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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

WM DOCKET CONTROL CENTER

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MEMORANDUM FOR: Hubert J. Miller, Chief
Repository Projects Branch
Division of Waste Management, NMSS

FROM: Frank A. Costanzi, Chief
Waste Management Branch
Division of Radiation Programs
and Earth Sciences, RES

SUBJECT: INFORMATION FROM THE RESEARCH PROGRAM FOR THE NRC REVIEW OF DOE'S ENVIRONMENTAL ASSESSMENTS

As agreed upon, we have prepared the attached summary of information developed by our research program which we believe will be of direct use to you in NRC's upcoming review of the DOE environmental assessments. The summaries are categorized as follows: Hydrology, Far-Field Geochemistry, Near-Field Environments, Waste Package, Coupled Effects, and Measurement Techniques. Also attached is a description of potential societal/institutional considerations.

We are sending you these summaries to provide you with the broadest possible background of information from which you may choose those pertinent to your EA review.

Please let me know if we can elaborate on any of this or provide you with further assistance.

Frank A. Costanzi, Chief
Waste Management Branch
Division of Radiation Programs
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Enclosures:
1. Summary Information
2. Incoming letters w/encl.

WM Record File 109

WM Project 1
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End to 9-11-84
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HYDROLOGY

Neuman Letter Report - Fratured Media

Neuman's report is particularly applicable to a BWIP-type site, although some of his more general comments are also applicable to crystalline rock sites.

The fluid flow in entablatures and collonades can be treated as flow in an anisitropic porous medium. Horizontal hydraulic conductivities have been measured in such units but no vertical hydraulic conductivities have been measured. Vertical hydraulic conductivity in the collonade can be expected to be as much as 1000 times as large the horizontal hydraulic conductivity. Avenues for horizontal groundwater flows are provided primarily by flow tops and sedimentary interflows. The prediction of such flows requires measurement of horizontal conductivities of the flow tops and interbeds and vertical conductivities of the flow interiors.

Mode of outcrop and surface and subsurface topography affect regional recharge and discharge. Local features (e.g. domes and faults) may cause localized flow anomalies in the regional hydrology. The hydrologic effect of structural anomalies can be ascertained from a combination of data taken from geological, geophysical, hydrological, and hydrochemical studies. For example, hydrologic head data at BWIP indicate that such anomalies may exist near the prospective repository site. These data also suggest the possibility of unsteady flow around such anomalies. Water chemistry analysis can be used to determine if flow in a particular unit is steady state or transient. Lateral variations of hydraulic head, when combined with water chemistry data, are often indicative of large-scale discontinuities such as vertical faults. Hydraulic head and water chemistry data are also important in delineating regional flow patterns and regional recharge/discharge boundaries, as are groundwater dating techniques.

Hydrologic models usually require hydraulic conductivity data averaged over regions within which there may be large fluctuations of conductivity. Arithmetic and harmonic means are often used but seldom appropriate for such averaging and the data collected may be too sparse for meaningful averaging to be made with confidence. Hydraulic conductivities other than horizontal can be measured with inclined single hole tests or vertical cross hole tests. Cross hole tests have to cover some range of langth scales and there is an averaging process inherent in them.

Measurement of thermal conductivity and heat capacity is fairly straightforward compared to measurement of hydraulic properties.

With regard to transport characteristics, measurements of effective porosity, dispersivity, and retardation characteristics are needed. Measurements of dispersivity can be made directly by using tracers or indirectly by analyzing the variation in hydraulic conductivity.

Modeling of retardation is now in such a state of flux that it is not clear how much and what kind of data need to be collected at BWIP for predicting retardation. However, there is general agreement that use of simple distribution coefficients is inadequate.

Evans Letter Report - Unsaturated Zone

The most obvious pathway for contaminants is from the repository downward with the percolating water to the regional water table, then through the saturated zone to the accessible environment. Lateral flow through perched saturated zones may alter the downward pathway. A possible second pathway that requires evaluating is through the air-filled primary and secondary pores of the unsaturated rock. In this case, the contaminant would need to be in the vapor state or included within aerosol particles.

Stored radioactive waste will cause nonisothermal conditions surrounding the repository, drying of the rock in the immediate vicinity of the repository, and a wetting of the rock at some distance from the repository. The dried zone surrounding the repository should enhance waste isolation, while the wetted zone may increase downward percolation under this zone.

For the unsaturated zone it may be important to consider three separate but interacting fields because assessment techniques and computer models may be somewhat different for the three. The fields can be described by; (a) the region directly influenced by the emplacement wastes including the thermally influenced zone and the evaporation/condensation zone, (b) a meso-field which is the remainder of the unsaturated zone to the water table, and (c) the far-field which is the zone below the regional water table. Detailed geologic descriptions of each stratum, measurements of relevant physical/chemical properties by different methods and on different scales, and theoretical treatments with appropriate computer modeling on different scales will likely be necessary to sufficently understand the hydrology of the unsaturated zone to make reliable estimates of travel times and release rates for critical radionuclides.

For Far-Field characterization in tuff, the major problems are associated with scale of measurements, obtaining sufficient spatial distribution of hydrologic and geochemical data, and the prediction of flow and transport over long time spans. Characterization of the far-field in a tuff is not unlike that for other geologic media, such as basalt. However, the source of contaminants for the far-field will be over an area above the water table instead of within the saturated zone as it would be if the repository is at depth below the water table.

