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

November 2, 1983

MEMORANDUM FOR: Colleen Ostrowski, RES

FROM: Sheldon L. Trubatch, OGC

SUBJECT: 10 CFR PART 60 - PROPOSED AMENDMENTS (SECY-83-444)

I have reviewed the proposed amendments and believe that the proposed rule is one of the best I have ever seen. It addresses the principal issues and relates the decisions on specific requirements to the resolution of those issues. The rulemaking package is also well-documented and, thus, appears to meet the most stringent legal requirements for notice. For these reasons, I believe that this rulemaking package should be used as a model for evaluation the procedural aspects of proposed technical rules.

AB44-2

REGULATORY ANALYSIS
10 CFR PART 60

1. Statement of the Problem

10 CFR Part 60 -- "Disposal of High-Level Radioactive Wastes in Geologic Repositories," as currently written (48 FR 28194), was primarily developed for disposal of high-level radioactive wastes (HLW) within the hydrogeologic region termed the saturated zone. The provisions of 10 CFR Part 60 were originally directed towards the saturated zone because at the time they were being developed the licensee -- the U.S. Department of Energy (DOE) -- was only considering potential repository sites at sufficient depths to be contained within the saturated zone. The saturated zone, as defined in existing 10 CFR 60.2 means "that part of the earth's crust beneath the deepest water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric" (48 FR 28218).

Commenters on the proposed 10 CFR Part 60 technical criteria (46 FR 35280) viewed this limitation as unduly restrictive, and considered geologic disposal within the unsaturated zone to be a realistic alternative to disposal within the saturated zone. Additionally, in its comment letter on the proposed technical criteria DOE, noting that opportunities may arise for exploratory studies in unsaturated geologic media, requested that NRC ensure that 10 CFR Part 60 will apply to all geologic media. Since DOE may submit site characterization plans to NRC for potential repository sites that may be situated within the unsaturated zone, it is necessary to modify the appropriate provisions of 10 CFR Part 60 in a timely manner so that the NRC may review license applications that may be submitted for geologic repositories within the unsaturated zone. The term "Unsaturated zone" as used by NRC means "the zone between the land surface and the regional water table. Generally, fluid pressure in this zone is less than atmospheric pressure, and some of the voids

may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies the water pressure locally may be greater than atmospheric."

Existing provisions of 10 CFR Part 60 are generally applicable to disposal within either the saturated or unsaturated zone. However, minor modifications are still necessary to ensure that the rule applies equally to sites in both hydrogeologic zones. On February 16, 1984, NRC published for comment proposed amendments to 10 CFR Part 60 related to the unsaturated zone (49 FR 5934). In response to its solicitation of public input on the proposed amendments NRC received 14 comment letters. These letters represented the views of other Federal agencies, States, representatives of industry and public interest groups. In general these commenters were supportive of both NRC's decision to consider the licensing of HLW disposal in the unsaturated zone and the provisions set forth in the proposed amendments. The public comment letters primarily addressed questions posed by NRC on groundwater travel time calculations in the unsaturated zone, and suggested minor word changes for the sake of clarity and technical accuracy.

The final amendments should not result in any additional costs to DOE, and will clarify the Commission's regulations concerning the licensing of HLW disposal in unsaturated geologic media.

2. Objectives

The objective of the proposed regulatory action is to broaden the scope of 10 CFR Part 60 to cover licensing of the disposal of HLW within the unsaturated zone.

3. Alternatives

(1) Leave the final provisions of 10 CFR Part 60 intact. (48 FR 28194)

(2) Develop an entirely separate rule to apply to the unsaturated zone.

(3) Publish proposed guidelines for HLW disposal in the unsaturated zone as a regulatory guide.

4. <u>Consequences</u>

(a) <u>Proposed Action</u>: Publish final amendments to make 10 CFR Part 60 equally applicable to license applications for HLW repositories in both the saturated and unsaturated zones.

The final amendments would provide NRC with the maximum flexibility with respect to reviewing license applications for HLW disposal with the minimum expenditure of time or money. The amendments were developed after consideration of the public comments received on the proposed 10 CFR Part 60 technical criteria (46 FR 35280). Many of the points raised by commenters with respect to modifying 10 CFR Part 60 to apply to both the saturated and the unsaturated zones were accommodated in the final technical criteria (48 FR 28194) in response to comments received on other issues. The final technical criteria were reviewed in light of these comments and the staff considered the minor modifications presented as proposed amendments (49 FR 5934) sufficient to make the rule equally applicable to reviewing license applications submitted for HLW disposal in either hydrogeologic zone. This view generally was supported by the public commenters on the proposed amendments relating to the unsaturated zone.

The impacts associated with this action (i.e., promulgating the final amendments) are minimal. The impacts associated with disposal of HLW in geologic repositories within the unsaturated zone should be comparable with saturated zone repositories since the general performance objectives for the natural and engineered barriers apply to each hydrogeologic zone. The addition of the final amendments to 10 CFR Part 60 should result in no changes to the radiological safety consequences or to the impacts relating to safeguards, operations, economics, environments or general information collection associated with disposal in the saturated zone. Finally, the cost of the proposed action to NRC would be negligible.

(b) Alternative 1: Leave the provisions of the final rule - 10 CFR Part 60 intact.

As noted previously, public comments on the proposed technical criteria (46 FR 35280) requested that NRC modify its original decision to limit the technical criteria to HLW repositories within the saturated zone. Further, public comments on the proposed amendments published in February, 1984 reinforced the view that disposal of HLW within the unsaturated zone should be considered. NRC received comment letters from the U.S. Department of Energy, U.S. Environmental Protection Agency, the U.S. Department of the Interior, and the U.S. Geological Survey supporting the concept of HLW disposal within the unsaturated zone.

Potentially, this alternative would have few associated impacts since it would not represent any change in the status quo. DOE could still file a license application for a geologic repository within the unsaturated zone under the existing provisions of 10 CFR Part 60. In considering such an application NRC would need to determine if the proposed site conformed with the provisions of the technical criteria set forth in Part 60. However, certain of these existing provisions may be technically inappropriate for an unsaturated zone site and could result in inappropriate analyses of the site-specific data. Therefore, this alternative could result in a certain degree of technical ambiguity which could complicate and delay the license review process.

(c) Alternative 2: Develop a separate regulation for disposal of HLW within the unsaturated zone.

It would be possible for NRC to develop a parallel regulation to 10 CFR Part 60 which would set forth provisions for disposal of HLW within the unsaturated zone. This alternative would offer no preferred benefits to the proposed action, and would drastically increase the amount of time and money associated with this type of action.

Reviews of 10 CFR Part 60 by both the public commenters and the NRC staff indicated that only minor changes to the final technical criteria are necessary to

ensure that the rule is equally applicable to HLW disposal in either the saturated or unsaturated zone. Therefore, the staff considers that there would be no justifiable reason for developing a new parallel regulation.

(d) Alternative 3: Publish additional criteria for disposal in the unsaturated zone as a regulatory guide.

If this alternative were adopted, disposal within the saturated zone would still be comprehensively governed by the regulations of 10 CFR Part 60, while disposal in the unsaturated zone would need to receive additional guidance in the form of a regulatory guide. There would be no legal requirements to be met in the latter instance. Therefore, the regulatory guide approach would not achieve the objective of equally applicable provisions for HLW disposal within both the saturated and unsaturated zones.

5. Decision Rationale

The NRC staff has evaluated the proposed action and three alternative courses of action in light of the public comments received on the proposed technical criteria as well as the staff's review of the issues involved in disposal within the unsaturated zone. The staff prepared a technical support document -- draft NUREG-1046 which explored pertinent issues and presented a review of the provisions of the final rule - 10 CFR Part 60 with respect to these issues. The public comment letters on the proposed unsaturated zone amendments (49 FR 5934) and draft NUREG-1046 were reviewed in detail. Generally, the Commission's approach was favorably viewed by these commenters. Some changes and clarifications were made in the rule as a result of the comments received. Additionally, draft NUREG-1046 will be revised to reflect changes made as a result of public comments, and will be published as a final NUREG report.

The final amendments contain provisions for modifying those sections of 10 CFR Part 60 related to the definitions, siting criteria and design requirements. The NRC staff considers the proposed action as the most direct and cost - effective method of ensuring that the provisions of 10 CFR Part 60 are equally applicable to HLW disposal within the saturated and unsaturated zone.

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NUREG 1046

DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTES IN THE UNSATURATED ZONE: TECHNICAL CONSIDERATIONS AND RESPONSE TO COMMENTS

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ACKNOWLEDGEMENTS

Several additional people contributed to the production and internal review of this document, most notably C.N. Ostrowski, the original task leader of this project.

ABSTRACT

On July 22, 1985, the U. S. Nuclear Regulatory Commission (NRC) promulgated amendments to 10 CFR Part 60 concerning disposal of high-level radioactive waste (HLW) in geologic repositories in the unsaturated zone (50 FR 29641). NUREG-1046 contains a discussion of the principal technical issues considered by the NRC staff during the development of these amendments. This NUREG expands or revises certain technical discussions originally presented in draft NUREG-1046 (February 1984), based upon public comment letters and upon an increasing understanding of the physical, geochemical, and hydrogeologic processes operative in unsaturated geologic media.

The following issues related to disposal of HLW within the unsaturated zone are discussed: hydrogeologic properties and conditions, heat dissipation and temperature, geochemistry, retrievability, potential for exhumation of the radioactive waste by natural causes and by human intrusion, the effects of future climatic changes on the level of the regional water table, and transport of radionuclides in the gaseous state.

The changes to 10 CFR Part 60 in definitions, siting criteria, and design criteria for the geologic repository operations area are discussed. Other criteria examined by the NRC staff but which were not changed in rule are the minimum 300 meter depth for waste emplacement, limitations on exploratory boreholes, backfill requirements, waste package design criteria, and provisions for ventilation.

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I. INTRODUCTION:

I.a. Background:

The Nuclear Regulatory Commission (NRC) has established a regulatory framework for licensing the disposal of high-level radioactive wastes (HLW) in geologic repositories. On February 25, 1981, NRC promulgated final licensing procedures of 10 CFR Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories" (46 FR 13971). Technical criteria against which license applications will be reviewed under 10 CFR Part 60 were promulgated on June 21, 1983 (48 FR 28194).

Prior to issuance in final form, the 10 CFR Part 60 technical criteria were proposed for public comment in 1981 (46 FR 35280). Ninety-three comment letters were received on these proposed technical criteria. Several commenters on the proposed rule, including the U.S. Department of Energy, the U.S. Department of the Interior, and separately the U.S. Geological Survey (USGS), took issue with a statement made by the Commission at 46 FR 35281 which explained that the proposed technical criteria were developed specifically for disposal in saturated geologic media because DOE plans at that time called for HLW disposal at sufficient depth to be situated in the hydrogeologic regime termed the saturated zone. These commenters considered disposal in the unsaturated zone to be a viable alternative to disposal in saturated geologic media, and noted that since the technical criteria were generally applicable without regard to the possibility of saturation, their scope and applicability should not be unduly restricted. NRC found this criticism to be well founded, and stated its intent to promulgate specific criteria that apply to the unsaturated zone for public comment. To that end, NRC published specific technical

criteria for HLW disposal within the unsaturated zone as proposed amendments on February 16, 1984 (49 FR 5934).

In addition to these proposed amendments, NRC specifically requested public input on two questions related to ground-water travel time calculations within the unsaturated zone (49 FR 5937). In conjunction with the proposed amendments, NRC published for public comment draft NUREG-1046 which contained a discussion of the principal technical issues considered by the NRC staff during the development of the proposed amendments.

A total of fourteen groups and individuals commented on the proposed amendments and draft NUREG-1046. There was general acceptance of NRC's view that disposal of HLW within the unsaturated zone is a viable alternative to disposal within the saturated zone. The commenters addressed the specific questions on ground-water travel time within the unsaturated zone and provided additional comments suggesting word changes to improve the technical accuracy and to clarify the intent of the proposed amendments. The NRC staff considered these comments during the development of the following final amendments, which were published on July 22, 1985 (50 FR 29641).

1. New definitions of the terms "Ground water" and "Unsaturated Zone" were added to § 60.2 and a conforming technical change was also made to the existing definition of the term "Saturated Zone" to read as follows:

"Ground water" means all water which occurs below the land surface.

"Saturated zone" means that part of the earth's crust beneath the regional water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

"Unsaturated zone" means the zone between the land surface and the regional water table. Generally, water pressure in this zone is less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies the fluid pressure locally may be greater than atmospheric.

2. Section 60.122 was amended by revising paragraphs (b)(2)(iii) and (c)(9) redesignating paragraph (b)(2)(iv) as (b)(7), and adding new paragraphs (b)(8), (c)(22), (23) and (24) to read as follows:

<u>§ 60.122 Siting criteria</u>.

