 millimeter across, which were subjected to microscopic examination while being heated, frozen, crushed and decrepitated.

The petrographic survey of intracrystalline fluid inclusions from the evaporite section is largely complete. Efforts will continue to determine the solute geochemistry of the larger (greater than 1 millimeter across) fluid inclusions in the particular horizons of interest to WIPP.

The general geochemistry of the volatile constituents in the WIPP evaporites, given the paucity of data, is poorly understood. The few extant data have confirmed the expected dependence of volatile constituency upon mineralogy. The characterization of volatiles will require subjecting a large selection of evaporite samples to stepwise pyrolysis to temperatures in excess of 800°C, and simultaneous collection of gas chromatograms and mass spectra. The raw data and experimental conditions of these analyses will be preserved to serve as a record of each set of analyses, and to facilitate reprocessing of the data for statistical correlations as more data become available. These experiments will serve to recover analyses of all the volatiles in a sample (hence, required heating to 800°C or more). Complete recovery of volatiles is a form of assurance that the volatiles have not been recombined with solids at some arbitrarily lower cut-off temperature. The high temperature is necessitated by the fact that complex chloride solutions typical of evaporites tend to have extremely low vapor pressures. The data from these investigations will allow a complete determination of the amounts and kinds of fluids available to participate in any particular sample of rock, whether it be borehole core or mine exposure.

Preliminary experiments (Powers *et al.*, 1978) have shown that by pyrolysis/gas chromatography/mass spectrometry it is possible to identify generations of volatiles originating from the various mineral sources of volatiles. The contribution of intergranular fluids is the most difficult to evaluate. A possible approach is microanalysis of grain boundary residues remaining after exposure, and comparison of the solids with primary mineralogies in adjacent grains.

2. Mathematical simulation. Given the fluid source term (Method #1) and models of migration of fluid inclusions explicated in the literature for single crystals, migration of fluid through the evaporite rocks will be numerically simulated. Also, models will be developed to describe the other mechanisms outlined in Table 1 and Figure 2. The validity of the use of a particular mechanism in modeling calculations can then be tested in subsequent experiments.

Mathematical modeling is an iterative process, to be used for prediction of experimental results. The ultimate selection of a proper theoretical model is achieved after successful prediction by a model of a variety of experimental results. As well as being iterative, mathematical modeling is interactive. It must be cognizant of each experimental result, and re-evaluate the modeling approach in the light of each result and be prepared to make appropriate changes.

3. Microscopic observation of phenomenology of fluid inclusion movement. This process involves placing polished evaporite plates on a heating stage, establishing calibrated temperature gradients, and documenting the paths and rates of movement and morphologic changes of the inclusions as they migrate in the temperature gradient. At best, the results of this method will allow confirmation or modification of the numerical parameters used in the mathematical modeling. At worst, it will allow an assessment of the relative importance of intragranular ("pass-through mode") or intergranular ("rupture mode") paths that fluids tend to take during migration (see Table 1). In any case, these results will be useful in predicting results of subsequent experiments.

The conventional methods described here apply very well to movement of intragranular fluid inclusions through the solid state. More difficult is a documentation of the phenomenology of encounters of fluid inclusions with grain boundaries. A preliminary approach will be photomicrographic, with an attempted correlation of rate and mobility of inclusions across grain boundaries with inclusion size and host mineralogy in grains and grain boundaries. Microprobe analyses of grain boundaries will be attempted before and after induction of fluid migration, to determine net gain or loss of material at the boundaries.

4. Evaluation of contribution of fluids from mine air. Measurements of relative humidity of air in potash mines have been made. Sources of water in the air include influx from ventilation intake, human bodies, and the water of efflorescence given off from mine walls as evaporites are exposed to unsaturated air. The sinks include ventilation effluent and hygroscopic phases exposed in the mine walls (such as kieserite). A rather elaborate matrix of experimental conditions might be necessary to quantitatively determine the various sources and sinks in a rock salt-air-water system. The quantity of water from mine air retained by the rock then adds to the source term of Method #1, and water vapor/evaporite interactions will govern the rate and degree of corrosion experienced in open drifts by containers of contact-handled wastes.
5. Laboratory experiments with evaporite blocks. Experiments on blocks of evaporites under carefully controlled laboratory conditions can be used to determine which of the following parameters affect the fluid migration. This in turn will provide considerable insight into the mechanism of fluid migration.
  - a. Evaporite characteristics. Obviously, the quantity, location and chemistry of the fluid in the evaporite will affect fluid migration. Evaluation of the effect of fluid characteristics will be difficult because there is no way to measure fluid content of a sample without destroying the sample.
  - b. Temperature-temperature gradient. A series of tests need to be performed to determine whether the observed fluid migration is driven by the increased temperature of the evaporite or by the temperature gradient.

