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Enclosure in DCC

Dr. Morton E. Wacks, Chairman
Waste Management '86
Office of Special Professional Education
College of Engineering and Mines
Box 9
University of Arizona
Tucson, Arizona 85721

Dear Dr. Wacks:

Enclosed is my paper "Disturbed Zone and Ground Water Travel Time in The NRC High Level Waste Rule (10 CFR 60)" to be presented at Waste Management '86. I have previously asked by phone to have the deadline extended for this paper to February 24.

As you know, I cannot relinquish the copyright for this paper since it represents work performed by the U.S. Government.

Sincerely,

/s/

Richard Codell

Enclosure:
As Stated

OFC	:WMGT	:WMGT	:WMGT	:WM	:WM	:	:
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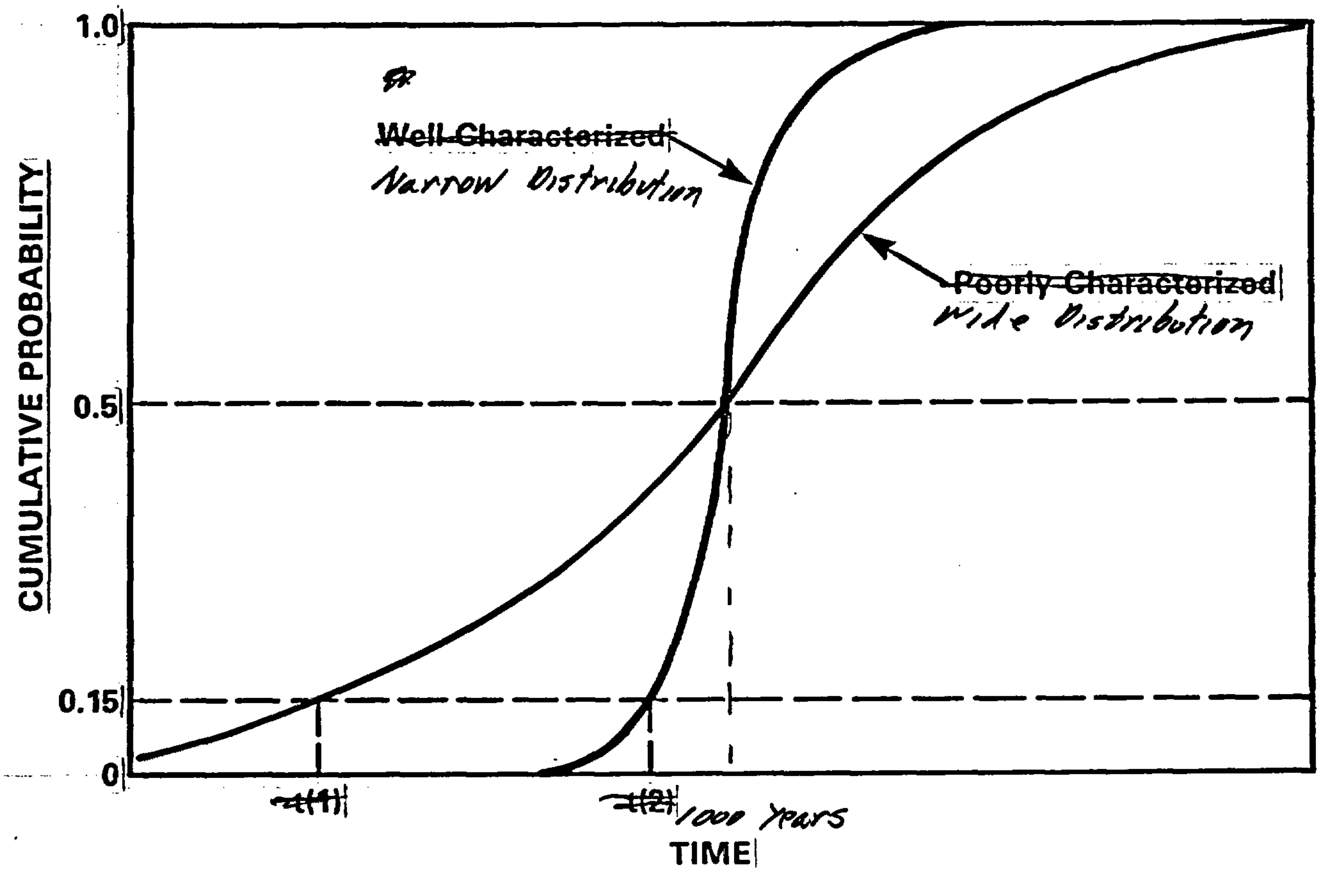
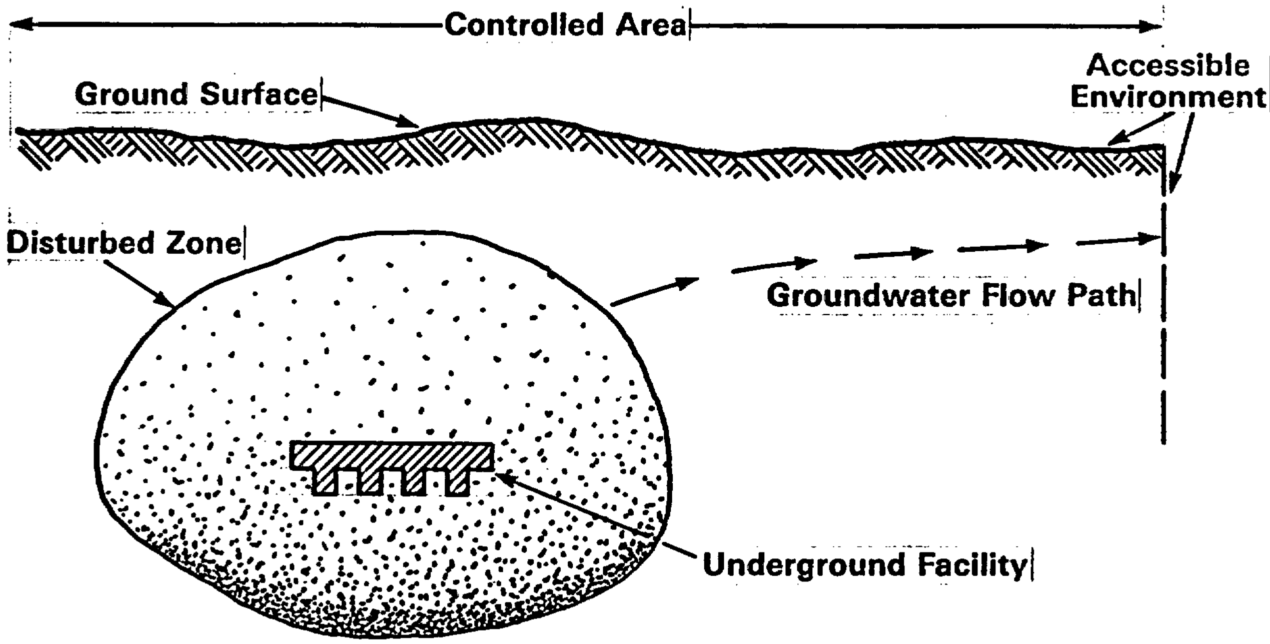