Except for near the land surface and for the normal geothermal temperature gradients, the meso-field may be considered isothermal. Transport velocities in this zone would be expected to be extremely low. However, the informational data bank for unsaturated rock systems is quite limited. During the past few years, studies have been made to assess the applicability to unsaturated rock of theories, measurement techniques and computer models developed for unsaturated consolidated porous media and for saturated consolidated media.

To date, no single approach seems to suffice for the hydrologic characterization of this zone in rock, and several approaches likely will need to be followed and the results integrated.

A detailed description of the rock matrix and fracture pattern should be made at all depths as excavation proceeds. Samples of the rock matrix should be taken for measurements, such as total porosity, pore-size distribution, moisture release curves and hydraulic conductivity as a function of water content and potential. Methods for these measurements are available and the results will give evaluations as to the water conducting properties and times of travel for solutes for the rock matrix at different depths. This type of information can be coupled later with information on the fracture system to give flow and transport through the combined matrix and fracture flow system.

An idealized characterization scheme might be: (a) Horizontal tunnels excavated in the proposed repository zone and into at least one member above and another one below the repository zone. From the tunnels at each level, (b) small diameter bore-holes core drilled at different angles and to specified depths for examing spatial variability. Some of the boreholes should be in parallel with a spacing of approximately one meter for flow tests. (c) Logged coves and samples used for measurement as discussed above the rock matrix. (d) Measurement of hydraulic gradients and hydraulic conductivities as a function of water potential. The hydraulic gradient may be close to unity and the vertical percolation rate equal to the hydraulic conductivity at the existing water potential, and the average downward velocity is the percolation rate divided by the effective water content (not including deadend pores containing water), (e) Hydraulic gradient evaluated using tensiometers and psychrometers with adapted emplacement techniques for minimally fractured tuff, (f) Hydraulic conductivity of the medium as a function of potential determined using undisturbed cores. Several techniques are available for this determination for example, one technique is calculation from the measured saturated hydraulic conductivity and the moisture release curve. Laboratory determined saturated hydraulic conductivity should be checked by an _in situ_ method such as outflow tests from packed off section of boreholes. Other approaches to confirm the hydraulic results may become apparent after preliminary testing. (g) The level below the repository level should be evaluated for radionuclide retardation properties as well as for water conductance properties. If the percolation rates above and below the repository are nearly the same, long term steady state conditions may be assumed, and the percolation rate through the repository zone may be considered to be similar to that at the other levels.

Characterization of the fracture system for liquid and vapor conductance probably is critical. At present, the most promising approach appears to be through a 3-dimensional computer simulation model (Dr. Huang, U of A). The model requires the probability distribution for several fracture parameters pertaining to location, orientation, aperture, density, shape and length. Fracture distribution and orientation can be obtained from borehole observations. Fracture density, length and shape combine to form a fracture surface area per unit volume, a measureable quantity in the field. For a range of rock mass, surface area/volume, apertue distribution and orientation distribution appear sufficient to reasonably model a rock mass of interest.

Using the simulated fracture system, numerical experiments can be run to show hydraulic and solute transport characteristics. At present, however, Dr. Huang's 3-D model can only be applied to a water saturated fracture system and where the permeability of the rock matrix is zero.

The recharge characteristics at the land surface is an important characterization not only for defining present conditions but also for predicting possible effects of future climatic changes.

An assessment of contaminant transport as vapor through the air-filled pore space should be made.

Borehole/shaft sealing requirements in an unsaturated rock may be different from those for saturated conditions and the degree of sealing may influence water flow and contaminant transport significantly. An assessment of this seems necessary.

FAR FIELD GEOCHEMICAL ISSUES-SUMMARY (LBL Letter report)

GENERAL GROUNDWATER CHEMISTRY

- Quality Control Over Sampling and Analysis.
    - Production zones for groundwater must be defined.
    - Contamination by drilling fluid, metal casing corrosion, or atmospheric gasses is a problem.
    - Unstable chemical factors such as pH, Eh, D.O., alkalinity, NH_7, S- and Fe^{+2}/Fe^{+3} must be analyzed in the Field.
    - Cation/Anion balances should be checked in assessing data quality
- Chemical Heterogeneities in groundwater can be used to assess geochemical controls on groundwater chemistry
    - Identify the sources of dissolved species, extent of solution solid equilibrium, ion exchange mechanisms and reaction rates by assessing heterogeneities.
    - Computer speciation codes can be used to understand data better.

HOST ROCK MINERALOGY

- Characterization of Host Rock Mineralogy
    - The extent of interaction of primary mineral phases with groundwater is important. What phases control radionuclide behavior?
    - The geologic history of the site should be interpreted petrologically
    - The evolution of groundwaters should be interpreted based upon mineralogical evidence.

AQUIFER SURFACE AREAS

- The effective contact area between the repository rocks and groundwater is important to assessment of radionuclide transport.

RADIONUCLIDE ANALOGUES

- Radionuclides and Radionuclide analogue elements such as U, Th, Ra, C, Cs, I, Pb and Se, which are contained in measureable quantities in basalt, tuff, and salt, can be measured to provide information on probable Far-Field radionuclide behavior.

  - Sources and sinks of radionuclides and stable isotopes.

  - The extent and reversibility of ion-exchange and sorption of rock along groundwater flow paths.

  - Solubility controls.

  - Secondary minerals distributions and formations.

SORPTION ON HOST ROCKS

- Sorption is a critical mechanism for isolating radionuclides within the repository system.