* * * * *

(b) ***

(2)***(iii) Low vertical permeability and low hydraulic gradient between the host rock and the surrounding hydrogeologic units.

* * * * *

(7) Pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment that substantially exceeds 1,000 years.

(8) For disposal in the unsaturated zone, hydrogeologic conditions that provide--

(i) Low moisture flux in the host rock and in the overlying and underlying hydrogeologic units;

(ii) A water table sufficiently below the underground facility such that fully saturated voids continuous with the water table do not encounter the underground facility;

(iii) A laterally extensive low-permeability hydrogeologic unit above the host rock that would inhibit the downward movement of water or divert downward moving water to a location beyond the limits of the underground facility;

(iv) A host rock that provides for free drainage; or

(v) A climatic regime in which the average annual historic precipitation is a small percentage of the average annual potential evapotranspiration.

* * * * *

(c) ***

(9) Ground-water conditions in the host rock that are not reducing.

* * * * *

(22) Potential for the water table to rise sufficiently so as to cause saturation of an underground facility located in the unsaturated zone.

(23) Potential for existing or future perched water bodies that may saturate portions of the underground facility or provide a faster flow path from an underground facility located in the unsaturated zone to the accessible environment.

(24) Potential for the movement of radionuclides in a gaseous state through air-filled pore spaces of an unsaturated geologic medium to the accessible environment.

3. Although no changes to the design criteria were included in the proposed amendments, these provisions were addressed by commenters on the proposed amendments. Following consideration of discussions presented in these public comments, NRC revised § 60.133(f) and § 60.134(b)(1) to read as follows:

§ 60.133 Additional design criteria for the underground facility.

(f) Rock excavation. The design of the underground facility shall incorporate excavation methods that will limit the potential for creating a preferential pathway for ground water to contact the waste packages or radionuclide migration to the accessible environment.

§ 60.134 Design of seals for shafts and boreholes.

(b)(1) The potential for creating a preferential pathway for ground water to contact the waste packages or radionuclide migration through existing pathways.

I.b. General discussion of the saturated and unsaturated zones:

The term "ground water" as defined in the final amendments to 10 CFR Part 60 refers to all water which occurs below the land surface, i.e., in both the saturated and unsaturated zones. Todd (1980) noted that generally, a single saturated zone is overlain by a single unsaturated zone which extends upwards to the ground surface. These two subsurface hydrogeologic zones are separated by an irregular surface called the water table (Linsley et al., 1982). The water table as defined in 10 CFR Part 60 (48 FR 28219) is that surface in a ground-water body at which water pressure is atmospheric. Often however, locally saturated conditions may exist in portions of the unsaturated zone creating a perched water table. The existence and position of the perched water table varies with the magnitude of the initiating water recharge events, the infiltration properties of the soil, and the occurrence of less permeable

hydrogeologic units (e.g., aquitards) at depth. A schematic view of these hydrogeologic concepts is presented in Figure 1.

The saturated zone is defined in the final amendments as that part of the earth's crust beneath the regional water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric (i.e., positive gauge pressure). The saturated zone may extend to considerable depth, but as depth increases, the weight of overlying rock and soil materials also increases, usually causing less pore space to exist. This results in little ground water existing at depths greater than 3 kilometers (Linsley et al., 1982).

As defined in the final amendments to 10 CFR Part 60, the unsaturated zone is the zone between the land surface and the regional water table. Generally, fluid pressure in this zone is less than atmospheric pressure, and some of the voids contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies the water pressure locally may be greater than atmospheric.

Roseboom (1983) stated that placing radioactive wastes in the unsaturated zone will add a new and very effective natural barrier--an environment that should remain relatively dry during the desired period of containment. He further noted that because soil moisture in the unsaturated zone would ultimately percolate downward to the saturated zone, many, if not all, of the additional natural barriers that exist below in the saturated zone also apply to the isolation capabilities of the unsaturated zone.

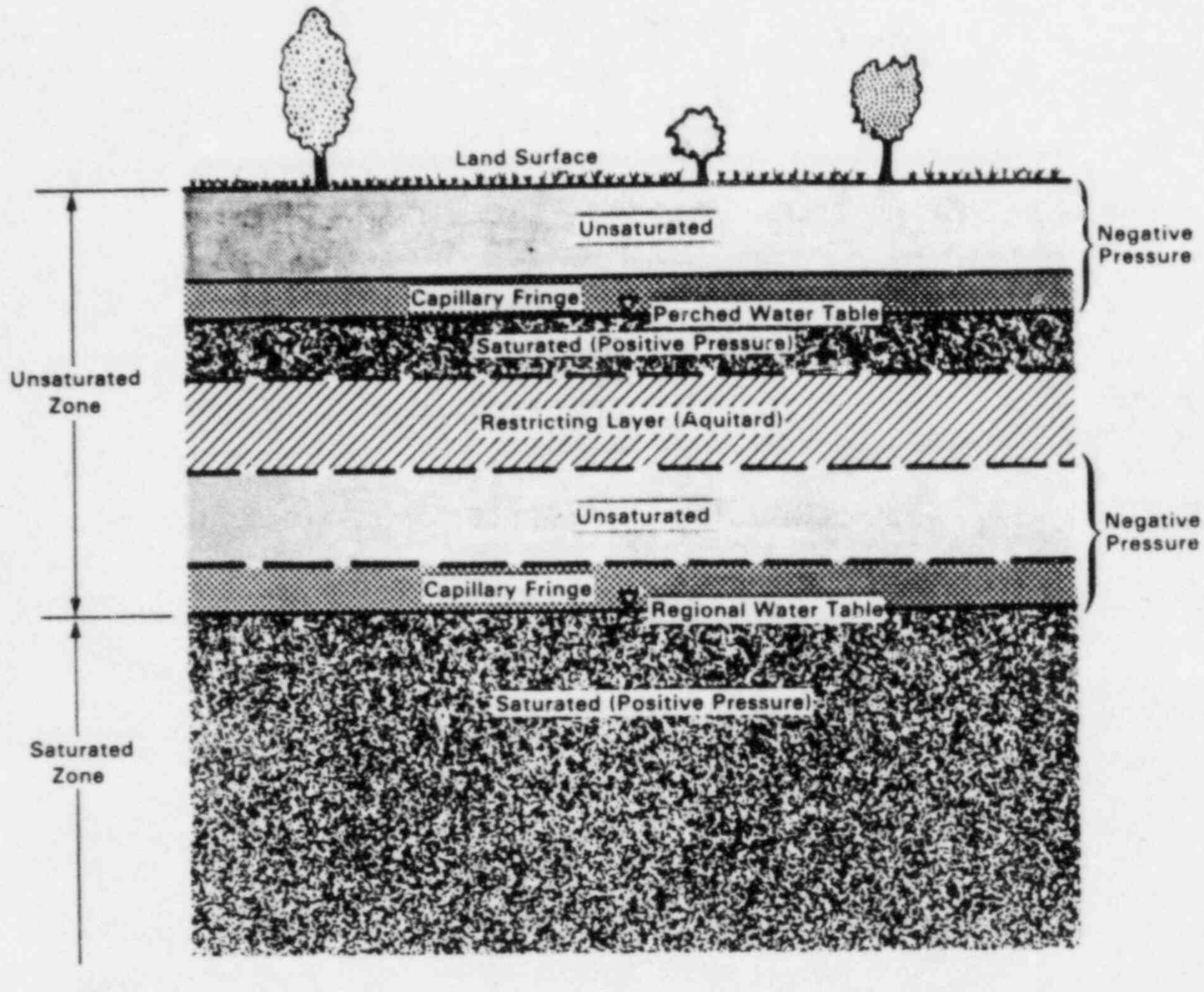

Figure 1. Schematic vertical section of a hypothetical ground-water flow system. System includes a perched ground-water table and associated capillary fringe overlying a restricting layer (i.e., aquitard); these are separated from the regional water table by a second unsaturated layer and capillary fringe. The water pressure is greater than atmospheric pressure where the geologic material is saturated, less than atmospheric pressure where the material is unsaturated, and equal to atmospheric pressure at the water tables. In the Basin and Range Province of the western United States, the regional water table can be as much as 600 meters below the land surface.

Water flow and, hence, contaminant transport through the unsaturated zone will probably differ significantly from that through the saturated zone. The air contained within certain pores or fractures reduces the cross-sectional area for liquid water flow and provides channels for the movement of gases. As the water pressure becomes progressively more negative, smaller and smaller pores are drained and water flow is confined to the remaining smaller water-filled pores, as wedges of water at points of contact of solid particles, and as water films on solid particles (Figure 2). The reduction in cross-sectional area and the confinement of flow to the smaller pores or to film flow within the larger voids drastically reduce the hydraulic conductivity of the unsaturated zone. The hydraulic conductivity of the unsaturated zone (termed effective hydraulic conductivity or unsaturated hydraulic conductivity) can be several orders of magnitude smaller than the saturated hydraulic conductivity of the same geologic material, and is a function of water content and negative pressure of the water.

Water flow through a thick unsaturated zone is normally gravity controlled and is therefore vertically downward unless there are discontinuities which could cause a horizontal flow component. Thus, one credible pathway for the migration of water-soluble contaminants from a geologic repository located in an unsaturated zone to the accessible environment is vertically downward to the underlying regional water table, and subsequently through the saturated zone to the accessible environment. If the unsaturated zone beneath the geologic repository is hundreds of meters thick, travel times for contaminants in solution could be exceedingly long, offering additional assurance of waste isolation.

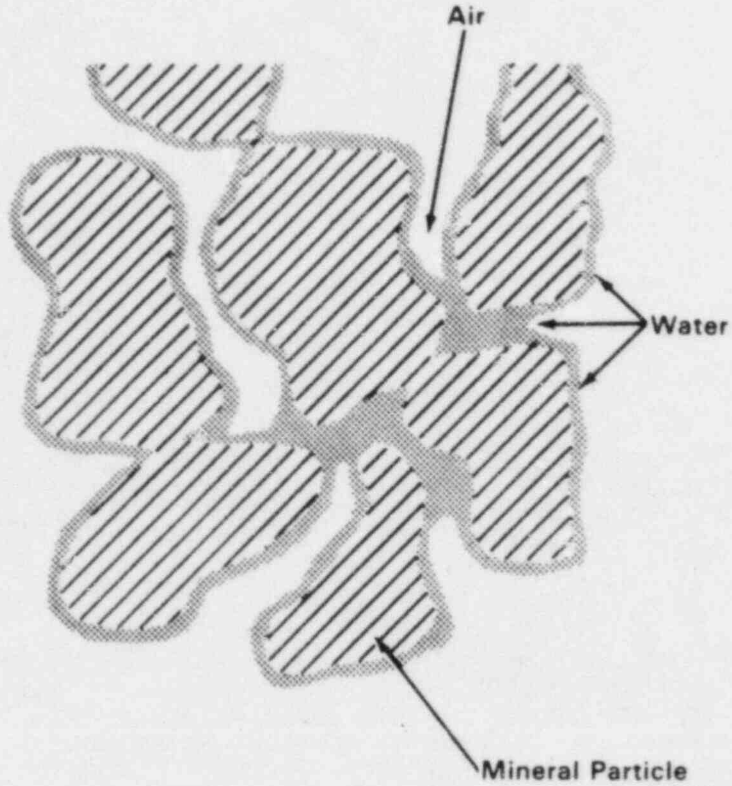

Figure 2. In the unsaturated zone, water exists as a film on particle surfaces and as wedges near points of contact between mineral particles. The films and wedges of water increase in size with a decrease in negative water pressure, and decrease in size with an increase in negative water pressure. Compared to flow in the saturated zone, the reduced cross-sectional area and increased tortuosity for water flow drastically reduce the effective hydraulic conductivity in the unsaturated zone.

The depth to the regional water table varies throughout the United States, and consequently, the thickness of the unsaturated zone also varies. Temporal and spatial fluctuations of the regional water table are dependent upon a number of factors (see Figure 3) including infiltration, percolation to the water table, air entrapment during ground-water recharge, evapotranspiration and plant uptake, bank-storage effects near streams, ground-water pumping and injection, artificial recharge from surface-water impoundments and surface depressions (e.g., ponds, lagoons, and landfills), agricultural irrigation and drainage, regional topography, and geotechnical drainage systems (Freeze and Cherry, 1979). The annual water budget of an arid climate (i.e., precipitation minus potential evapotranspiration) leads to large moisture deficits and little or no recharge to the regional water table, except perhaps along stream channels or mountain fronts where recharge is concentrated. Commonly, the recharge areas for underlying ground-water units are many kilometers from a given arid site.

Unsaturated geologic materials range from highly porous, granular material such as alluvial fill, to extremely low permeability, consolidated rock with low fracture density such as granites and some densely welded tuffs. Included within this range are porous, unconsolidated and consolidated materials with varying degrees of fracturing (for example, low permeability soils, slightly welded tuff, and certain types of sandstones).