Figure 7 - Cumulative Distribution Function For Different Levels of Site Characterization



(schematic - not to scale)

Figure 1 - High Level Waste Repository

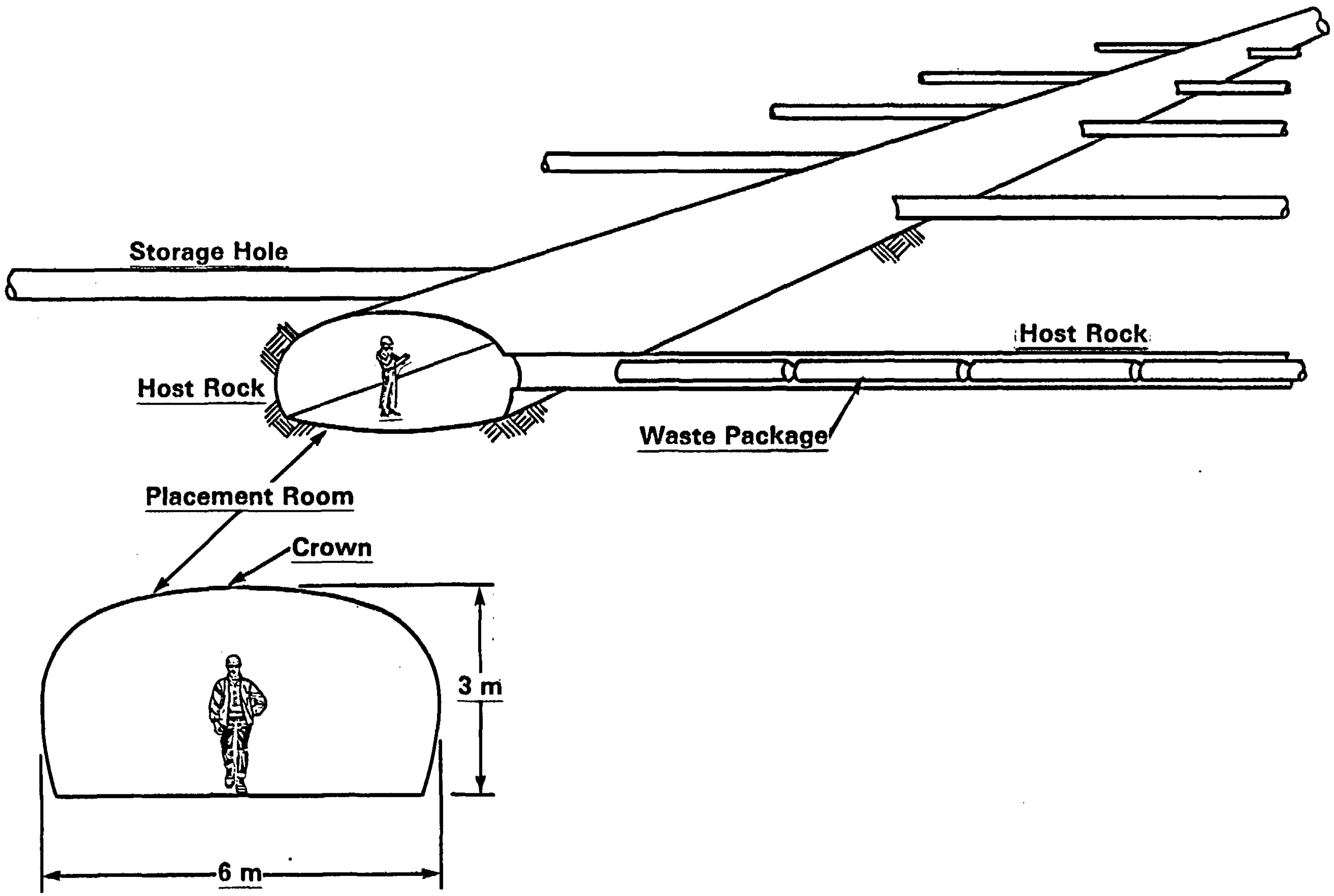


Figure 2 - Placement Rooms and Storage Holes in a HLW Repository

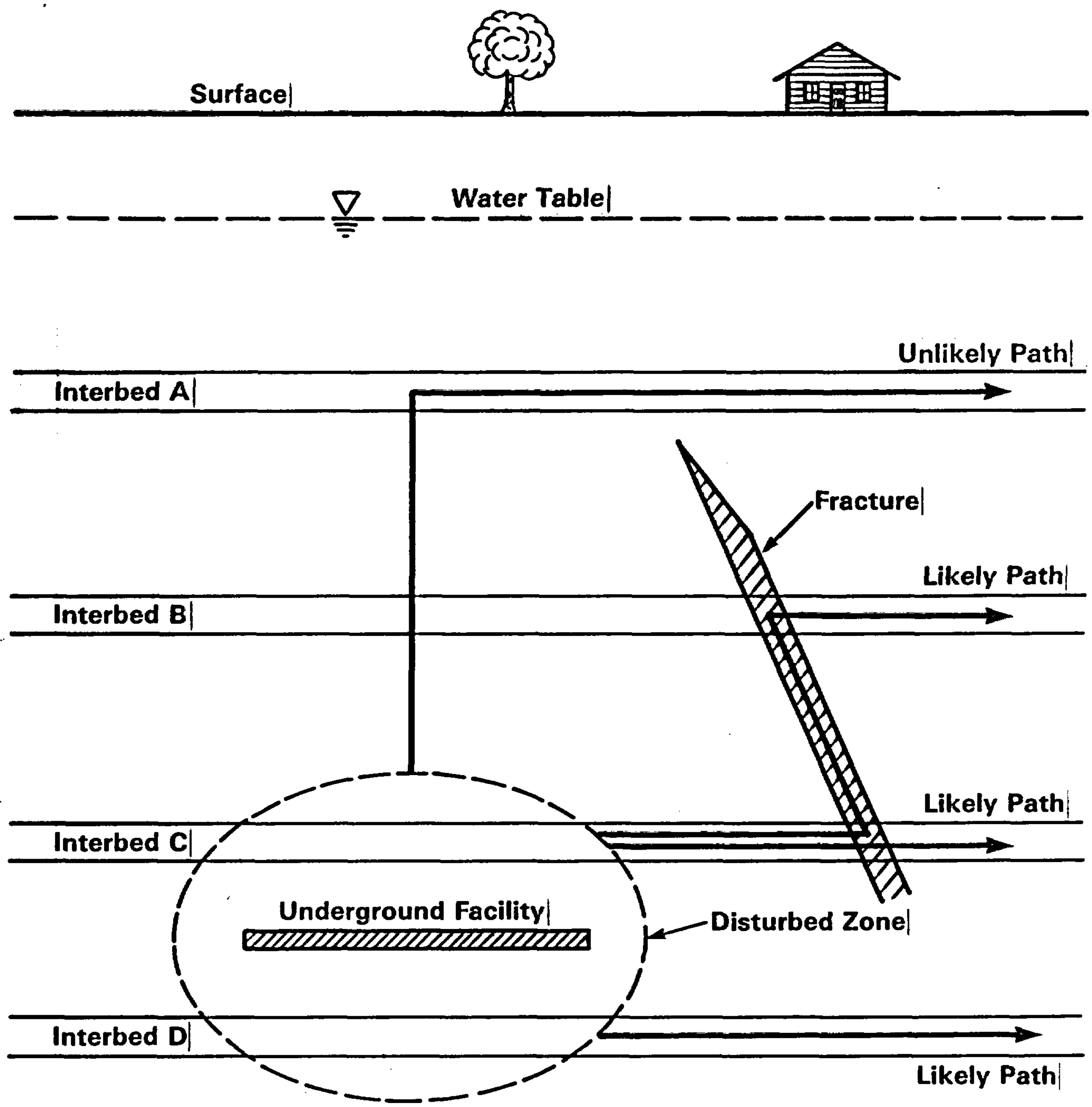


Figure 3 - Paths in Saturated Medium

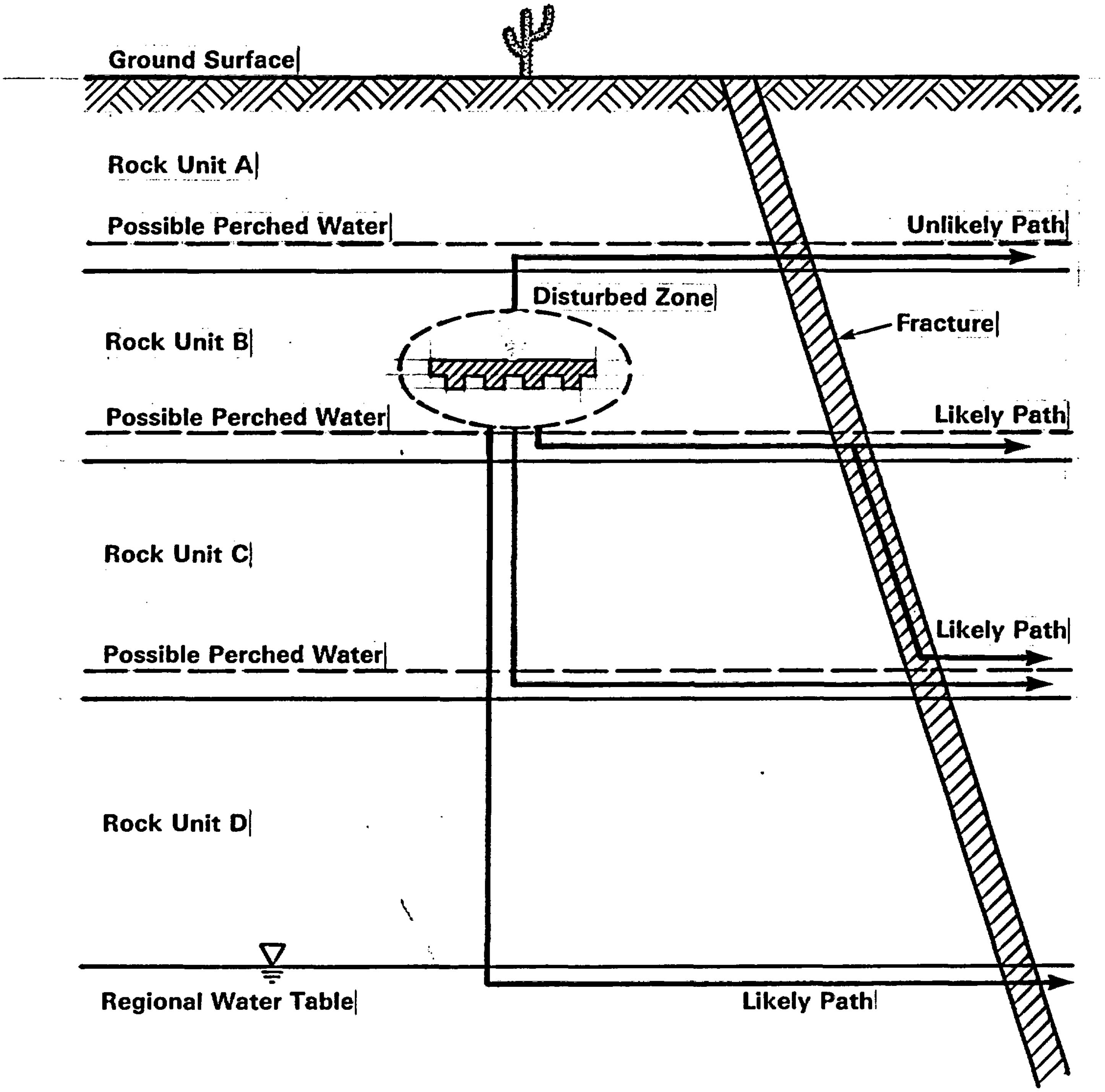


Figure 4 - Paths in UnSaturated Medium

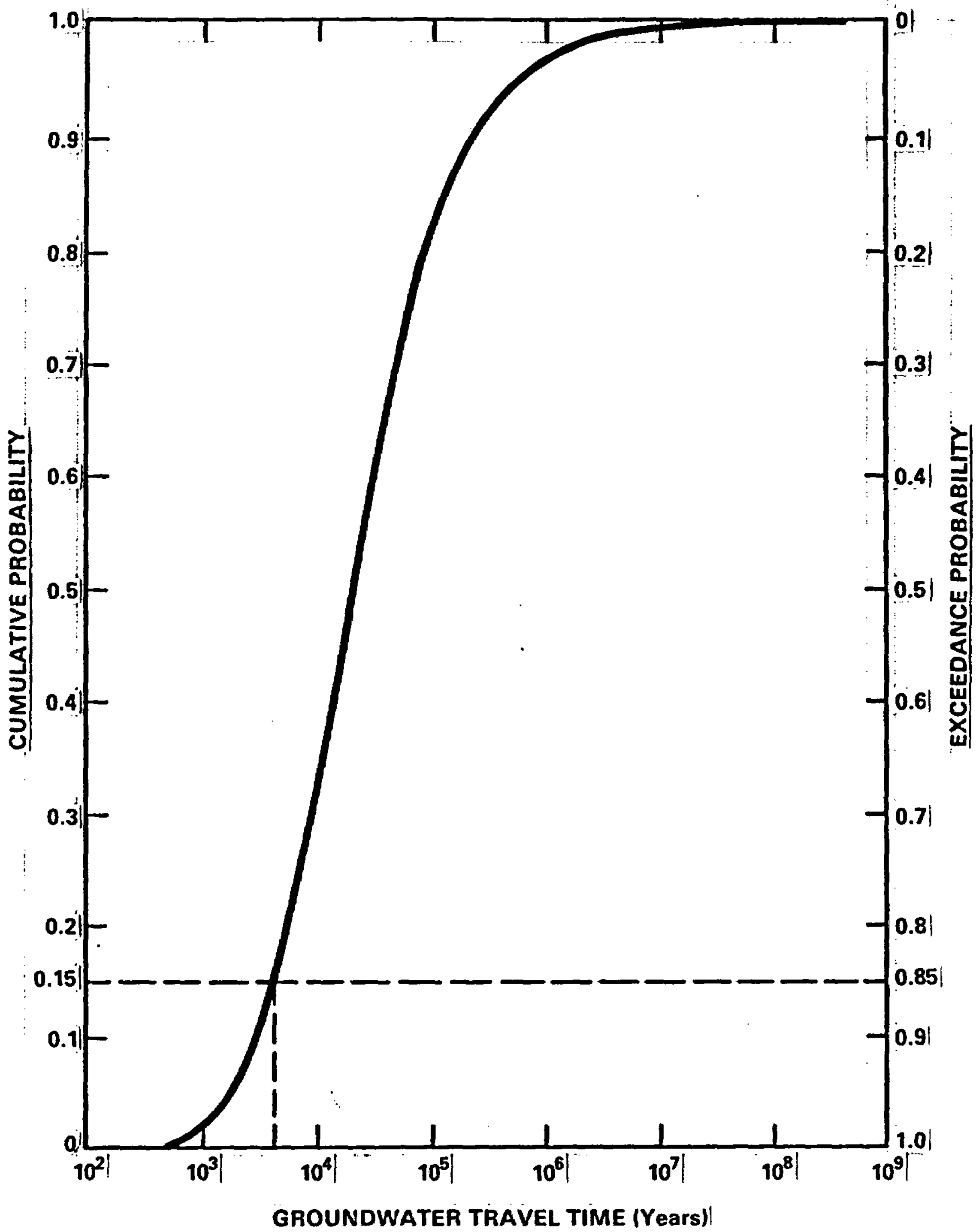


Figure 5 - Ground Water Travel Time Distribution

DRAFT

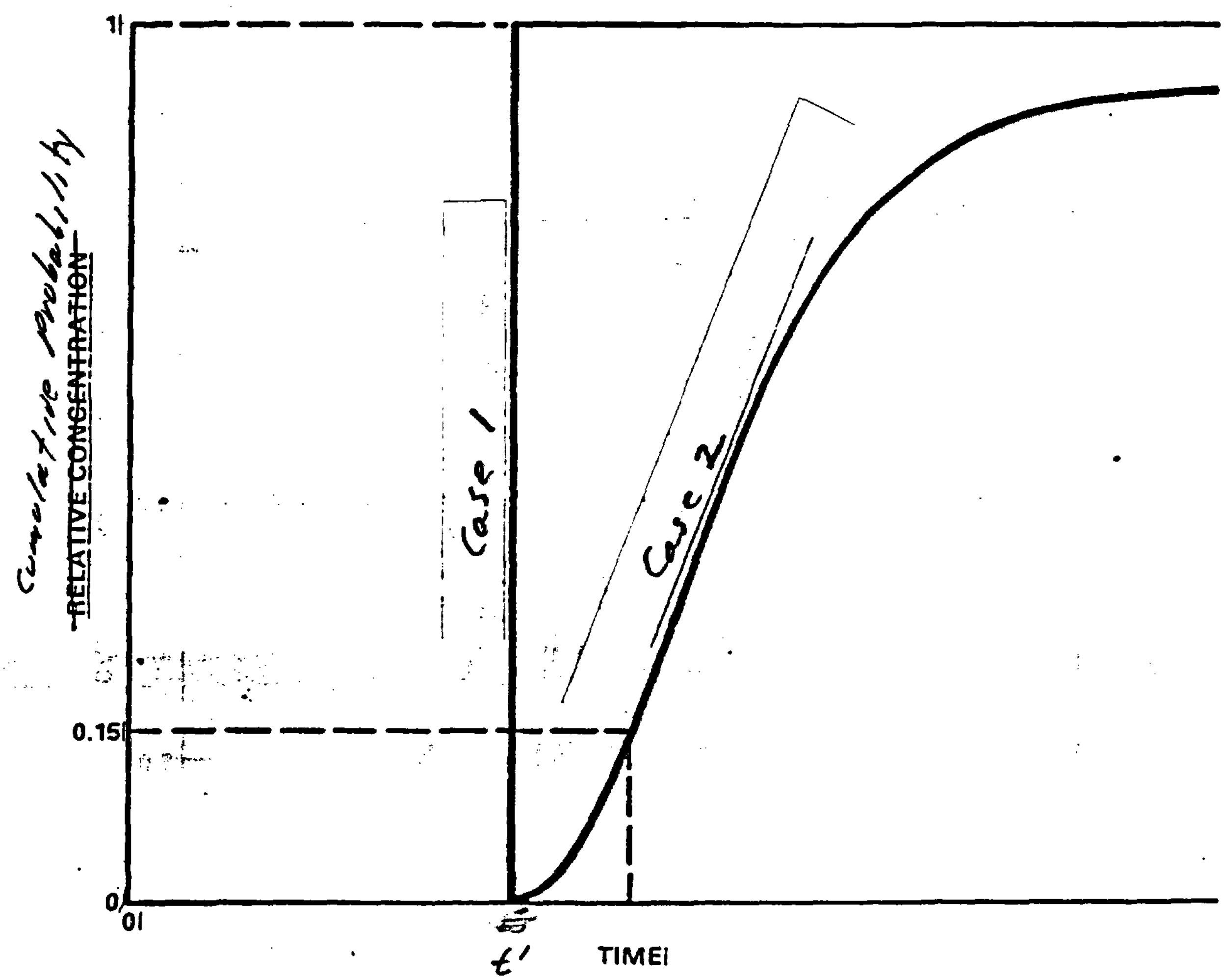


Figure 6 - cumulative distributions of travel time [redacted] with same minimum but different variance

Disturbed Zone and Ground Water Travel Time in the NRC High Level Waste Rule (10 CFR 60)