Critical factors to look for which have been overlooked in some sorption experiments include: redox conditions and control, reversibility of adsorption (was the reaction actually precipitation, co-precipitation or diffusion?), surface characterization, adequate sample preparation, and full documentation of experimental procedures and conditions.

  - Natural weathered surfaces of basalt and tuff obtained from cores should be used in sorption experiments

  - The surfaces of mineral substrates should be carefully characterized using analytical surface techniques

DIFFUSION PROCESSES

- Diffusion may significantly augment sorption over long time periods. Diffusion may be significant in volcanic glasses in tuff and basalt. Diffusion processes should be assessed on a site and lithologic specific basis.

COLLOIDS

- Colloidal transport of radionuclides could potentially short-circuit processes which retard radionuclide mobility. The concentrations, adsorptive properties, and mobilities of colloids should be assessed on a site-specific basis.

Redox Conditions

- Concentration levels and rates of radionuclide transport are dependent on solubilities and complexation which in turn are functions of their valence state and redox conditions of the groundwater. Experience indicates that the few direct downhole measurements of Eh that have been made in repository aquifers using Pt electrodes may be subject to many errors.

- Data on specific redox couples such as Fe^{+2}/Fr^{+3}, SO_4^{-2}/S^{-2}, As^{+3}/As^{+5} and dissolved oxygen concentrations would be useful. In addition, other redox defining species, including radionuclides, could be added to groundwater tracer tests and their speciation and effect on over all buffering of redox system defined.

- The effect of mineral reaction kinetics on aqueous redox conditions may be important.

In the case of basalt host rocks, redox may be controlled and buffered by the abundance of iron silicates and oxides. Recent NRC research suggest that such minerals can contribute electrons directly to solution during weathering reactions. This suggests that aqueous redox may not be controlled by aqueous redox equilibrium but by kinetic rates of surface oxidation of the minerals. Redox controls on tuff aquifers are probably the least well defined due to low concentrations of iron both in the groundwater and in the host rock. Such a redox system would be expected to be poorly buffered as is apparently suggested by the presence of dissolved O_2 in Pleistocene-age groundwater. Salt repository rocks may have redox conditions dependent on sulfur components as well as interbedded organics.

- For Soft Basalt and Tuff, comprehensive data on individual redox species as well as mechanisms and reaction rates of electrochemically active solids may be needed in addition to electrode methods.

SUMMARY OF POSSIBLE NEAR FIELD ENVIRONMENTS OF HIGH LEVEL WASTE REPOSITORIES

A. BASALT

Major items pertaining to HLW disposal in Thick walled (approx. 15 cm) mild steel canisters surrounded by crushed basalt in the Cohassett flow of the Grande Ronde formation are as follows:

(1) The interaction of the waste form, package and canister with the backfill and host rocks, and how this may influence radionuclide containment and isolation.

(2) The extent to which thermal and mechanical alteration may affect the hydrologic properties of the near field and hence transport of radionuclides to adjacent aquifers.

(3) The effect of hydrothermal alteration on the concentration of radionuclides migrating from a breached waste package.

Some particular questions relative to item (1) that might be considered are:

What is the effect of radiation-induced free radicals on corrosion rates as a function of temperature and in the presence of host rock chemical components?

How will the corrosion of the canister affect the oxidation state of the system? What is the buffering effect of a large steel mass on Eh, and how will this in turn affect the corrosion rate?

Is there evidence that uniform corrosion will be a continuing predictable mechanism under changing temperature and environment during the cannister lifetime?

What will be the corrosion products at elevated temperatures? Will they impede corrosion? Is there a possible effect from sulfidation? Will the production of methane (CH_4) from the carbon in the steel affect canister integrity?

Is there potential for substantial hydrogen overpressure developing during canister corrosion, leading to the formation of gas pockets, or will the hydrogen produced dissipate by diffusion and advection? If a gas pocket is possible, are there disruptive effects?

What is the effect of canister corrosion on the oxidation state of the near field?

The net effect of steel canister corrosion in a relatively closed system will probably be a shift to alkali conditions, thus:

$$22H_2 + Fe_3O_4 + 6SO_4^{2-} = 3FeS_2 + 16H_2O + 12OH^-$$

Will this affect radionuclide transport and host rock solubilization?

The radiation flux emerging from the waste canister will produce a dynamic state of equilibrium with many unstable chemical species. These may diffuse from the canister at different rates and affect both the oxidation state and pH of the surrounding media.

Item (2) deals with the change in hydrologic properties of the near field due to hydrothermal alteration. LBL has indicated that an argument in favor of basalt as a host rock the presumption that hydrothermal alteration will cause sealing of the thermally-effected portion of the host rock due to the formation of secondary clays along joints and fractures.

Answers to the following questions would be useful to include in substantiating documentation that permeability reduction will indeed take place.

To what extent will hydrothermal alteration occur and over what time period?

How does hydrothermal alteraton affect the permeability of the rock?

What is the effect of silica transport and precipitation? What secondary minerals are expected to form?

To what extent will the groundwater composition be modified, and what will precipitate from the groundwater in the near field due to the elevated temperatures?

The third item deals with the impact of hydrothermal alteration on the potential retardation of radionuclides. The radionuclides will react with the host rock and precipitate or sorb in varying degrees, temperature of the repository at the time and the reactivity of the hydrothermally altered host rocks being major factors. The radionuclides behavior in the "near-field" will effectively define the "source term" for modelling radionuclide transport through the far field to the accessible enviroment.