The behavior of any water eventually entering the subsurface will be influenced by the water conductance and retention properties (e.g., effective hydraulic conductivity and pore size distribution) of the geologic medium (see Figure 4). For example, in the case of unsaturated highly fractured rocks, the downward movement of water at certain times can be quite rapid (Roseboom, 1983) but the quantity of flow may be extremely small. In contrast, in a highly porous medium with extremely low permeability (e.g., tight clays), the vertical

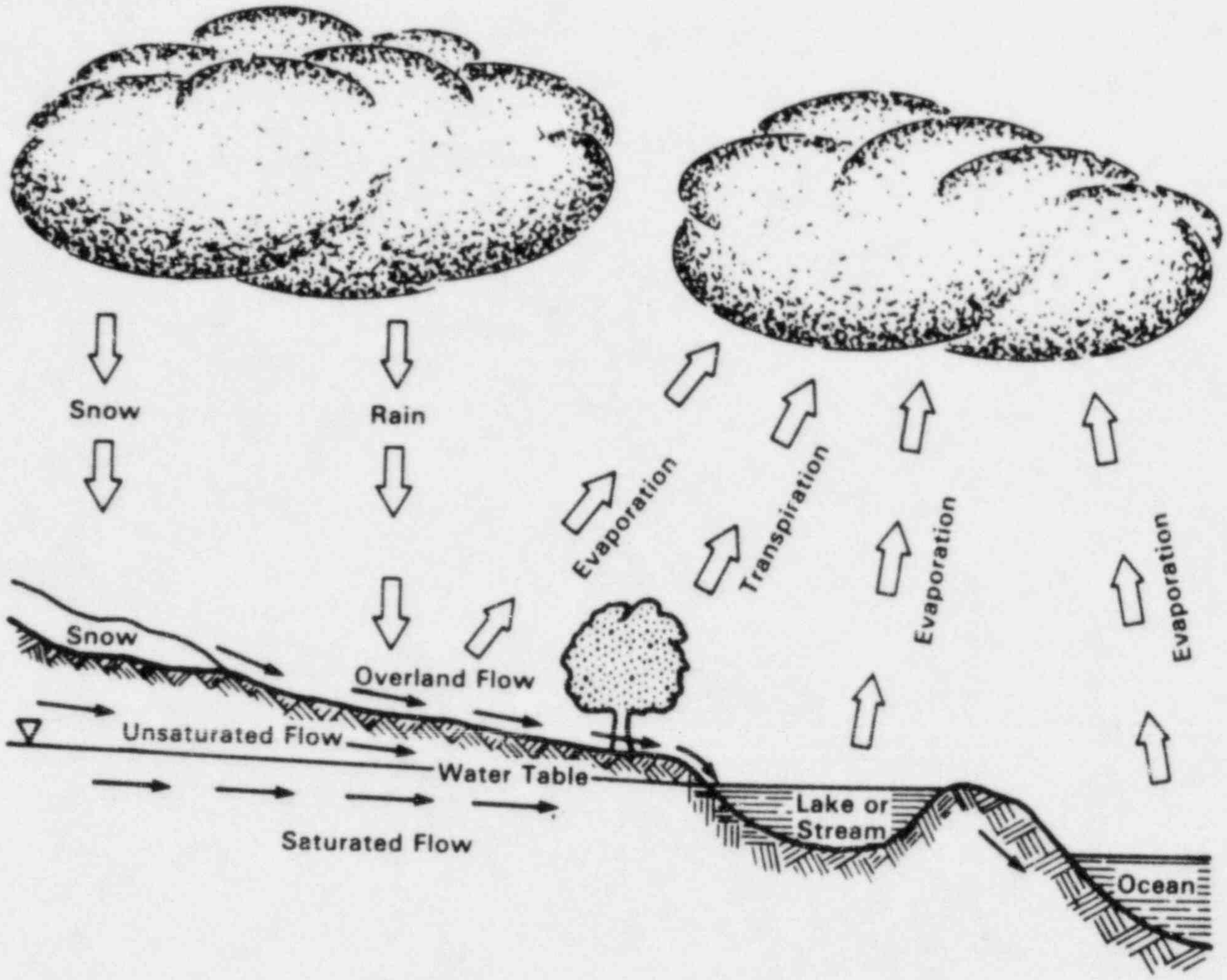

Figure 3. Simplified view of the hydrologic cycle. Important factors which affect the water table depth below land surface include precipitation vesus evaporation/transpiration characteristics, overland flow versus infiltration, water levels in lakes and streams, surface topography, and subsurface hydraulic conductivities.

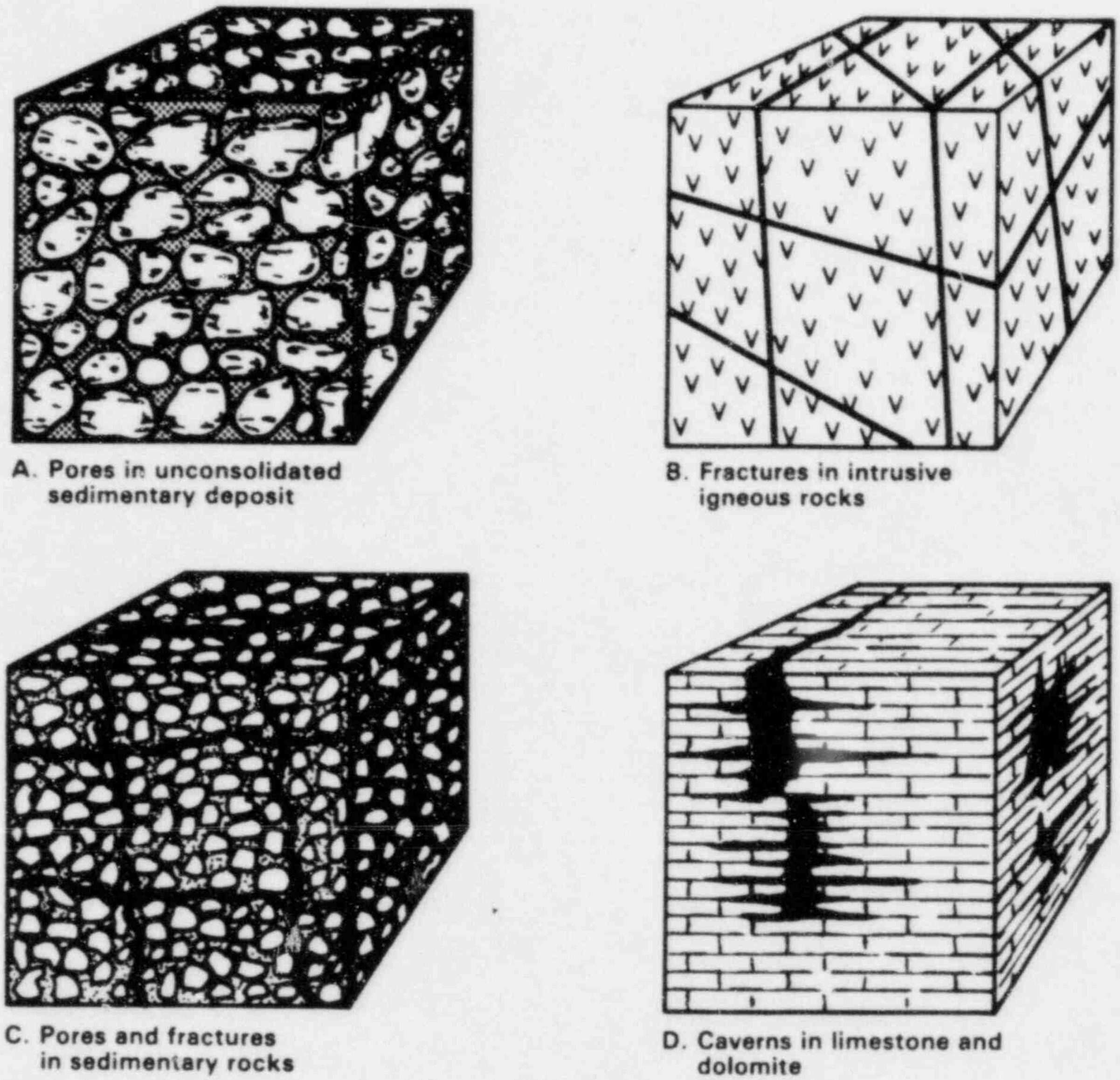

Figure 4. Types of openings in selected geologic media. The scale for block A is on the order of a few millimeters in width; for blocks B and C, a few meters; and for block D, a few tens of meters. The size and spatial distribution of pores between grains, as well as fractures and dissolution caverns, greatly affect the saturated and effective hydraulic conductivities of the medium (modified from Heath, 1984).

movement of water may be very slow (Roseboom, 1983). Unsaturated zone properties of interest in determining ground-water flow rates are water content, negative pressure heads, and the functional relationships of effective hydraulic conductivity with water content and with negative pressure head (see Figures 5 and 6). The water content can vary from full saturation (which is equal to the effective porosity) to virtually zero. Pore water pressures in the unsaturated zone range from above atmospheric (e.g., in perched water bodies) to highly negative pressures.

II. DISPOSAL OF HLW WITHIN THE UNSATURATED ZONE:

II.a. Background:

The unsaturated zone has been viewed as a potential location for the disposal of HLW for approximately 20 years. In recent years, one of the major advocates of the concept of HLW disposal within the unsaturated zone has been the United States Geological Survey (Winograd, 1981). Many positive aspects and accompanying concerns associated with HLW disposal in the unsaturated zone have been identified (Winograd, 1981; National Academy of Sciences, 1983; Roseboom, 1983; Wollenberg et al., 1983). The positive aspects and potential concerns associated with this concept will be discussed within the NRC evaluation of principal issues presented in the following sections of this chapter.

The NRC staff recognizes that there is little likelihood that a "perfect" site will be identified within the unsaturated zone. As in the case of potential geologic repository sites within the saturated zone, the staff believes that a site should exhibit an appropriate combination of favorable conditions

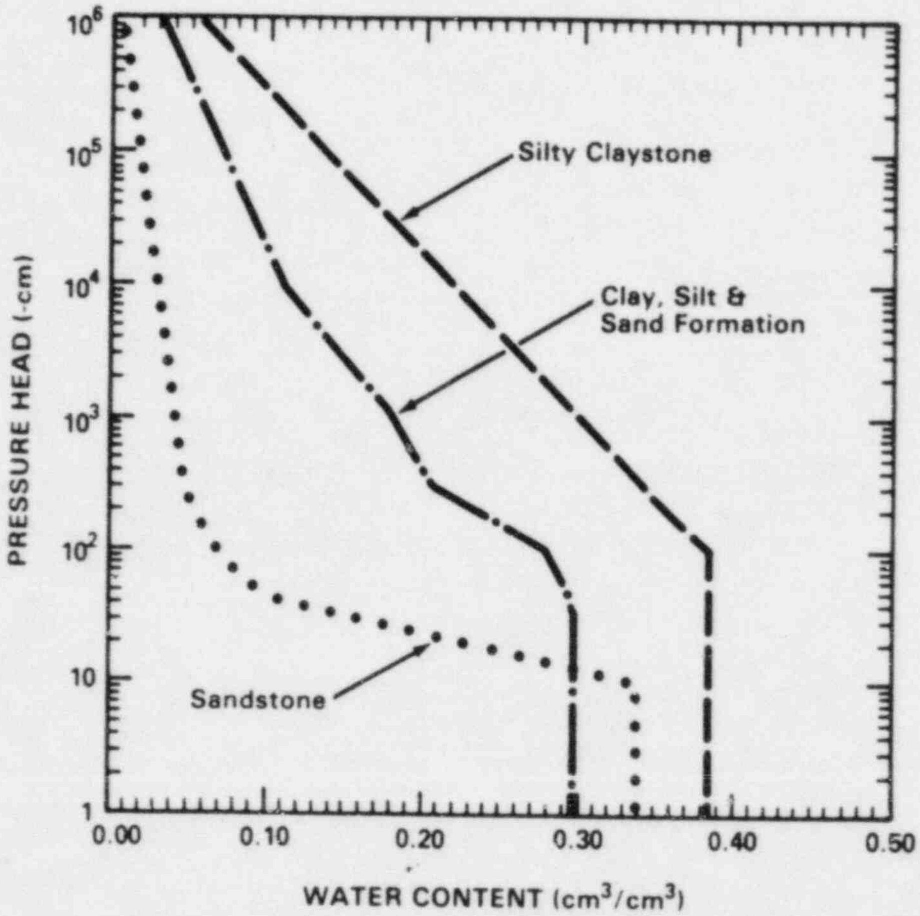

Figure 5. Pressure head versus water content for three geologic media. The head changes several orders of magnitude for a small change in water content. Also note the large differences between the three geologic media shown (modified from Nelson, Reisenauer, and Gee, 1980).