by Richard Codell and Naiem Tanious

INTRODUCTION

Ground water is the most likely means by which significant quantities of radionuclides could escape a High Level Waste (HLW) repository. Release of radionuclides through ground water pathways is limited primarily by three "barriers": (1) the waste package and engineered facility, (2) the rate of ground water flow from the waste to the environment, and (3) geochemical interaction of radionuclides with the rock along the path of ground water movement. The present paper deals only with the second barrier.

The staff of the U.S. Nuclear Regulatory Commission (NRC) has established performance objectives for the geologic setting of HLW repositories. One of these criteria, commonly referred to as the "pre-waste-emplacement ground water travel time" or "GWTT" objective is stated as follows:

> "The geologic repository shall be located so that pre-waste-emplacement ground water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1000 years or such other travel time as may be approved or specified by the Commission"[1] (10 CFR 60.113(a)(2)).

The "disturbed zone" cited in the above criterion is the portion of the controlled area where changes caused by construction or the heat generated by radioactive decay of the waste are great enough to have a significant effect on the performance of the repository. The "accessible environment" is defined as the atmosphere, land surface, surface water, oceans and the portion of the lithosphere that is outside of the controlled area. In this case, the defined "controlled area" is consistent with the Final EPA high level waste rule[2] as extending no more than 5 kilometers from the original emplacement of the waste in the

disposal system, with a maximum land surface area of no more than 100 square kilometers. The disturbed zone, accessible environment and path are depicted in Fig. 1.

The ground water travel time performance objective was established by NRC to serve as a quantitative, yet conceptually simple measure of the waste isolation potential of the geologic setting at candidate repository sites. The travel time criterion was selected as 1000 years to provide a significant delay for the transport of radionuclides from the engineered barrier system to the accessible environment.

The disturbed zone definition is intended to establish the inner boundary from which GWTT is determined. The evaluation of GWTT is simplified by avoiding consideration of the effects of complicated and ill-defined processes related to the construction of the repository and the heat generated by the waste. This paper summarizes the NRC staff's guidance on the GWTT objective and disturbed zone definition, which we anticipate will be contained in two draft Generic Technical Positions[3,4]. The intent of the disturbed zone is discussed first, followed by a description of the staff's attempt to place meaningful limits on its size.