Some questions pertaining to item (3) are the following:

Which elements require primary consideration in the source term? (e.g., particular attention has been paid to Ni -59, Se-79, Tc-99, Pd-107, Si-126, I-129, Cs-135, and the actinides, particularly Np-237, Pu-239, -240 and Am-241, -243. In addition, consideration should be given to such daughters as Ra-226, and also to C-14.

What are the limiting solubilities of toxic radionuclides in the near field environment as a function of temperature?

What are the secondary phases limiting solubility? To what extent do groundwater components cause complexing?

What is the impact on radionuclide speciation and transport in the reducing environment generated by the oxidizing canisters?

To what extent will the radiation field affect oxidation state of the radionuclides, and how will this in turn affect their transport in the groundwater?

Will radiocolloid transport be significant in the near field?

B. TUFF

Major items pertaining to HLW disposal above the water table in Tuff are as follows:

(1) The corrosion rates of canisters in a low pressure steam environment.

(2) Volatile and gas transport of radionuclides.

(3) Thermal alteration of the waste package environment.

The canister can be expected to be exposed to a vapor phase at about one atmosphere total pressure containing a significant proportion of steam. The following questions pertain to item (1) above.

How were experiments conducted to measure canister corrosion rates?

What is the effect of radiation on the corrosion rate?

What are the corrosion products? Were the experiments conducted so that observed cannister behavior is indicative of what can be expected in the repository?

What are the potential consequences of periodic flushing due to fluctuating rainfall? Will dissolved salts precipitate out on the canister and modify corrosion rates?

The second issue concerns volatile transport of radionuclides. Some radioelements notably, Se, I, Sn can form volatiles, which would diffuse in the vapor phase some 100 times faster than in the liquid phase. Other elements may also form volatile halogens, although little is known about their physical and chemical properties. The following questions may be useful.

Has volatile transport been a significant pathway?

Which radionuclides would be of concern vis-a-vis volatile transport?

Will C-14 be a particular problem as CO_2 gas?

The third item concerns the impact of hydrothermal alteration due to the thermal field generated by the decaying radioactive waste.

Devitrification could lead to the formation of soluble secondary salts such as sodium-magnesium carbonates, bicarbonates, chlorides and sulfates, which could leach out rapidly in the event of groundwater flushing. These salts could be quite concentrated, and readily complex actinides, particularly if the host rock environment is oxidizing.

The following questions should help focus this item.

If tuff devification of significance?

What is the effect of soluble salt production?

Will soluble carbonates form, and if so how will C-14 transport be affected?

C. SALT

Bedded and domal salt are discussed as one. Differences affecting near field properties and containment are noted.

The major items pertaining to salt repositories are as follows:

(1) In situ Measurement and interpretation of osmotic pressure profiles and their possible use to demonstrate a closed system and radionuclide isolation.

(2) The impact of a thermal gradient on the osmotic pressure gradient and the effect of such coupled phenomena on radionuclide containment.

(3) Fluid inclusion migration.

(4) Canister corrosion in a saline environment.

(5) The effect of grain boundary diffusion and radionuclide migration in salt.

The following questions relate to the first and second items.

What is the effect of osmotic pressure on groundwater flow?

What is the consequence of the thermal gradient imposed by the wastes?

Will semi permeable membranes, if present, hinder radionuclide transport and by how much? How will a thermal gradient affect this?

The following questions relate to items 3 and 4.

Wat problems can be expected from the migration of fluid inclusions to the canister?

What corrosion rates are expected? How were the tests done to determine corrosion rates? What was the environment assumed in those tests?

What conditions are expected upon closure of the repository? Will the canister be used to reestablish reducing conditions? Are precautions to prevent excessively acid conditions adjacent to the canister needed?

Will anhydite build-up be expected to minimize corrosion?

What are the consequences of radiation on the formation of free radicals in the salt. Will their formation accelerate corrosion rates?

In the final item, radionuclide migration in salt is considered. Since there is little for radionuclides on which to sorb or precipitate, the question of isolation reduces to limiting solubilities (i.e. source terms), possible use of backfill to induce precipitations, sorbtion or coprecipitation of radionuclides and assessment of grain boundary diffusion.

The following are questions relating to item (5):

What are the maximum solubilities of toxic radioelements in magnesium brine and how were they established?

Will the additional precipitants be added to the backfill to reduce radio nuclide solubilities be considered necessary?

Would grain boundary diffusion of radionuclides in the salt matrix be sufficiently slow and of such low magnitude that the salt is an effective barrier to radionuclide migration?

WASTE PACKAGE

Attached are pertinent excerpts from a letter report requested from Battelle Columbus Laboratories (FIN B6764) that describe some of the key items to be considered in waste form/waste package performance. These should further help to focus judgment as to the coverage and depth of site characterization activities anticipated in the EA.

WASTE FORMS

In borosilicate glasses, the glass-forming agents can be expected to be tailored to optimize the waste-form properties for each type of high-level waste. After the waste forms are produced, particularly during the very long period of time after disposal while sealed in their container, they will experience processes that will cause changes. One detrimental effect is devitrification of the glass, which can lead both to new phases with increased solubility and to cracking of the glass (which is detrimental becuase it allows a greater surface area of the glass to be contacted by the groundwater). A model has been developed to predict the degree of devitrification that will occur from subsequent reheatng in the repository after disposal. Another detrimental effect is cracking, which could be induced by the effects of radiation on glass. A study of the radiation effects on glass has revealed no new approach to evaluating this phenomenon experimentally, so we are largely dependent on the existing literature which indicates that radiation produces only a small effect on glass performance.