- c. Stress. One of the proposed conduits for the migrating fluid is the permeability of the evaporite. It is known that this permeability can be reduced significantly and the solubility of salt can be increased by placing the sample under hydrostatic pressure. A series of experiments need to be performed to measure the effect of stress on the fluid migration.
  - d. Water vapor pressure at the sample surface. In most of the previous tests, the water vapor pressure at the surface of the salt has been maintained at low levels by flowing dry gas over the sample surface. This will cause water to evaporate from the migrating fluid and may distort the results. A series of experiments need to be performed where water vapor is not forcibly and continuously removed from the system.
  - e. Phase changes. A series of analyses need to be conducted to determine the changes in mineralogy and volatile constituents remaining in the rock after various episodes of experimentation. Microchemical analyses may enable the tracing of fluid migration by following the recrystallization track and identifying products of rock/fluid interactions in host crystals and at grain boundaries.
6. Determination of nuclide carrying capacity of migrating fluid. This method has direct bearing on process 8. The question here is whether nuclides become entrained in fluids migrating in evaporites or whether the nuclides become preferentially entrapped in the evaporites. The process might be analogous to zone-refining, in which either the fluid or the rock gets nuclides zone-refined out. This determination would probably best be done on a microscopic or laboratory bench scale, doping a rock salt sample with a low-activity nuclide or stable simulant, applying a temperature gradient and determining the amount of dopant migration. Sorption on grain boundary material of the simulants can be evaluated by microchemical analyses.
  7. In situ simulation of evaporite heating by cylindrical waste forms. Since this experiment must be performed in a mine, the conceptual planning of it must await acquisition of a mine environment which can come under Sandia control.
  8. Characterization of phenomenology of igneous intrusive effects on evaporites. The northeast-trending (lamprophyre ?) dike intruding the evaporites about 10 miles northwest of the WIPP site center appears to represent a natural laboratory experiment involving high-temperature interactions among salts, groundwaters and "alien" mineralogies such as emplaced waste would also represent. The igneous intrusion does not exactly simulate emplaced waste, because magmatic temperatures are about a factor four higher than those of emplaced waste, and the mafic intrusive is not geochemically identical to emplaced waste. There are, however, a number of fruitful pursuits:
    - a. Numerical modeling of the original temperature distribution in dike and country rock.

- b. Mapping of fluid inclusions and determining their contents.
  - c. Geochemical examination of the thermal history of dike-rock interactions. This effort might involve attempted Rb/Sr dating of rocks and fluid inclusion formation at various distances, to determine the relative rates of host-rock cooling at various distances from the dike.
  - d. Geochemical examination of redistribution of nuclide analogs. By comparison of lanthanide element distributions in dike, altered and unaltered rock, an approximation of the degree of "nuclide" migration away from the dike in this originally hot, wet, geochemically complex system might be obtained. This has important implications for an empirical evaluation of the importance of the entrainment of nuclides in the fluids (Process #8 in Figure 1).
9. Re-evaluation of mathematical simulations and assessment of consequences of fluid migration to various phases of WIPP. This is by far the most important effort in the entire fluid migration study; a successful achievement of it depends upon the other eight. In this context, an experiment, calculation, evaluation or observation shall be considered a success if it provides numerical results of direct application for this final method of research.

TABLE 1
POSSIBLE MECHANISMS FOR FLUID MIGRATION

<u>Fluid Source</u>	<u>Conduit</u>	<u>Driving Force</u>
Intra-crystal Inclusions	Change in Solubility with Temperature	Temperature Gradient
Fluids Entrapped Along Grain Boundaries	Heat Pipe Effect	Stress Gradient
Water of Hydration	Sample Permeability Due To:	Concentration Gradient
Fluid Absorbed During Sample Exposure and Preparation	A) Inherent connected porosity	Soret Effect
Humidity of Mine Atmosphere	B) Cracks caused by sample preparation stresses, thermal stresses, phase transition stresses, or inclusion vapor pressure stresses	Vapor Pressure of Heated Fluid
		Pressure of Entrapped Gases

FIGURE 1
PROCESSES LEADING TO POTENTIALLY
ADVERSE WASTE/ROCK INTERACTIONS
CAUSED BY FLUID MIGRATION

FIGURE 2 FLUID MOBILIZATION TOWARDS THE WASTE

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