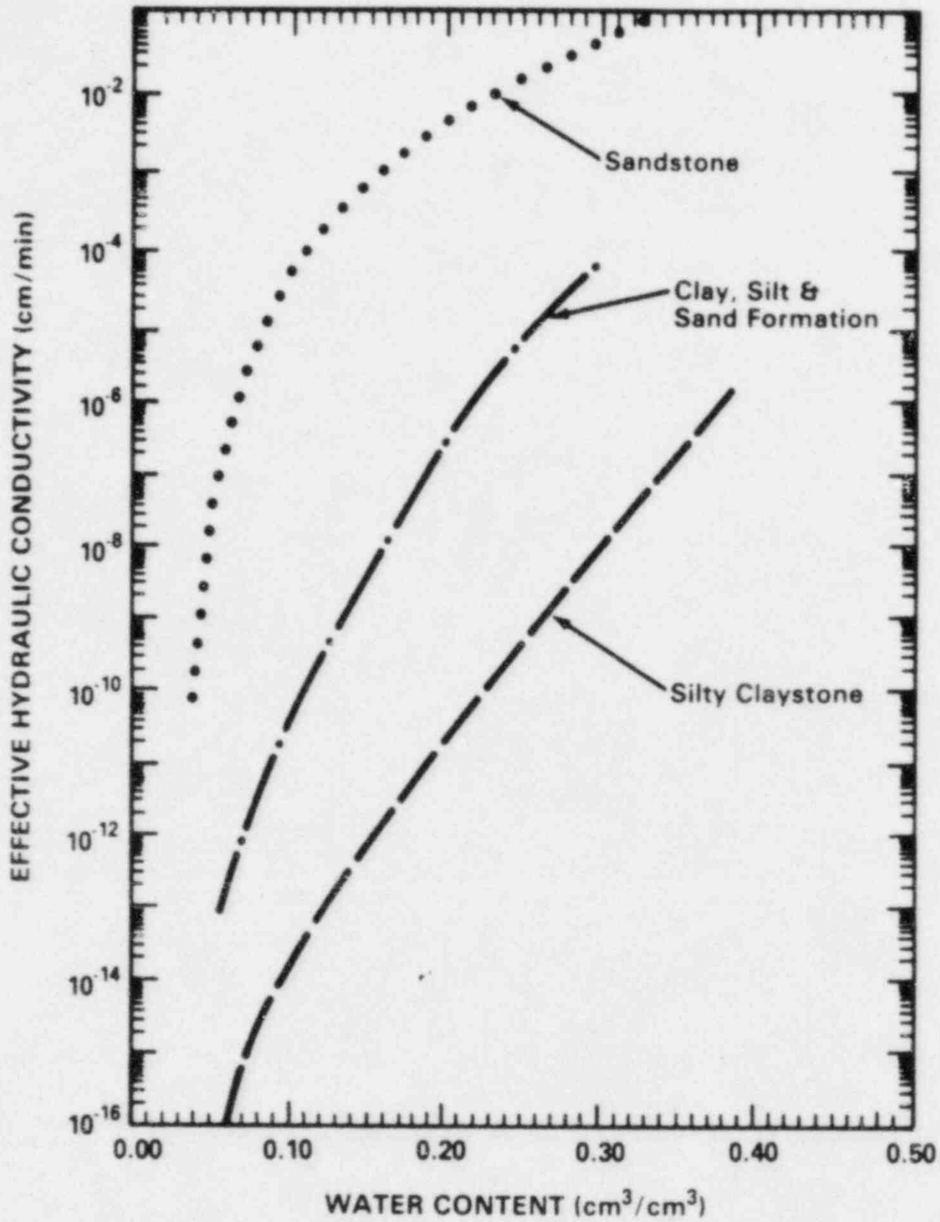

Figure 6. Effective hydraulic conductivity versus water content for three geologic media. Effective hydraulic conductivity changes several orders of magnitude for a small change in water content. Also note the large differences between the three geologic media shown (modified from Nelson, Reisenauer, and Gee, 1980).

so as to encourage the selection of a site that is among the best that reasonably can be found. Meaningful comparisons of performance can only be made for specific sites, and will require consideration of non-geologic factors as well as geologic and hydrologic factors. Further, any potentially adverse conditions identified at a particular site (whether in the saturated or unsaturated zone) should be assessed to assure that they will not compromise the ability of the geologic repository to meet the performance objectives of 10 CFR Part 60. The staff reiterates the Commission's view set forth in 48 FR 28201 that a site would not be disqualified simply as a result of the absence of a favorable condition or the presence of a potentially adverse condition.

One of the most important issues that must be addressed in evaluating any potential geologic repository site is how effectively the site will isolate radioactive waste from the accessible environment for the necessary period of time. It is generally recognized that ground-water migration constitutes the most probable mechanism for radionuclide transport from a geologic repository to the accessible environment (Bredehoeft and Maini, 1981; Witherspoon et al., 1981; Roseboom, 1983; Kocher et al., 1983). It is the importance of ground-water flow and transport mechanisms and the identification of credible pathways to the accessible environment that has led to serious consideration of the unsaturated zone in the siting of potential geologic repositories.

II.b. Issues addressed by NRC in considering the disposal of HLW within the unsaturated zone:

The concept of HLW disposal within the unsaturated zone clearly has a number of important issues associated with it. The NRC staff believes it may be premature to divide these issues into definite advantages and disadvantages

at this time because of the current paucity of scientific data in the area of ground-water flow through unsaturated geologic media other than porous granular materials. The purpose of the following sections is to provide a generalized discussion of the principal issues that may be involved in disposal of HLW within the unsaturated zone. In some cases, the issues (e.g., human intrusion) are generally applicable to disposal within either the saturated zone or the unsaturated zone.

II.b.1. Hydrologic properties of the unsaturated zone:

The final amendments to 10 CFR Part 60 identified "low moisture flux in the host rock, and in the overlying and underlying hydrogeologic units" as one of five favorable hydrogeologic conditions for disposal in the unsaturated zone (§ 60.122(b)(8)).

The NRC staff considers the relatively low moisture flux of certain unsaturated geologic media to be a favorable condition in the siting of a geologic repository because the generally low moisture flux could minimize leaching of the waste packages and thus reduce significantly the rate of radionuclide transport from the underground facility by ground-water migration.

It is generally recognized that in the unsaturated zone vertical ground-water flux can be very small. The flow path to the saturated zone and its regional discharge points would be extremely long in arid regions, where the unsaturated zone could extend to depths of up to 600 meters (Winograd, 1981; Wollenberg et al., 1983). A fundamental principle of soil physics is that as the water content decreases, larger pores drain before smaller pores and the effective hydraulic conductivity is drastically reduced (Klute, 1965) (see Figures 5 and 6). Conversely, as the water content approaches saturation, the

large pores are the last to fill. This principle explains "capillary barriers" (also termed the "wick effect") where large contrasts in pore size distributions between distinct layers act to impede unsaturated flow. Although this concept is generally associated with geotechnical design criteria for creating restrictive flow boundaries, existence of natural geologic "capillary barriers" could enhance the low ground-water flux attributes for siting geologic repositories in the unsaturated zone. Hence, "a water table sufficiently below the underground facility such that fully saturated voids continuous with the water table do not encounter the underground facility" is another favorable hydrogeologic condition for the unsaturated zone identified in § 60.122(b)(8).

One major concern raised with respect to disposal of HLW in unsaturated geologic media is the current lack of scientific data on ground-water flow in deep unsaturated, fractured, geologic media. The principal hydrogeologic parameters which need to be characterized are: (1) water storage properties; (2) changes in water content and pressure; (3) rate of ground-water movement (i.e., flux); and (4) distribution and transport of contaminants. Techniques for measuring and monitoring these parameters have already been developed for unsaturated soils (e.g., Black et al., 1965; Bouma et al., 1974) and porous geologic media (e.g., Wilson, 1980). Therefore, the staff does not currently consider the present low level of scientific information on ground-water movement in deep unsaturated zones to be an insurmountable concern at this time.

II.b.2. Heat dissipation and temperature:

The ability of the host rock to dissipate heat generated by the waste packages is a primary concern in designing an underground facility (Wollenberg et al., 1983). Changes in the temperature of the host rock will have some

effect on all processes involved in isolating HLW (Kocher et al., 1983). Rapid heating of the host rock due to HLW emplacement could induce fractures, and hence, alter ground-water flow patterns (Donath, 1980). This could have a positive effect of enhancing free drainage. Slow heating could have the opposite effect of causing rock expansion and reduction of fracture apertures (Kocher et al., 1983). Therefore, to evaluate the thermomechanical response of the host rock to HLW emplacement, it will be necessary to determine the thermomechanical properties of a host rock (e.g., heat capacity, thermal conductivity and thermal expansion) as functions of temperature and degree of saturation (Wollenberg et al., 1983), and to determine the effects of thermally induced processes on the ability of the geologic repository to effectively contain and isolate the HLW for the required periods of time.

The thermal conductivity of a host rock is dependent upon physical parameters such as porosity, mineral composition, density and degree of saturation (water content). The relative ratio of water to air present in the pore spaces affects the thermal conductivity of the host rock since air is a relatively poor thermal conductor as compared to water (Wollenberg et al., 1983). The relatively low thermal conductivities of unsaturated materials compared to their saturated equivalents have been raised as a principal point of concern (National Academy of Sciences, 1983; Wollenberg et al., 1983). The bulk thermal conductivity will control the maximum temperature rise for a given waste form and thermal loading (Wollenberg et al., 1983). Low thermal conductivity values will result in a higher temperature rise in response to a given thermal loading. In contrast, liquid convection induced by heat is less likely to be a potential mechanism for transport of radionuclides from an underground facility within the unsaturated zone to the accessible environment (Wollenberg et al., 1983).

Wollenberg et al. (1983) point out that data on thermal expansion of unsaturated media are currently scarce, and that the increase in vapor pressure in response to heating and its ramification for radionuclide transport are presently not well understood. However, these authors also noted that the transport of latent heat by water vapor which is driven by temperature gradients can effectively increase heat transport through unsaturated geologic media, thereby reducing the temperature of the underground facility.

Mineralogical changes in the host rock may occur as a result of changes in temperature. For example, Lappin (1980) noted that welded tuff may experience contraction upon heating if the discontinuities (e.g., fractures) in the rock mass contain significant amounts of expandable clays or zeolites. Conversely, welded tuff containing cristobalite may undergo volumetric expansion due to phase inversion on heating to temperatures of 150-200°C (Wollenberg et al., 1983). Further, in some instances the permissible thermal loading of an underground facility may be seriously limited since clays and zeolites dewater at temperatures of 100°C under atmospheric pore pressure (National Academy of Sciences, 1983). If a shallower depth of waste emplacement and equal regional thermal gradients are assumed for disposal in the unsaturated zone than in the saturated zone, lower ambient temperatures should exist earlier in the life of an underground facility within the unsaturated zone (Wollenberg et al., 1983). Further, temperature rises in the underground facility also can be reduced by lowering thermal loading. This could be accomplished in several ways including extended surface storage of the waste (Donath, 1980; Wang et al., 1981) and increased canister spacing within the underground facility (Donath, 1980; Wollenberg et al., 1983). Heat also may be dissipated more readily from a geologic repository operations area by an appropriate choice of backfill material (Donath, 1980) and by an efficient ventilation system.

However, the relative benefits of maintaining a low temperature (approximately 100°C) in the unsaturated zone are currently being reconsidered by the NRC staff in light of continuing research on vapor phase transport. The possibility that a dry envelope could form around the waste packages and could effectively retard the migration of radionuclides by diverting the movement of ground water around the waste packages is currently under consideration by the staff.

The NRC staff expects that these and related issues would be addressed during site exploration and characterization of a candidate area containing a potential site within the unsaturated zone.

II.b.3. Geochemistry:

After permanent closure of a geologic repository, the immediate vicinity of the underground facility will be partially drained and will have an air pressure of approximately one atmosphere. The presence of air in pores and fractures of the host rock and any packing and backfill that might be used could promote non-reducing conditions in the underground facility. Unlike an underground facility in the saturated zone, an underground facility within the unsaturated zone could maintain non-reducing conditions and an air pressure of approximately one atmosphere throughout its lifetime because surface air can be connected with water and air at the horizon of the underground facility through open pores and fracture channels within the host rock.

As the temperature in the underground facility rises, it is probable that any ground water present in pores and fractures of the host rock increasingly will be converted to water vapor. Dissolved solids in the ground water can then be precipitated. Expansion of heated air plus water vapor probably will

cause air and water vapor to move away from the waste packages. Calculations by some authors (e.g., Preuss and Wang, 1984) suggest that over time, gaseous oxygen originally present in the underground facility might be purged entirely from the immediate vicinity of the waste packages. If emplaced HLW heats the surrounding environment above about 100°C, then liquid water will boil. At some distance from the waste packages, lower temperatures should allow condensation of escaping water vapor back into the liquid phase. The liquid water will tend to flow toward the waste packages due to capillary action (Preuss and Wang, 1984; Travis et al., 1984). This liquid water movement can cause redistribution of chemical elements in any packing and backfill materials present as well as in the host rock. Depending upon factors such as thermal loading, thermal conductivity, heat capacity, porosity, and the initial water content of the host rock and surrounding strata, a "dry zone" might develop around the waste packages.