CONTAINER MATERIALS

The dominant degradation processes that affect the outside of the container are general corrosion, stress-corrosion cracking, pitting, crevice corrosion, hydrogen attack, and mechanical stress. These processes may occur individually or in combination. The parameters that affect these processes include chemical composition and physical state of the steel, groundwater composition and flow rate, temperature, radiation intensity, availability of air, lithostatic forces, redox state, alkalinity/acidity, and availability of hydrogen. These can produce general corrosion, in which the rate of general corrosion will determine the necessary wall thickness, or localized corrosion (such as pitting or crevice corrosion), in which the rate of the localized attack and the container life must be used to establish the wall thickness.

If the steel is susceptible to cracking, failure can be so rapid relative to required container life that the corrosion-allowance approach cannot be used to achieve acceptable performance. What is important is the susceptibility of the metal to crack initiation. Cracking may result from stress-corrosion cracking or from reduction in fracture toughness from hydrogen attack. Both of these processes are under investigation.

SUMMARY OF RESULTS RELATIVE TO PRELIMINARY SITE DATA

Site-specific data are needed to design the waste package and to predict the performance of the materials making up the waste package. Much of this data will not be available until the site characterization process is in the final stages. The data available during site screening can only give some preliminary information which may allow approximating values for the data being sought. However, preliminary information on groundwater characteristics can give some insight into the performance of the waste package materials.

GROUNDWATER FLOW RATES

Our studies of container material corrosion and waste form dissolution have shown that groundwater flow rate will influence the kinetics of the chemical reactions of corrosion and dissolution. At high flow rate a continuous supply of reactive species in the groundwater and a removal of reaction products will tend to accelerate chemical reactions. At low flow rates reactive species, such as oxidizing agents, in the groundwater will be consumed (if a production source is not available) and a buildup of reaction products will tend to retard chemical reactions and permit the approach to thermodynamic equilibrium. The degree of the effects of groundwater flow rate is being analyzed in our modeling studies.

Generally, the groundwater flow rate in the repository locations is expected to be very low. Smith* reports hydraulic conductivities on the order of 10^{-12} m/sec for regions in basalt which, depending on the head, should result in

*Smith, M. J., Engineered Barrier Development for a Nuclear Waste Repository in Basalt, RHO-BWI-ST-7, May 1980.

very low flow rates in a basalt repository. A salt repository will have no groundwater flow unless faulted but will have some brine which will migrate toward the waste package and may accumulate at the container surface. A tuff repository is planned to be located in a dry unsaturated region above the water table and be subject to infrequent percolating water from the surface.

Preliminary site data on water flow rate will be helpful in determining whether these expected conditions will be realized. For basalt, actual flow rate data should be sought. For a salt location, site specific data on brine inclusions can indicate the quantity of brine available for migration to the waste package, and flow rate data for aquifers above or below the salt deposits can indicate the magnitude of groundwater flow that could occur from shaft seal leakage or other faults. For a tuff repository actual rates, quantities, and other frequencies of percolating water should be examined.

GROUNDWATER CHEMISTRY

It is generally recognized that the chemical environment created by the groundwater and the materials near the waste package will largely control the type and rate of corrosion processes that affect all of the materials of the waste package.

There is much to be learned about the chemistry of the groundwater but our research has shown some important preliminary factors. The initial (prior to construction) composition and chemical state of the groundwater can give some insight into the chemical environment that may exist as equilibrium conditions are approached in the sealed repository. The composition of the groundwater affects the corrosion of both the waste form and the container. Some groundwaters are found to be a less aggressive environment for glass waste forms than deionized water because the former contain some dissolution products of the local rock (silicates) which are common to the dissolution products of the glass, thus suppressing the reaction. On the other hand, some groundwater constituents may react with dissolved components of the glass to form insoluble species which precipitate and enhance the corrosion process by removing glass species from solution. Iron, which may be initially present or added from waste package materials, can cause precipitation of silicates and enhance glass dissolution.

Low-carbon steel is a leading candidate for the waste container material. The theory is to use a sufficient thickness of material to allow corrosion to consume a portion of the wall without causing failure during the planned life of the container. Recent results show that in some environments steel will passivate. Whereas this will reduce the rate of general corrosion, it will enhance localized corrosion such as pitting, crevice corrosion, and stress-corrosion cracking. Attack by localized corrosion is more difficult to predict than general corrosion. Again, the water chemistry controls the passivation which, in the observed case, appears to be silicates in an alkaline environment.

Minor constituents in the groundwater can have significant effects. For example, magnesium salts in brine were found to hydrolyze at a liquid-vapor interface on titanium, producing HC7, an aggressive species, in the vapor phase. Many of the minor constituents in groundwaters are known to have caused stress-corrosion cracking of steels in some environments. However, our results thus far show that stress-corrosion cracking of low-carbon steel will not occur in basalt groundwater unless some process causes significant increase in concentration of these species.

The oxidation state and the pH of the groundwater will control many of the corrosion processes. Both of these chemical states will be changed from their initial state by the introduction of air and new materials of the waste package during construction and operation. However, information of the initial state may be indicative of the values which may be achieved after sealing the repository and may give some insight into the performance of the waste package materials.

Environment Variability and Sensitivity Analyses

It has been reported in several references that groundwater and brine chemistry vary greatly within a geologic setting. This can lead to vastly different behavior of the waste package and the resultant release, upon waste package failure, of radionuclides to the accessible environment. Thus it would be very useful if reference groundwater and brine chemistries could be provided for each site along with information on their expected ranges. Such information on groundwater flow rates would also be very useful.

The chemistry and flow rate baseline data could be utilized by the NRC in evaluating the compliance of DOE release data to EPA and NRC requirements under expected conditions, while the range information could be used in sensitivity analyses under worse-case conditions. For the latter analysis, it is assumed that models will be available to determine the uncertainty of the output given the range of uncertainty in the input data.

Items Associated with Waste Packages and Engineering

A. Hydrology

Range of flow rate: This is an important parameter with respect to solubility/leachability determination. The ground water flow rate should be discussed in terms of not only Darcy velocity, but also volumetric rate and residence time.

Heat transfer effect: Hydrologic condition such as permeability and hydrologic head are important to discussions of heat transfer from waste packages. The possibility of "dry out" and "resaturation" under and the state H_2O (e.g. liquid, steam, vapor, mixture, etc.), may be important also.

B. Geochemistry

Ground water composition: Ionic, colloidal, and particulate species need to be quantified. Species that may be introduced during excavation and operation should also be identified.

Heat transfer and radiation effects: These can lead to augmented concentrations in ground water and new species.

Effect of waste leaching and container corrosion.

Effect of atmospheric air on the chemical and mechanical properties of the Crost rock.

C. Geomechanics

Effect of excavation: Consideration of stress and strain changes of host rock due to excavation in particular with respect to operational safety and waste retrievability. For soft media (e.g. salt), degree of expected creep and deformation is important.

Effect of heat and radiation: These may alter the stress field, deformation characteristics, and possibly induce fracture in the Crost rock.

COUPLED EFFECTS

Draft LBL Panel Report

This report was prepared by a panel of experts convened under the auspices of FIN B3046 at LBL in January 1984. The report provides a preliminary understanding of coupled thermal, hydrological, mechanical, and chemical effects which may have to be understood in order to predict repository performance with confidence. Table III on page 7 of the report lists coupled processes in detail and this list carries the implication that certain site specific data will be needed in order to predict the coupled effects. Coupled effects which are important for some host rocks may not be important for other host rocks, and vice versa. What follows is a list of data needs taken from the report. Accompanying each data need listed is a reference to the page or pages explaining why that data need is important for some or all of the candidate host materials DOE is considering. Other useful tables can be found on pages 48 and 49, 51, and 67-77.

Data needs involving thermal couplings depend on the packing density of waste packages, hotter host rocks will require more thermal related data.

SITE CHARACTERIZATION DATA NEEDS FOR COUPLED PROCESSES

Thermodynamic data for radionuclide solid solutions in major rock forming minerals (13, 16)

Thermodynamic data for metastable minerals including alumino-silicates which may form near waste packages at elevated temperatures (16)

Rock leaching and dissolution characteristics at elevated temperatures (17)

Rates of alteration of temperatures of packing materials (which the report calls backfill) (18)

Packing material alternation at high temperatures (18)

Diffusion in the absence of thermal gradients (18)

Ion diffusivities as a funcion of temperature (18)

Solute transport along thermal gradients (Soret effect) (19)

Thermal and chemical osmotic effects (19)

In situ pH and Eh (21)

Analyses of naturally occurring daughter products of U, Th, and Ra (21)

Data for radionuclide mineral solution states (22)

Age dating of groundwater (22, also see the Neuman letter)

Stable isotope data for groundwater, fluid inclusions, and fracture and pore filling minerals (22)

Chemical and mechanical stability of packing materials in a repository environment (27)

Liquid and gaseous properties in unsaturated flows: relative permeability, capillary effects, sorption effects, and vapor pressure effects (37)

Data on mechanisms for liquid flow via chemical and thermal gradients in unsaturated media (37, 38)

Data on the effect of thermal stress and high pressure on hydraulic conductivity (38)

Data on the creation of groundwater pathways through salt to the emplaced HLW (38)

Dissolution characteristics of rock (39)

Natural rate of clogging of fractures (39)

Characterization of dispersion in fractures (40, also see Neuman letter)

Behavior of colloids in fractures (saturated and unsaturated) (41)

Susceptibility of groundwater to gas formation due to radiolysis (41)

Fracture characterization for model selection (42, 43)

Joint spacing, direction, and persistency of fractures (50)

Deformability of intact rock (50)

Stiffness of joints (50)

Initial state of stress (50)

Sizes of openings of fractures (50)

Effect of excavation on fracture alteration (50)

Swelling of fracture fillings (52)

Thermal expansion (53)

Favorable and unfavorable environments for piping (54)

Salt creep (55)

Potential for bulk movement of rock masses due do seismicity (56)

Susceptibility of fractures to deformation by water pressure (57)

Susceptibility of host rock to initiation of new fractures due to excavation (58)

Susceptibility of host rock to triggering of latent seismicity caused by excavation (59)

Host rock's potential for thermal cracking (61)

Host rock's potential for thermal spalling (61, 62)

Host rock's potential for hydraulic fracturing (62)

Stress corrosion characteristics of host rock (64)

MEASUREMENT TECHNIQUES

The parameters listed in the report pertain to the most important site selection criteria listed in DOE's upper and middle level categories. The report can be used for comparing parameters listed by Livermore with those used by DOE in order to define any deficiencies that may need to be corrected.