Within the dry zone, hot, vapor-laden air could cause accelerated corrosion of the waste packages, forming metal oxides and hydroxides (Evans, 1937). Host rock, backfill, and packing materials might also be altered. For example, volcanic glasses can undergo devitrification and dehydration to form clays, zeolites, oxides, hydroxides, and secondary silicates (Levy, 1984) and hydrated mineral phases in the host rock, backfill, and packing (e.g., clays) might dehydrate and collapse (Singh, 1981; Allen et al., 1984). If a waste package is breached while surrounded by a dry zone, glass waste forms can alter principally via devitrification, surface hydration, and radiation damage (Bates and Steindler, 1983). Spent fuel might be subject to surface hydration and radiation damage. However, the only radionuclides that might be expected to migrate to the zone of higher water content at the edge of the dry zone are those either released as a gas or those which readily form gaseous compounds (Roseboom, 1983) (see also Section II.b.8 for further discussion).

The temperature within the geologic repository is expected to peak within a few hundred years of waste emplacement; as the temperature decreases, the volume of any dry zone will also decrease (Preuss and Wang, 1984; Travis et al., 1984). Returning liquid ground-water can react with previously altered minerals and redistributed chemical elements in the host rock, backfill, and packing, thereby changing ground-water chemistry. Solids which were precipitated during the formation of a dry zone could be redissolved by returning ground-water, thus increasing the ionic strength of the solutions. Reversibly dehydrated minerals along the path of returning ground-water might be rehydrated, so that the time elapsed before liquid water can reach the canisters could in part be delayed by mass balance considerations. However, experiments on mixtures of bentonite and sand have shown that even brief exposures to water vapor at temperatures above about 150°C can cause bentonite to lose swelling ability, with consequent increases in porosity and permeability (Couture, 1985).

Eventually liquid water might reach the waste packages. Some calculations suggest that during the final disappearance of a dry zone around the waste packages, the ground-water flux through the underground facility might temporarily increase (Travis et al., 1984). If metallic components have been armored by earlier corrosion products, then the ability of waste package materials to reduce the Eh of solutions might be compromised, and non-reducing conditions could exist even adjacent to the waste packages. High ionic strength solutions, especially under non-reducing conditions, could increase local corrosion rates (Uhlig, 1948) and add to the uncertainty in predicting waste package performance.

If liquid water reaches the waste form, radionuclides probably will be leached into the ground-water. Thermal, chemical, and electrical potential

gradients will be the driving forces for release of radionuclides from the waste packages (Carnahan, 1984). Radionuclide colloids could form during dissolution of the waste form, or by interactions between the waste package and released radionuclides, or by sorbing onto preexisting colloids in the ground water (Avogadro and de Marsily, 1984).

Ground water containing dissolved radionuclide species and radionuclide colloids might be forced to flow along mineral surface films in the unsaturated zone. This low water to rock ratio could provide increased opportunity for reaction between radionuclides and rock materials compared to radionuclide migration in the saturated zone. However, radionuclide solution species which form under non-reducing conditions might be more soluble and less retarded by interactions with packing, backfill, and host rock components, compared to species which form under reducing conditions (Burney and Harbour, 1974; Palmer and Meyer, 1981; Salter and Jacobs, 1982, Serne and Relyea, 1982; Torstenfelt and Allard, 1984). The concentration of a given radionuclide should be lowered along a flow path by hydrodynamic dispersion, filtration, precipitation and coprecipitation, ion exchange, chemical substitution, isotopic exchange, diffusion into pores (matrix diffusion), diffusion into solids (volume diffusion), and electrostatic attraction by mineral surfaces. As fluids migrate away from the geologic repository, cooler temperatures will generally cause reaction rates to be slower.

In sum, the NRC staff recognizes several positive geochemical aspects and possible concerns for high-level waste disposal in the unsaturated zone. Positive aspects include the overall low water content of the rocks, which could increase stability of the waste package and reduce corrosion. A dry zone may develop around the waste packages, also possibly enhancing the expected performance of the waste package materials; then, when the waste packages are

breached, the lack of liquid water to transport radionuclides could hinder radionuclide movement from the underground facility. If and when the waste form contacts liquid water, a low water flux through the repository would limit the release rate of the radionuclides. Contaminated ground water flowing through unsaturated rock would have a low water to rock ratio, thus maximizing interactions between radionuclides and rock components and enhancing the performance of geologic barriers. Matrix diffusion could be an especially important retardation process for fracture flow through porous unsaturated rocks (Ogard et al., 1984).

One probable concern related to HLW disposal in the unsaturated zone is ground-water conditions in the host rock which are not reducing. As with disposal in the saturated zone, corrosion rates of waste package materials may increase in a non-reducing environment. After a waste package is breached, radionuclides would tend to be more soluble and more mobile under non-reducing chemical conditions. Thus, NRC has modified § 60.122(c)(9) to identify ground-water conditions that are not reducing as a potentially adverse condition in both the saturated and the unsaturated zones. Another possible concern might be a temporary increase in the ground-water flux through the underground facility during the final disappearance of a dry zone. Alteration of bentonite packing material by water vapor at high temperatures may degrade swelling properties. Finally, irreversible dehydration of minerals such as clays and zeolites during the early, high temperature stage of the evolution of the geologic repository could cause collapse of these mineral structures and subsequent degradation of the engineering properties as well as the sorptive capacities of the geologic barriers.

II.b.4. Retrievability:

10 CFR Part 60 specifies that the design of a geologic repository must maintain the option of waste retrieval throughout the period during which the wastes are being emplaced and, thereafter, until the completion of a performance confirmation program and Commission review of the information obtained from such a program. Retrieval of the HLW could occur for any reason pertaining to the public health and safety, or the environment. The retrievability requirement does not imply ready or easy access to the emplaced waste at all times prior to permanent closure. NRC recognizes that a retrieval operation would be an unusual event, and could be a complicated and costly operation.

A geologic repository located in the unsaturated zone could be more accessible than a geologic repository located at the same depth in the saturated zone. The relatively dry nature of the rock in the unsaturated hydrogeologic zone could minimize, or eliminate, the need for dewatering operations. Further, if DOE selects a backfill plan similar to that discussed by Roseboom (1983) it could be easier to gain access to the waste packages in an underground facility within the unsaturated zone. Therefore, retrieval of waste packages from a geologic repository operations area in the unsaturated zone could be less complicated and expensive than in the saturated zone. However, additional evaluations of the complications and expenses involved in such retrieval operations must be evaluated on a case-by-case basis.

In connection with the issue of retrievability, the stability of underground openings must also be considered. Provisions of § 60.133(e) require that underground openings: (1) permit operations to be carried out safely,

(2) maintain the retrievability option, and (3) reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock (48 FR 28227). These provisions will apply to geologic repositories located within either hydrogeologic zone. Stability of underground openings depends primarily on the in situ stress and strength of the rock in the excavation areas. Stress magnitude and orientation in relation to the geometry of the excavation, and rock mass properties are the major factors which dictate the stability of an underground opening. Underground excavations can be located in either rock or unconsolidated alluvium.

Wollenberg et al. (1983) present a detailed discussion of the mechanical properties of alluvium and the relationship of these properties to repository construction. Two major factors influence the stability of underground openings in alluvium -- cementation (i.e., degree of induration) and the depth of the underground openings. These authors recognize that even relatively small amounts of cohesion can eliminate the need for immediate support provided by a shield, and significantly reduce permanent support pressures.

Wollenberg et al. (1983) further state that the depth at which stability problems will require the use of supports and/or reinforcements can be estimated from the compressive strength of the alluvium. Korbin and Brekke (1975) have found that significant stability problems do not occur until the overburden pressure exceeds twice the compressive strength. This has been estimated as ~210 m for alluvium by Wollenberg et al. (1983).

Based primarily upon results provided by Wollenberg et al. (1983) the NRC staff has concluded that it should be possible to maintain stable openings in both unsaturated alluvium and hard rock. Therefore, it should be possible to

maintain the retrievability option for a geologic repository located in the unsaturated zone.

II.b.5. Potential for exhumation of the radioactive waste by natural processes:

Continuous geologic processes and discrete geologic events acting at a given site will progressively change the present geologic environment over time (Kocher et al., 1983). Such geologic processes that may either singularly or in combination affect a geologic repository site include tectonism, seismic activity, erosion, glaciation, flooding, meteorite impact, intrusive magmatism and volcanism. Changes in the geologic environment could affect a site in two major ways--by affecting ground-water transport rates and pathways through the subsurface, and by possible exhumation of a geologic repository. Some of these processes (e.g., glaciation) might act to remove some of the surface covering from the geologic repository, while other processes (e.g., tectonism and seismic activity) might create discontinuities (i.e., fracture zones) that could create new pathways between the geologic repository and the accessible environment with shorter travel times or larger release rates. The concern of exhumation by natural processes will be site dependent, and thus, must be evaluated on a site-by-site basis.

II.b.6. Potential for exhumation of the radioactive waste by human intrusion:

In addition to the uncertainties associated with the performance of a geologic repository, there has been repeated concern over the uncertainty of future human behavior during the lifetime of a geologic repository. The question of human intrusion (whether inadvertent or deliberate) into a geologic

repository has received considerable attention from NRC during the development of 10 CFR Part 60. NRC views on this issue are discussed in detail at 46 FR 35282-35283 and 48 FR 28199.

Human intrusion into a geologic repository within the unsaturated zone may be more likely than into one within the saturated zone, if it is located at a significantly shallower depth than a geologic repository within the saturated zone. This may not necessarily be the case at potential sites where a thick unsaturated zone exists.

With respect to a possible influx of ground water that may occur if a geologic repository were reopened, Roseboom (1983) believes there would be virtually no effect on a geologic repository in the unsaturated zone because of an assumed arid to semi-arid climate with very small net recharge, as well as the negative water pressure and the low ground-water flux through the unsaturated zone.

Throughout the development of the technical criteria for 10 CFR Part 60, the question of future development of potential resources at the site of a geologic repository has been closely linked to the issue of human intrusion (48 FR 28199). NRC has expressed the view that selection of a site with no forseeably valuable resources could so reduce the likelihood of human intrusion as to reduce, or eliminate, any further need for it to be considered. Potential future development of resources at the site of a geologic repository would therefore be of corcern regardless of whether the site was situated in either the saturated or the unsaturated zone. Further, it is possible that the unsaturated zone could be penetrated if underlying rock units contain a valuable natural resource (e.g., minerals, petroleum, or even potable water in arid regions). The potential for future development of resources is clearly a site-dependent issue that necessarily must be evaluated on a case-by-case

basis, regardless of whether the potential site is in the unsaturated zone or the saturated zone.

II.b.7. Effects of future climatic changes on the level of the regi al water table:

The impacts of climatic changes upon the earth's hydrologic cycle have been well documented in the geologic record. Major global climatic changes have resulted in the waning and waxing of glaciers, fluctuations in sea level and the expansion and drying of pluvial lakes (Flint, 1971). Short term (10^1 - 10^2 years) climatic changes, although important, might not constitute a major concern to the siting of a geologic repository. However, longer-period (10^3 - 10^4 years) climatic changes, as well as their potential driving mechanisms, encompass time spans over which the components of the geologic repository must function effectively to isolate HLW from the accessible environment. For example, the present Holocene Epoch is one in a series of relatively brief (7×10^3 to 2×10^4 years) interglacial periods within much longer periods of glaciation (Wright, 1972; Broecker and Van Donk, 1970), while possible driving mechanisms such as the obliquity of the earth's axis and the precession of the equinoxes have cycles of $\sim 4.1 \times 10^4$ and $\sim 2.1 \times 10^4$ yrs, respectively (Broecker, 1968; Hays et al., 1976). Therefore, the long-term environmental stability of the site and the impact of future climatic changes need to be considered in designing the geologic repository to assure long-term integrity of the geologic repository system.

The effects of a major climatic change on the hydrology of the earth's surface could be profound (Kocher et al., 1983). For example, global sea level dropped over 100 m during a previous glaciation (Imbrie and Imbrie, 1979).

Kocher et al. (1983) noted that a worldwide heating (e.g., via the greenhouse effect) also could have important climatic consequences. While climatic change has long been recognized as a factor to be considered in siting a geologic repository within the saturated zone, it may assume even greater importance when applied to a geologic repository within the unsaturated zone.