The report lists critical parameters, grouped as geomechanical, geological, hydrological and geochemical parameters and in accordance with their application to different phases of repository development. The critical parameters are listed in order of decreasing priority. Although, in detail, this could be done differently by different experts, the overall ranking is reasonable and would probably not change substantially in any case. Parameters are considered critical in inability to measure them accurately would have a bearing on the assessment of safety and performance of a repository.

The report presents comments on parameter measurements in basalt, salt and tuff. For basalt, the most important measurements are considered to be a) performance of canisters, backfill and seals and b) the hydro-thermo-mechanical response of the repository system. Long-term measurements, such as determination of canister corrosion, should be started during the site characterization phase.

In salt, the same general types of measurements are required, although the measurements may be different in detail. There will also be differences in priority depending on whether the repository will be located in bedded or domal salt and above or below the water table. It is important to determine the presence of inclusions or voids and, in domal salt, the hydrology of surrounding strata determines the salt dissolution rate.

The plastic behavior of salt is of special importance. Salt creep affects the thermomechanical behavior of the repository, and validation of rheological models based on laboratory measurements is critical. Because of creep properties, in situ stress measurements are also of special importance in salt. Fracture properties, on the other hand, are not as critical because salt tends to be self-sealing.

Instead of permeability, moisture migration is a more important parameter in salt to determine corrosion potential and other properties related to radionuclide containment. Retrieval may present special problems because of closing of openings in salt.

Tuff is generally similar to basalt. Major questions are whether the repository is to be located in welded or unwelded tuff, and above or below the water table. The assumption used in the LLNL report is welded tuff above the water table with 95% saturation. A major problem in this case are hydrological measurements and interpretation methods for determining potential radionuclide escape, because the conventional methods have been developed for the saturated zone.

Tuff also has very variable mechanical properties which, however, can be related to porosity. Modulus and strength of tuff tend to increase exponentially with decreasing porosity. Thermal parameters are important; they are dependent on porosity, water content and mineralogy. Welded tuff may contract when heated if clays and zeolites are present in fractures.

SOCIETAL AND INSTITUTIONAL

This section concerns the societal and institutional areas for the Standard Review Plan (SRP) for the EA's for HLW Repositories. In population-related siting criteria, the NRC does not believe that there should be explicit numerical requirements concerning population centers to the repository. However, the NRC views as a favorable condition, a low population density within the geologic setting of the repository and a controlled area that is remote from population centers (Fed. Reg.-Vol 48, No. 120, p. 28198, June 21, 1983).

The staff believes that socital and institutional data such as population density and distribution, site ownership and control, socio-economic impact and transportation may best be displayed and evaluated by maps since most of this data is spatially oriented. All mapped data should be fully described by text including tabels and figures if appropriate. It is important that all site maps (displaying data within a 10-20km radius of the site) be at the same scale and use the same base map (1:24,000 or 1:25,000 or larger). It is also important that critical physical and cultural information such as topography, surface drainage, major and minor roads be clearly identified on the site maps. In addition to site maps, one generalized regional map should be developed (discussed in more detail later). The use of recent aerial photographs should be very beneficial in identifying important physical and cultural data in the vicinity of the candidate repositories The use of aerials will be especially helpful in those areas (especially very large countries in the Western U.S.) where little demographic or social-economic data has been published for a 10-20km radius of the site.[1]

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1. In sparsely populated areas, the smallest statistical unit for published demographic and socio-economic data is often the county. This means that such published data by itself is not adequate for assessing the societal and institutional impacts within a 10-20km radius of the site if the county is very large. Nye County (candidate area) in Nevada, for example, is approximately 200 miles long from North to South.

Regional Maps

A generalized map of candidate repostory area should be developed which includes the major political units (state(s), cities, towns, etc.), transportation network, streams or other important physical factors. Major land uses, such as Indian Reservations, military installations, national forests etc. should also be delineated. The map may be a relatively small scale of 1:100,000 - 1:250,000 and should identify the location of the candidate repository site.

Site Maps:

1. Geographic Description (Site Location Map*)

The site location should be delineated on 7.5-minute U.S. Geological Survey (USGS) quadrangle maps. Maps of similiar scale may be substituted the USGS quadrangle maps if comparable levels of detail for topography, cultural and natural features are maintained. The approximate center of the site should be identified by specifying the latitude and longitude to the nearest second and the UTM coordinates to the nearest 100 meters.

In addition to topography, the site location map should identify prominent geographic features such as surface drainage, areas of steep slope, excavation sites, political boundaries and major cultural features such as roads, railroads and towns and cities within an approximate 10-20km radius** of the site. A brief narrative should describe the significant cultural and natural features identified on the site location map.

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*In very sparsely populated areas, it may be possible to place site location, population and land use and environmental description on one or two maps. The same base map should be used for all these maps.

2. <u>Existing Population and Land Use and Ownership</u> (Population and Land Use Maps*)

The population and land use map should identify all significant population centers and land uses within a 10-20km radius** of the site. Population data should be presented and based on the 1980 U.S. Census and recent State and local population estimates if available. Migrant population if significant should also be noted.

A population density dot map should be developed for a 10-20km radius of the site (this may not be appropriate for very sparsely populated areas). Significant seasonal or diurnal population variations should be noted. Areas having at least 1,000 individuals in an area 1 mile by 1 mile in proximity to the site should be noted.