Any climatic change which results in increased precipitation with subsequent higher net infiltration and ground-water recharge can cause a rise in the regional water table. A rise in the regional water table might reduce the ground-water flow path from the geologic repository to the accessible environment. A corresponding increase in recharge could result in increased ground-water velocity and hence shorter residence times for dissolved radionuclides. During a pluvial period, increased ground-water recharge could allow more frequent water/waste contact, thereby increasing the probability of canister corrosion and leaching of the waste (Wollenberg et al., 1983). Increased precipitation could produce local perched water tables with increased lateral water movement above the more impermeable zones. These conditions could create locally saturated conditions, and hence, large recharge (moisture) fluxes. Finally, gross changes in sea levels, related to climatic changes which affect the cryosphere, could produce a new drainage stream base level with commensurate changes to both regional water tables and discharge points.

It is possible for scientists to postulate future climatic conditions based upon paleoclimatic reconstructions for a specific area using geologic and biologic evidence. Techniques used in such reconstructions include, but are not limited to, the study of strand lines which mark the stillstands of former lakes (e.g., Russell, 1885; Meinzer, 1922; Malde, 1968), records of the $^{18}O/^{16}O$ ratio in continental ice sheets (Dansgaard et al., 1971), analysis of paleodistribution of floral and faunal species, investigations of fossil seeds

and spores in packrat middens (Van Devender and Spaulding, 1979); and tree ring analyses (Smith and Stockton, 1981). Kocher et al. (1983) noted that although effects of previous glaciations on surface land forms are readily observable, evidence of the effects of glaciation at depth is much more difficult to obtain. These authors believed that ground-water age dating might allow estimates to be made of changes in ground-water flow rates or flow directions which coincided with previous glacial/interglacial cycles. If it can be shown that such changes are not significant, then the effects of future glaciation on ground-water flow at depth reasonably may be ignored (Kocher et al., 1983).

The NRC staff believes that a carefully designed geologic repository would not necessarily be affected adversely by cyclical climatic changes. As Wollenberg et al. (1983) noted, certain regions prone to development of local perched water tables (e.g., past locations of playa lakes) obviously should be avoided. The effects of climatic changes on arid and semi-arid regions might not contribute significantly to the net amount of ground-water flux such that the isolation capability of the geologic repository would be compromised. The potential thickness of the unsaturated zone in arid regions could allow designers to compensate for any predictable rise in the regional water table during pluvial periods by locating the geologic repository well above the predicted maximum water table level, and well below any periodic perched water tables. This consideration along with the consideration discussed in Section II.b.1 supports the NRC decision to identify "a water table sufficiently below the underground facility such that fully saturated voids continuous with the water table do not encounter the underground facility" as a favorable condition in 60.122(b)(8).

II.b.8. Radionuclide transport in the gaseous state:

As stated in Section II.b.3., the unsaturated geologic media surrounding the underground facility will be partially drained and will possess connected air-filled pores which can form potential pathways for gaseous movement. Any "dry zone" formed by the elevated temperatures in the immediate vicinity of the underground facility might increase the capacity of that zone to transmit gases. Radionuclides in the gaseous state could move from the underground facility through air-filled pore spaces in the surrounding host rock.

The issue of radionuclide transport in the gaseous state is a relatively new waste management issue that has developed from recent scientific investigations of the feasibility of HLW disposal in unsaturated geologic media. Because most of the investigations were only recently initiated, the issue of radionuclide transport in the gaseous state from a HLW underground facility has not as yet been examined in any great detail by the scientific community.

Radionuclides in waste with significant vapor pressures are tritium, krypton-85, carbon-14 (as carbon dioxide, methane, or other gaseous compounds), and iodine-129 (Hamilton et al., 1976), with half-lives of 12.26 years, 10.76 years, 5730 years, and 1.7×10^7 years, respectively. Of these radionuclides, iodine-129 is recognized by Roseboom (1983) as being of primary concern because of its high vapor pressure and long half-life. Other radionuclides, including those with very low vapor pressures, may move within aerosol-size particles of ground water through an unsaturated geologic medium (Green and Evans, 1985), but the significance of this transport mechanism has not yet been established.

Transport of radionuclides in the gaseous state can occur primarily by two processes: convection and molecular diffusion. Convection may occur because of the thermal cells developed in the non-isothermal field around the

underground facility. Radionuclide convective flux and spatial distribution will depend upon the specific radionuclide concentration and release rate at the source, the transient temperature distributions, the air permeability of the geologic medium, the viscosity of the air, the sorptive capacity of the geologic medium, and a geometric design factor. Molecular diffusion of gaseous radionuclides can be a combination of ordinary diffusion (concentration gradient driven), forced diffusion due to an electric field established around the waste, and thermal diffusion resulting from non-isothermal conditions (Green and Evans, 1985). The three types of diffusive flux can be additive and each component will depend primarily upon the same factors as indicated above for convection, with the exception that air permeability is replaced by effective diffusion coefficients. Additionally, forced diffusion flux will depend upon the electrical field strength surrounding the waste. All of these factors are site and engineering design specific.

Ordinary diffusion is likely to be the most significant type of gaseous diffusion in an unsaturated geologic setting. It is a process in which a molecular constituent in a gaseous mixture moves under the influence of a concentration gradient. Under isothermal conditions, the diffusive flux is proportional to the concentration gradient. The proportionality parameter (diffusion coefficient) is a function of the properties of the gases and the prevailing temperature and pressure. Slattery and Bird (1958) presented an expression for the calculation of the diffusion coefficient of a dilute, nonpolar gas at low pressure in a binary system. The expression was based on kinetic theory and included the critical temperature and pressure of the two gases as well as two constants which must be obtained experimentally. Green and Evans (1985) showed that for hydrogen, methane, carbon dioxide, krypton, and iodine, the diffusion coefficients increase monotonically by a factor of 2

to 3 as temperature is increased from 30 to 250°C, and that the coefficients are inversely related to pressure.

The diffusion coefficients discussed above apply to diffusion through open spaces such as drained fractures, boreholes and shafts in consolidated rock. For diffusion through a rock matrix or granular material, an effective diffusion coefficient is used which depends upon the percentage of the rock volume that is air-filled pore space and the tortuosity of the pathways as well as the partitioning coefficients between gas and liquid and between liquid and solid. A generalized equation for ordinary diffusion through a partially saturated porous medium is given by Weeks et al. (1982) from which an effective diffusion coefficient can be defined mathematically.

Diffusive flux by forced diffusion could be insignificant when compared to ordinary diffusion. However, it should be recognized that gamma radiation emitted during the decay of HLW can create an electric current by Compton scattered electrons. The magnitude of the developed electric field is related to the current density and the resistivity of the medium. Electrically charged molecules and atoms in the gaseous phase and charged aerosol particles will respond to the electric field. The average range of a gamma ray in air is at most a few meters and is much less in liquids and solids. Therefore, forced diffusion may be important only in the immediate vicinity of the waste package.

Thermal diffusion of gaseous radionuclides could also be important close to the waste package. This type of diffusion can take place without a concentration gradient or a force field, in the presence of a temperature gradient. The thermal diffusive flux is proportional to the gradient of the logarithm of the temperature. As noted previously, temperature gradients are expected to exist in the vicinity of an underground facility for very long time periods.

An analysis of radionuclide transport in the gaseous phase should include consideration of the several related processes adjacent to the waste package as well as on a larger scale. Radionuclide transport in the gaseous phase may be effective in bridging a "dry zone" surrounding the emplaced waste packages, thus providing a mechanism whereby radionuclides can migrate to the zone of condensation (wetter region). Within the wetter zone, subsequent solution and downward transport of radionuclides with moving ground water may be more rapid than it would be if the geologic medium were at its initial water content. This could result in a shorter travel time for the movement of some radionuclides.

A larger scale situation may involve radionuclide transport in the gaseous state from the underground facility to the accessible environment, probably upward toward the land surface. Diffusive and convective flux of radionuclides could be through open natural or man-made channels and also through the unsaturated rock matrix.

Radionuclide transport in the gaseous state may not necessarily be a potentially adverse condition but, given the fact that gaseous state transport could provide a realistic mechanism for radionuclide transport from an underground facility within an unsaturated zone, the NRC staff prefers to retain the opportunity to evaluate whether or not radionuclide transport in the gaseous state could adversely affect a geologic repository system. To that end, the potential for gaseous state transport of radionuclides from the underground facility to the accessible environment is identified as a potentially adverse condition in the amendments to 10 CFR Part 60 (§ 60.122(c)(24)). NRC has not yet reached any conclusions on the issue of radionuclide transport in the gaseous state as a significant mechanism for radionuclide migration from the

underground facility but rather is currently sponsoring research on processes in unsaturated rock in an effort to better understand the subject.

For an underground facility located in the saturated zone, a temporary, localized, unsaturated region could form around the facility as a result of activities related to construction and operation of a geologic repository operations area (e.g., dewatering of shafts and drifts). To date, the issue of gaseous state transport of radionuclides has not been raised for a geologic repository system within the saturated zone primarily because in this case the localized unsaturated region could be expected to be encompassed within a much larger saturated region. Further, it is anticipated that the time required for waste package integrity (300 to 1000 yrs) will generally exceed the post-closure time required for resaturation of the underground facility (assumed by the NRC staff to occur within a few hundred years following permanent closure). Therefore, the NRC staff does not consider it necessary at this time to identify gaseous state transport as a potentially adverse condition for high-level waste disposal within the saturated zone. However, if future research in the area of gaseous transport challenges these current assumptions, the staff may recommend that NRC broaden the provision of § 60.122(c)(24) to include both the saturated and the unsaturated zones.

III. REVIEW OF NRC REGULATIONS

III.a. Background:

Prior to developing amendments to 10 CFR Part 60 specifically related to HLW disposal in unsaturated geologic media, the NRC staff reviewed the final technical criteria published in June 1983 to determine which provisions of the

existing rule were equally applicable to HLW disposal within either the saturated or the unsaturated zone. The final technical criteria were generic in nature, and most provisions applied regardless of the hydrogeologic zone in which a geologic repository might be located. Many of the issues discussed in Chapter II already are addressed in the final technical criteria since they pertain to the saturated zone as well as to the unsaturated zone. For example, the siting criteria of § 60.122 (48 FR 28225) identify favorable and potentially adverse natural conditions. These provisions address among other items: the nature and rates of tectonic, hydrogeologic, geochemical and geomorphic processes; structural deformation; igneous activity; and seismicity. These provisions, as currently written, can be applied equally to sites within the unsaturated zone. Similarly, human activity, a possible concern regardless of hydrogeologic zone, is addressed in the provisions of § 60.122.

III.b. Amendments to 10 CFR Part 60:

The issue of whether NRC regulations should address considerations relevant to the disposal of HLW in all geologic repositories regardless of whether the site was situated in the unsaturated zone or the saturated zone was initially raised in 1981. In the statement of considerations to the proposed technical criteria published for public comment on July 8, 1981 NRC explained that the proposed criteria were developed for disposal in saturated geologic media since the then-current DOE plans called for HLW disposal at sufficient depth to lie within that portion of the hydrogeologic regime termed the saturated zone (46 FR 35281). NRC further noted that additional or alternative criteria may need to be developed for regulating HLW disposal in the unsaturated zone. Several commenters on the proposed technical criteria criticized this approach

on the bases that disposal in the unsaturated zone was a viable alternative and that since the technical criteria were generally applicable without regard to the possibility of saturation, their scope and applicability should not be unduly restricted. NRC reviewed the technical criteria in light of these public comments and found this criticism to be well founded. In the statement of considerations to the final technical criteria promulgated in June 1983, NRC recognized that although the final technical criteria are generally appropriate to disposal in both the saturated and the unsaturated zones, certain distinctions were needed (48 FR 28203). Rather than promulgating the specific technical criteria which would apply to the unsaturated zone at the time the final technical criteria were promulgated in June 1983, NRC preferred to issue such criteria in proposed form to afford further opportunity for public comment. NRC published proposed amendments to 10 CFR Part 60 specifically related to HLW disposal within the unsaturated zone on February 16, 1984 (49 FR 5934). As mentioned in Chapter I, NRC received fourteen comment letters on these proposed amendments. These comment letters were considered by the NRC staff during the development of the final amendments and resulted both in the addition of new amendments and in the modification of existing amendments for the sake of technical accuracy. These changes, with differences between the proposed and final amendments shown in comparative text, are discussed below.

III.b.1 Definitions:

The terms "ground water" and "unsaturated zone" have been added to § 60.2 Definitions as follows:

"Ground water" means all water which occurs below the land [Earth's] surface.

"Unsaturated zone" means the zone between the land surface and the regional [deepest] water table. Generally, fluid pressure [water] in this zone is [under] less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies the [water] fluid pressure locally may be greater than atmospheric.

In the proposed amendments to 10 CFR Part 60 NRC defined the term "ground water" as "all water which occurs below the Earth's surface." Although some commenters on the proposed amendments commended NRC for proposing this definition other commenters expressed the view that NRC should restrict the use of the term "ground water" to the saturated zone. Although limiting the term "ground water" to water within the saturated zone currently might be a more widely accepted practice than applying it to all water below the Earth's surface, NRC notes that at present no unique definition of "ground water" appears to be universally accepted in the technical community. The NRC staff notes that no definition of this term was provided in U.S. Geological Survey Water Supply Paper 1988 (Lohman et al., 1972). However, in the Glossary of U.S. Geological Survey Water - Supply Paper 2250 (U.S. Geological Survey, 1983) the following definition of "Ground water" is included:

> "In the broadest sense, all subsurface water, as distinct from surface water; as more commonly used, that part of the subsurface water in the saturated zone." (p. 240).

Therefore, NRC has not actually redefined the term as one commenter suggested but rather has adopted one of the more commonly used definitions of "ground water" to effectively apply the provisions of 10 CFR Part 60 to the regulation of HLW disposal within unsaturated as well as saturated geologic media. Similarly, the terms, "hydrogeologic unit", "hydrogeologic properties", and

"hydrogeologic conditions" refer to units, properties and conditions in either the saturated or unsaturated zone. One minor change has been made to the wording of the definition of ground water -- the phrase "Earth's surface" has been replaced by "land surface" for the sake of technical clarity and for consistency with the wording of the definition of "unsaturated zone."

The proposed definition of "unsaturated zone" was derived from USGS Water-Supply Paper 1988 (Lohman et al., 1972). Two commenters on the proposed amendments stated that the phrase "deepest water table" introduced confusion into the definition of the term "unsaturated zone" (§ 60.2). NRC had inferred that the phrase "deepest water table" as used by the USGS referred to the regional water table and hence adopted this same phraseology in its proposed definition. In light of the confusion expressed by commenters, possibly due in part to an incorrect inference by some that the phrase "deepest water table" referred to local rather than regional water tables, the definition of the term "unsaturated zone" was modified in the final amendments. For the sake of technical clarity the phrase "deepest water table" was replaced by "regional water table," and the phrase "water in this zone is under less than atmospheric pressure" was rewritten as "fluid pressure in this zone is less than atmospheric pressure."

III.b.2 <u>Siting criteria</u>:

The siting criteria of § 60.122 contain provisions for favorable and potentially adverse conditions which may exist at a potential site for a geologic repository. The majority of the provisions set forth at § 60.122 are equally applicable both to the saturated and unsaturated zones. However, given

the natural differences between these two hydrogeologic regimes, it is necessary to differentiate between certain favorable and potentially adverse hydrogeologic conditions for each zone. The final technical criteria promulgated in June, 1983 contained favorable and potentially adverse conditions that are generally applicable without regard to the hydrogeologic zone under consideration as well as specific hydrogeologic conditions for HLW disposal within the saturated zone. In reviewing the favorable hydrogeologic conditions for the saturated zone contained in the final rule, the NRC staff recognized that paragraph 60.122(b)(2)(iv) which was related to pre-waste-emplacement ground-water travel time could apply equally to the unsaturated zone. Therefore, this provision was removed from § 60.122(b)(2) which contained hydrogeologic conditions specifically related to the saturated zone and renumbered as new paragraph 60.122(b)(7). It should be noted that the provisions of § 60.122(b)(2)(iii) specifically relate to hydrogeologic conditions of the saturated zone, <u>not</u> the unsaturated zone. This paragraph was included in the proposed amendments because it was necessary to delete the disjunctive between § 60.122(b)(2)(iii) and (iv) when as discussed above § 60.122(b)(2)(iv) was renumbered as § 60.122(b)(7). Further, NRC has modified the wording of § 60.122(b)(2)(iii) for the sake of technical clarity as suggested by a commenter on the proposed amendments. These provisions now read as follows:

§ 60.122(b)(2)(iii) Low vertical permeability and low hydraulic [**potential**] <u>gradient</u> between the host rock and the surrounding hydrogeologic units.

§ 60.122(b)(7) Pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment that substantially exceeds 1,000 years.

A new paragraph 60.122(b)(8) was added to the provisions of 10 CFR Part 60 to identify favorable hydrogeologic conditions that may exist at a site in the unsaturated zone. The provisions of this new paragraph as set forth in the final amendments read as follows:

§ 60.122(b)(8) "For disposal in the unsaturated zone, hydrogeologic conditions that provide--

(i) Low [~~and nearly constant~~] moisture flux in the host rock and in the overlying and underlying hydrogeologic units;

(ii) A water table sufficiently below the underground facility such that fully saturated voids continuous with the water table do not encounter the underground facility;

(iii) A laterally extensive low-permeability hydrogeologic unit above the host rock that would inhibit the downward movement of water or divert downward moving water to a location beyond the limits of the underground facility;

(iv) A host rock that provides for free drainage; or

(v) A climatic regime in which the average annual historic precipitation is a small percentage of the average annual potential evapotranspiration.

The NRC staff originally identified the favorable hydrogeologic conditions presented in § 60.122(b)(8)(i)-(v) for the following reasons:

(i) low moisture flux in the host rock and surrounding hydrogeologic units resulting from very low ground-water fluxes (i.e., little or virtually no outflow to deeper systems) would likely result in little solute transport because (a) there would be little water contact with, and hence, little leaching of the waste packages and (b) the moisture flux would provide for a small water gradient to induce movement of what little water content was available, except by gravity drainage. (See Section II.b.1 for further discussion);

(ii) in the event of both short- and long-term fluctuations of water table levels, fully saturated pores continuous with the water table would not encounter the underground facility, providing additional assurance that the rate of leaching of radionuclides from the waste packages would not be altered significantly. (See Sections II.b.1 and II.b.7 for further discussion);

(iii) inhibition or diversion of downward movement of water would minimize the potential for significant leaching of radionuclides from failed waste packages. (See Sections II.b.3 and II.b.7 for further discussion);

(iv) a freely-drained host rock would promote low moisture content around the waste packages, thus decreasing the amount of water available to corrode the waste packages, leach radionuclides from the waste and transport radionuclides away from the underground facility. (See Section II.b.1 for further discussion); and

(v) in arid zone environments, low amounts of precipitation will result in low recharge flux. (See Sections II.b.1 and II.b.7 for further discussion.)

In addition to the favorable conditions discussed above, the NRC staff identified three potentially adverse conditions that could exist at a site in the unsaturated zone in the proposed amendments. These new paragraphs 60.122(c)(22), (23) and (24) are additions to the existing provisions of § 60.122(c). Further, NRC has modified § 60.122(c)(9) as suggested by one commenter on the proposed amendments so that the provision is now equally applicable to both the saturated and the unsaturated zone. These potentially adverse conditions read as follows:

60.122(c)(9) [For-disposal-in-the-saturated-zone;] Ground-water conditions in the host rock that are not reducing.

60.122(c)(22) Potential for the water table to rise sufficiently so as to cause saturation of an underground facility located in the unsaturated zone.

60.122(c)(23) Potential for existing or future perched water bodies that may [have-the-effect-of-saturating] saturate portions of the underground facility or [providing] provide a faster flow path [for-radionuclide-movement] from an underground facility located in the unsaturated zone to the accessible environment.

60.122(c)(24) Potential for [vapor-transport-of-radionuclides-from-the-underground-facility-located-in-the-unsaturated-zone] the movement of radionuclides

in a gaseous state through air-filled pore spaces of an unsaturated geologic medium to the accessible environment.

The presence of ground-water conditions in the host rock that are not reducing has been identified in the final amendments as a potentially adverse conditions for HLW disposal in either the saturated or the unsaturated zone. Previously, this provision (§ 60.122(c)(9)) was applicable solely to disposal in the saturated zone (48 FR 28225). Following consideration of comments on this provision, the NRC staff suggested that § 60.122(c)(9) be modified as discussed above. The staff's rationale for suggesting this amendment is based on the fact that corrosion rates of waste package materials may increase in a non-reducing environment. Further, if a waste package is breached, radionuclides would tend to be more soluble and more mobile under non-reducing geochemical conditions.

With respect to the potentially adverse condition set forth in § 60.122(c)(22), the NRC staff assumes that the design for an underground facility located in the unsaturated zone can be quite different from one in the saturated zone, given the variation in hydrogeologic, geochemical and thermal properties between the two hydrogeologic zones. Therefore, any condition that could cause a rise in the level of the water table, and hence, possibly result in the saturation of an underground facility within the unsaturated zone could potentially affect the integrity of a geologic repository that was not originally designed for saturated conditions.

The NRC staff identified the presence of existing or future perched water bodies as a potentially adverse condition in the unsaturated zone (§ 60.122(c)(23)) because it may be possible for contaminated gas or ground

water to diffuse into the rock surrounding the underground facility. If this contaminated gas or ground water encountered a perched water body it could be transported horizontally. If this horizontal movement shortened the flow path to the accessible environment, the geologic repository system might not meet the performance objectives of 10 CFR Part 60. Minor word changes were made to clarify the intent of this provision.

During the development of the proposed amendments the staff identified vapor transport of contaminants as a potential concern associated with HLW disposal in the unsaturated zone. NRC noted at 47 FR 5935 that in unsaturated geologic media, water is transported in both liquid and vapor phases. The relative contribution of transport via both these phases and their direction of movement with respect to a geologic repository was deemed to directly influence the containment of contaminants. The comments received on the discussion of vapor transport at 49 FR 5935 and on the wording of the proposed amendment--§ 60.122(c)(24) indicated a need for the NRC staff to clarify its intent with respect to vapor transport.

Vapor formation may not necessarily be a potentially adverse condition but, given the fact that vapor transport could provide a realistic mechanism for radionuclide transport within the unsaturated zone, NRC wanted the opportunity to evaluate whether or not vapor transport could adversely affect a geologic repository system. To that end the potential for vapor transport of radionuclides from an underground facility located in the unsaturated zone to the accessible environment was identified as a potentially adverse condition in the proposed amendments (§ 60.122(c)(24)). NRC has not reached any conclusions on vapor transport as one commenter on the proposed amendments incorrectly inferred, but rather is currently sponsoring research on vapor phase transport in unsaturated fractured rock in an effort to better understand this subject.

Some confusion was expressed by the commenters with respect to the use of the term "vapor transport" in the proposed amendments and draft NUREG-1046. In particular, one commenter stated that § 60.122(c)(24), as written, was ambiguous and meaningless and could, under certain conditions, be applied to any geologic repository site. The term "vapor transport" as used in the proposed amendments referred to both water vapor and the gaseous state of some constituent contaminants. A second commenter on this issue suggested that quantitative clarifications be added to this provision since the proposed wording allowed no potential vapor transport of radionuclides by molecular diffusion (i.e., the process whereby solutes are transported at the microscopic level due to variations in tracer concentrations within the liquid phase) or convective transport (i.e., heat transported along with flowing ground water). The same commenter noted that while the flux values associated with these two transport processes might be miniscule, they would not be zero at any unsaturated site. NRC did not consider it appropriate to add quantitative clarifications to the final provisions of § 60.122(c)(24) as suggested by a commenter because the movement of radionuclides in the gaseous state is, to a large extent, dependent on site- and design-specific parameters. However, to alleviate the confusion surrounding proposed § 60.122(c)(24), the wording of this provision was modified extensively in the final amendments. Reference to vapor transport was deleted, and this provision now identifies the potential for the movement of radionuclides in a gaseous state through air-filled pore spaces of an unsaturated geologic medium to the accessible environment as a potentially adverse condition. The NRC staff believes the revised wording will more accurately convey its original intent and should remove any ambiguity associated with the previous wording, such as one commenter's query of where the vapor transport is occurring and when it is important.

III.b.3 Design Criteria for the Geologic Repository Operations Area

Sections 60.131 through 60.134 specify minimum criteria for the design of the geologic repository operations area (48 FR 28225-28227). During the development of the proposed amendments to 10 CFR 60 specifically related to the unsaturated zone, the NRC staff reviewed the provisions of the design criteria set forth by the final rule and concluded that no changes were necessary to ensure that the design criteria were equally applicable to both the saturated and the unsaturated zone. The bases for this conclusion were provided at 49 FR 5935-5936. One commenter on the proposed amendments pointed out that the wording of § 60.133(f) and § 60.134(b) served to limit the potential for creating a preferential pathway. However, as this commenter noted, a perferential ground-water pathway may be preferred to allow for a freely draining host rock. As an example, this commenter stated that it might be desirable to have a preferential pathway for ground water from an overlying unit where the ground water may tend to perch naturally to an underlying unit or completely through the underground facility horizon to an underlying permeable zone.

III.c. Other issues reviewed by the NRC staff:

In addition to those issues relating to disposal of HLW within the unsaturated zone which provided the bases for the development of the proposed amendments presented in the previous section, several other issues were reviewed by the staff. Some of these issues were identified by public commenters on the proposed 10 CFR Part 60 technical criteria. A more detailed discussion of most of these issues was presented by Roseboom (1983) and it is primarily his paper

that forms the basis of the following discussion. The staff believes that it is useful to review these issues although they resulted in no changes to the amendments.