With the assistance of published planning documents and aerial photographs, all major existing land uses should be identified and mapped within a 10-20km radius** of the site. In addition, major tracts of land at and near the site should be identified. Major land uses to be identified include but are not necessarily limited to the following categories:

- Residential
- Commercial
- Industrial
- Farms/Ranches
- Park Land and Recreational Areas
- Military and Other Federal Lands
- Transportation and Utilities
- Open Space
- Indian Reservations
- National Forests

In addition to the above, all residences within a 2-km radius of the site should be identified on the map. If no residences are located within 2 km of the site, the approximate distance to the nearest residence should be noted. A brief narrative including tables if appropriate should be written for this map.

** The 10-20km radius should be used as general range depending on condition such as population density, environmental impacts and political boundaries.

3. <u>Environmental Description</u> (Environmental Factors Map)

All significant environmental factors should be mapped within a 10-20km radius** of the site. Significant environmental factors to be identified include but are not necessarily limited to the following categores:

Wildlife Refuges	Adverse Factors Such as -
Wilderness Areas	Areas of Noise Pollution
Wet Lands	Disposal Sites (solid and liquid)
Historical Sites	Deterioriated Housing and/or Structures
Archaeological Sites	
Scenic Areas	

In addition to the above, important flora and fauna should be identified within a 10-km radius of the site. A species is important for the purpose of this SRP if the tailings disposal site may affect the species or its habitat and if one or more of the following criteria applies: (1) the species is commercially or recreationally valuable, (2) the species is threatened or endangered, (3) the species affects the well-being of some important species within criteria (1) or (2); or (4) the species is a biological indicator of radionuclides or chemical pollutants in the environment.

All the environmental conditions described above should be mapped within a 10-km radius as indicated and the SRP should also include a brief narrative description to support the map(s).

4. <u>Land Use Plan, Zoning and other Relevant Local Ordinances</u>

Many urban areas and some rural areas have officially adopted land use plans and/or zoning ordinances. All officially adopted land use plans and zoning ordinances should be mapped within a 10-20km radius of site. Published land use and zoning maps may be reproduced for SRP with the permission of local authorities at any appropriate scale. Land use and zoning categories identified on maps should be accompanied by a brief narrative which describes the limitations and uses for each land use and zoning category. For example, some communities permit residential development in commercial and industrial zones. Therefore, commercial or industrial zoning in proximity of the site does not by itself necessarily suggest that the impact of the site would be minimal. This type of information is important in terms of protecting the health and safety of people within proximity of the site. Other relevant local ordinances such as those concerning grading and stormwater management should be identified and described in terms of impacts and limitations to the site.

5. Local Socio-Economic Description and Impact Assessment

A socio-economic profile of the impact area should be provided (10-20km radius of the site and/or the county(s) in which the site is located) should be provided. The location of important community services such as schools, police and fire stations should be mapped (to the same scale and base map as the site location maps). This profile should include but not necessarily be limited to a description of the following factors:

A. Labor Force
- o Total existing permanent operating force estimate.
- o Estimated existing employment by major industry including construction work force.
- o Estimated employment increase during and after construction.

B. Impacts on Local Community Services (assess increased costs to local community)
- o Schools (give estimaiton of changes in school population characteristics before, during & after construction).
- o Fire and Police
- o Water and Sewer Service

C. Impact on Local Housing
- o Estimate existing housing stock.
- o Evaluate the need for addition public housing.
- o Assess the need for temporary housing during construction.
- o Assess the potential for local construction industry to meet the demand for increased housing.

D. Impact of New Population to Local Social Structure
- o Need for increased welfare, medical and other public assistance.
- o Need for increased police protection due to increased population.
- o Need for increased park and recreational facilities.

E. Impacts on Local Economy
- o Local purchases of goods and services by repository personnel and construction workers.
- o Total wage and salaries of repository operating work force.
- o Local supply response potential of local business community.
- o Estimation of indirect jobs created.
- o Impact on local tourism and recreation.
- o Potential impact on the marketability of local agricultural products.

6. Special Considerations

In addition to the above cited considerations, special consideration should be given to post-operational care of the repository site. Local ordinances, including zoning and land use plans, should be carefully evaluated in terms of reuse protection for the site.[2] It is important that the site and site environs be maintained as open space in perpetuity. As the federal government can not regulate local land use unless federally owned, perpetual Federal ownership may be required unless the State or local community can provide assurance through land use planning and zoning that the site will be maintained as undeveloped open space in perpetuality.

A very important aspect to consider are transportation impacts. Land use impacts along haul routes should be considered. Also care should be taken to avoid disruption to local traffic especially during rush hours. The impact of heavy trucks during the construction phase should also be assessed.

2 Sec. 60.121(a) of the rule requires that both the operations and controll area of the site be either acquired by DOE or that the lands permanently be reserved for repository use. Sec. 60.121(b) also states that... "appropriate controls shall be established outside of the controlled area."

In addition to land use and traffic impacts, the condition and availability of roadways and rail lines along proposed haul routes should be considered in the evaluation of alternative sites and haul routes. The cost of improving and/or building new roads and rail spurs to the site should also be considered.

Human Interference

The relationship of the site to the potential for future human intrusion or interference should be assessed. Key factors would be:

- Proximity to mineral resources which would attract future mining activity

- A site where future human activity could adversely affect the ability of the repository to isolate wastes. For example, a site where there was potential for future human interference with the hydrology of the site

- Any characteristics of the site which would make it especially difficult to establish an effective system of markers.