III.c.1. Minimum 300 meter depth for waste emplacement:

One commenter on the proposed 10 CFR Part 60 technical criteria (July, 1981) advocated applying the rule equally to both the saturated and the unsaturated zones because he considered it necessary to change the siting criterion which set a minimum depth of 300 meters for waste emplacement. However, the commenter incorrectly identified this provision (see § 60.122(b)) as a requirement rather than as a favorable condition. Hence, a minimum depth of 300 meters for waste emplacement is considered a favorable condition because the deeper the HLW is emplaced below the land surface the less likely it is to be disturbed. In that light such depth is a favorable condition irrespective of hydrogeologic zone. Since, as noted earlier the unsaturated zone may extend to depths of up to 600 meters in certain arid regions of the United States, the staff believes that this favorable condition is a realistic one for both the saturated and unsaturated zones. Therefore, this provision of the technical criteria has not been modified.

III.c.2. Exploratory boreholes:

Provisions relating to site characterization are set forth in the final rule at § 60.10 (48 FR 28219). Existing paragraph 60.10(d)(2) requires that the number of exploratory boreholes and shafts be limited to the extent practical consistent with obtaining the information needed for site characterization. Although he recognized the importance of exploring potential sites in

the saturated zone with as few drill holes as possible, Roseboom (1983) stated that in the unsaturated zone, if the host rock already had a high vertical permeability, there was no reason to limit the number of drill holes. Thus, Roseboom noted that if necessary, a proposed geologic repository could be explored like an ore body or coal bed, with drill holes every few hundred feet on a rectangular grid.

The Commission's view on the importance of not compromising the integrity of a site during the site characterization program of testing and exploration was stated clearly at 44 FR 70409. However, if DOE should opt for a site exploration and characterization program which includes plans for drilling numerous boreholes then DOE would have the burden of showing that the ability of the site to isolate HLW has not been compromised during these activities.

III.c.3. Backfill requirements:

Another issue which has been raised pertains to the necessity of backfill in a geologic repository located within the unsaturated zone. Roseboom (1983) believes that the role of backfill in the unsaturated zone would be the opposite of that in the saturated zone. Backfill material with high sorption that would serve to inhibit the flow of water to, and from, the waste packages may be highly desirable in the saturated zone. In the unsaturated zone, however, the designers of a geologic repository might wish to promote drainage. Roseboom (1983) stated that within the unsaturated zone, backfill should allow ground water to drain readily, rather than serve to impede drainage, and possibly cause local ponding. He further presented the argument that if the use of backfill is desired to retard radionuclide migration, it would only be effective if placed at or below the canister level since contaminated water

would move downward. Winograd, as cited in Roseboom (1983), suggested that if backfill were necessary to preserve structural or waste package integrity, a relatively permeable material (e.g., cobble-sized rock) could be used to enhance drainage.

Proposed 10 CFR Part 60 technical criteria (published for public comment in July 1981) contained design criteria for the underground facility (including backfill materials) (46 FR 35292-35293).

After careful consideration of the public comments received on proposed § 60.132, the staff concluded that the approach of specifying several design requirements for the engineered system (including backfill and barriers at shafts) would be unduly restrictive. Therefore, the final technical criteria contain only the general functional statement that the engineered barriers be designed to assist the geologic setting in meeting the performance objectives for the period following permanent closure (§ 60.133(h), 48 FR 28277).

III.c.4. Waste package design criteria:

As defined at § 60.2, the term "waste package" means "the waste form and any containers, shielding, packing and other absorbent materials immediately surrounding an individual waste container" (48 FR 28219). The point has been raised that because of the different nature of the emplacement environment, designs of waste package components for the saturated and unsaturated zones may be quite different. The NRC staff recognizes that several characteristics of the emplacement environment (e.g., oxidation conditions, lithostatic pressure, geochemistry, contact with ground water, etc.) may vary significantly between the two hydrogeologic zones. This variation of emplacement environment may

necessitate that DOE consider alternative designs for waste packages (including waste form, canisters, overpack, etc.) for geologic disposal in the unsaturated zone. However, 10 CFR Part 60 allows flexibility in developing and selecting any waste package that will meet the performance objectives.

The NRC staff has reviewed the performance objectives which pertain to the waste package (§ 60.111 and § 60.113), and believes that the provisions, as currently written, are equally applicable to waste packages emplaced within either the saturated or unsaturated zone. Similarly, the specific design criteria for the waste package and its components (§ 60.135, 48 FR 28227) have been determined to be generally applicable to both zones. Therefore, no changes have been made to §§ 60.111, 60.113 or 60.135.

III.c.5. Provisions for ventilation:

Roseboom (1983) addressed the issue of restricting the number of ventilation shafts associated with a geologic repository. In the case of the saturated zone, the number of ventilation shafts may be kept at a minimum since the shafts could constitute potential pathways to the accessible environment. In the unsaturated zone, Roseboom (1983) stated that additional shafts for ventilation would not compromise the geologic repository's performance because sealing shafts in the unsaturated zone is much simpler and of less consequence than in the saturated zone. Roseboom cited several potential benefits associated with an increased number of ventilation shafts -- reducing the problem of thermal load in the early phases of the geologic repository, removal of any water vapor during the operational period, drawing large amounts of desert air through the geologic repository to promote even drier conditions and increasing worker safety by providing alternate sources of ventilation and escape in

emergencies. Hammond (1979) noted that an air-cooled repository need not be designed to bear the load of thermally induced stresses placed on a repository where waste is tightly emplaced and buried in backfill.

The number of ventilation shafts included in any geologic repository will be decided by the designer -- DOE. No provision of 10 CFR Part 60 expressly limits the number of ventilation shafts that a geologic repository may contain. What is important is that surface facility ventilation systems comply with the design criteria in 60.132(b) (48 FR 28226) and the underground facility ventilation system be designed in accordance with § 60.133(g) (48 FR 28227). The NRC staff considers the design requirements for the ventilation systems set forth in §§ 60.132 and 60.133 to be reasonable and applicable to both the saturated and unsaturated zones. As long as the ventilation system complies with provisions of §§ 60.111, 60.132 and 60.133, and does not compromise the integrity of the site to host a geologic repository, DOE will have broad flexibility in designing the system. Therefore, the staff does not consider it necessary to amend the provisions of the final technical criteria pertaining to the design of a ventilation system for a geologic repository.

IV. CONCLUSIONS

The NRC staff has concluded that carefully sited and designed geologic repositories in the unsaturated zone can meet the provisions of 10 CFR Part 60 with the addition of the amendments at 50 FR 29641, as discussed in Chapter III. Several issues associated with disposal of HLW within the unsaturated zone have been examined, and positive aspects and possible concerns have been identified. In some instances, the possible concerns are generic in nature, and would apply to geologic repositories within either the saturated or unsaturated zone. As in the case of geologic repositories in the saturated zone, the favorable and potentially adverse conditions present at a site in the unsaturated zone must be evaluated on a case-by-case basis.

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APPENDIX

DEFINITIONS AND CONCEPTS

accessible environment means (1) the atmosphere, (2) the land surface, (3) surface water, (4) oceans, and (5) the portion of the lithosphere that is outside the controlled area. (U.S. NRC, 1983)

aquifer: A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs (Lohman et al., 1972)

aquitard: A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not readily yield water to wells or springs, but may serve as a storage unit for ground water. (American Geological Institute, 1980)

capillary fringe: The zone immediately above the water table in which all or some of the interstices are filled with water that is under less than atmospheric pressure and that is continuous with the water below the water table. The water is held above the water table by interfacial forces (for example, surface tension). The capillary fringe is typically saturated to some distance above its base at the water table; upward from the saturated part only progressively smaller pores are filled and the upper limit is indistinct. In some quantitative studies it is convenient to define the upper limit more or less arbitrarily.

conductivity, effective hydraulic [LT^{-1}]: The water flux under unit hydraulic head gradient through a porous medium that contains more than one fluid, such as water and air in the unsaturated zone.

conductivity, hydraulic, [LT^{-1}]: The water flux through a saturated porous medium under unit hydraulic head gradient.

engineered barrier system: The waste packages and the underground facility. (U.S. NRC, 1983)

flux, ground water: The quantity of ground-water flow per unit cross-sectional area per unit time.

gauge pressure: Pressure expressed as a difference from atmospheric pressure.

geologic repository: A system which is intended to be used for, or may be used for, the disposal of radioactive wastes in excavated geologic media. A geologic repository includes (1) the geologic repository operations area, and (2) the portion of the geologic setting that provides isolation of the radioactive wastes. (U.S. NRC, 1983)

geologic repository operations area: A high-level radioactive waste facility that is part of a geologic repository, including both surface and subsurface areas, where waste handling activities are conducted. (U.S. NRC, 1983).

ground water: All water which occurs below the land surface, including both the saturated and unsaturated zones. (modified after U.S. NRC, 1985)

ground water, perched: Unconfined ground water in a local saturated zone separated from the underlying regional water table by an unsaturated zone.

Perched ground water may be either (1) permanent, where recharge is frequent enough to maintain a local saturated zone above the restricting layer (aquitard) or (2) temporary, where intermittent recharge is not great or frequent enough to prevent the perched water from disappearing from time to time as a result of drainage over the edge of or through the restricting layer. NRC considers perched ground water to be part of the unsaturated zone (modified after Lohman et al., 1972).

ground-water recharge: The flux of water across a water table. (Wilson, 1980)

ground water, unconfined: Water in an aquifer that has a water table. (Lohman et al., 1972)

head, static, [L]: The height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point. The static head is the sum of the elevation head and the pressure head. (Lohman et al., 1972)

head, total, [L]: The total head of a liquid at a given point is the sum of three components: (1) elevation head, which is equal to the elevation of the point above a datum, (2) pressure head, which is the height of a column of static water that can be supported by the static pressure at the point, and (3) velocity head, which is the height the kinetic energy of the liquid is capable of lifting the liquid (modified after Lohman et al., 1972).

high-level radioactive waste: (1) Irradiated reactor fuel, (2) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel, and (3) solids into which such liquid wastes have been converted. (U.S. NRC, 1983)

hydraulic head gradient [dimensionless]: The change in static head per unit of distance in a given direction. If not specified, the direction generally is understood to be that of the maximum rate of decrease in head.

infiltration: The downward entry of water into the soil or rock matrix. (Modified after Soil Service Society of America, 1975)

isolation: Inhibiting the transport of radioactive material so that amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits. (U.S. NRC, 1983)

matrix: The solid framework of a porous system (e.g., soil, rock). (Wilson, 1980)

percolation: The downward movement of water through the unsaturated zone.

permeability, intrinsic, $[L^2]$: A measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient. It is a property of the medium alone and is independent of the nature of the liquid and of the force field causing movement. It is a property of the medium that is dependent upon the shape and size of the pores. (Lohman et al., 1972)

porosity, [dimensionless]: The ratio of the volume of interstices to total volume for a porous medium. It may be expressed as a decimal fraction or as a percentage.

porosity, effective, [dimensionless]: The amount of interconnected pore space available for fluid transmission expressed as a ratio of the interconnecting interstitial volume to the total volume.

pressure head: The head of water at a point in a porous system, negative for unsaturated systems, positive for saturated systems; quantitatively, it is the water pressure divided by the specific weight of water. (Wilson, 1980)

saturated zone: See zone, saturated.

static head: See head, static.

total hydraulic head: See head, total.

underground facility: The underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals. (U.S. NRC, 1983)

vadose zone: See zone, unsaturated.

water content: The amount of water stored within a porous matrix, expressed as either a volumetric (volume per unit volume) or mass (mass per unit mass) ratio of water to matrix. (Wilson, 1980)

water table: That surface in a ground-water body at which the water pressure is atmospheric. (U.S. NRC, 1983)

zone, saturated: That part of the earth's crust beneath the regional water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric. (U.S. NRC, 1983)

zone, unsaturated: The zone between the land surface and the regional water table. Generally, water in this zone is under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies the water pressure locally may be greater than atmospheric. (Modified after Lohman et al., 1972)

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

NOV 23 1984

MEMORANDUM FOR: Robert B. Minogue, Director
Office of Nuclear Regulatory Research

FROM: John G. Davis, Director
Office of Nuclear Material
Safety & Safeguards

SUBJECT: OFFICE CONCURRENCE ON FINAL AMENDMENTS TO 10 CFR PART 60 RELATED TO HLW DISPOSAL WITHIN THE UNSATURATED ZONE

This memorandum is in response to your request for office concurrence on the final amendments to 10 CFR Part 60 related to the unsaturated zone.

I concur in the final amendment to 10 CFR Part 60 and Commission Paper with the understanding that RES will make the changes that we have recommended in the attached mark-up. We have discussed these changes with your staff and ELD's staff.

John G. Davis

John G. Davis, Director
Office of Nuclear Material
Safety & Safeguards

Enclosure:
Mark-up of Commission Paper and 10 CFR Part 60

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