INTENT OF DISTURBED ZONE

The volume of the rock which contributes to isolation of HLW from the accessible environment clearly has its outer boundary at the accessible environment. For the inner boundary, the edge of the underground facility as shown in Fig. 1 would at first seem a sensible choice. However, the staff has identified two considerations in establishing the starting point for GWTT calculations which preclude adoption of the edge of the underground facility as the origin.

First, the travel time criterion is intended to ensure that the geologic setting provides significant protection from HLW releases to the accessible environment. Thus it constitutes a component of the

multiple-barrier approach to HLW isolation. The staff considers that geologic barriers at a given site should not be permitted to depend exclusively or predominantly on the favorable properties of the host rock directly adjacent to the underground facility. Instead, the staff considers that an acceptable repository site would be one where the bulk of the surrounding geologic setting contributes to isolation of HLW.

Second, the staff considers that credit towards the 1000-year pre-emplacement travel time should not be taken within that portion of the current geologic setting (the "near-field") that might be substantially disturbed by construction of the facility or by the thermal effects of emplacement of HLW (irrespective of the possible offsetting benefits of engineered barriers). Because of potential changes in the intrinsic rock properties, the geologic setting within the disturbed zone may not be well represented by pre-emplacement properties and conditions. Thus it may be difficult to predict the contributions of this volume of rock to repository performance. A pre-emplacement analysis based on existing conditions within this zone would not be an appropriate measure of the quality of the geologic setting for the purpose of assessing future performance. To avoid having to deal with the uncertainties of characterizing the rock very close to the emplaced waste, the disturbed zone was established as the inner boundary from which travel time calculations are to be made.

Shafts and surface boreholes are excluded from the disturbed zone. The staff recognizes that the rock immediately surrounding these openings will be disturbed to some extent, and may become a flow path connecting the repository to the accessible environment. Rather than assess the significance of these shaft for the GWTT determination, the performance of shaft and borehole seals should be assessed as part of the overall performance assessment of the repository system.

Interpretation of the Disturbed Zone Definition

Having clarified the intent of the disturbed zone concept, attempts to place meaningful limits on its size are now discussed. In the definition provided earlier, the disturbed zone is described as the zone of physical or chemical property changes resulting from underground facility construction or HLW heat generation that would significantly affect the performance of the repository. It includes the zone where coupled process interactions significantly perturb the physical and chemical properties of the geologic setting.

The staff does not interpret the definition of the disturbed zone to fully encompass temperature and buoyancy effects. It would be desirable of course to include these effects within the disturbed zone so that outside of this volume the pre-waste-emplacement and post-waste-emplacement ground water travel times would be identical. Unfortunately, it is likely that the disturbed zone defined in this way would be quite extensive and in some cases might extend beyond the boundary of the accessible environment. Effects such as buoyancy may have a significant impact on ground water movement and radionuclide transport in terms of overall repository performance, and they must be taken into account in assessing total system performance. The staff considers that assessment of pre-waste-emplacement GWTT, representing the geologic component of the multiple barrier system, need only be based on pre-emplacement conditions, except where the intrinsic properties of the rock which affect ground water flow are likely to be compromised as a result of HLW heat generation or underground facility construction.

For the purposes of evaluating the extent of the disturbed zone at a given site, the staff will consider that a change in porosity by a factor of two constitutes a significant adverse effect on repository performance. Several theoretical relationships (e.g., parallel plate analogy) and laboratory studies demonstrate that permeability can increase by an order of magnitute if porosity doubles. The increase in the

velocity of the ground water is somewhat less, being partially offset by a lowering of the effective porosity.

Furthermore, the velocity in the affected region might be controlled by external forces unaffected by the local changes in porosity. It is unlikely, however that permeability or porosity could be characterized within a factor of two at any of the proposed HLW sites, because of the variability of the rock media as well as measurement inaccuracies.

Based on the technical and policy considerations described above, the staff considers that the disturbed zone could be theoretically calculated through evaluation of the spatial extent of changes to the intrinsic hydraulic properties of the rock caused by (1) stress redistribution , (2) construction and excavation , (3) thermomechanical effects, and (4) thermochemical effects.

The discussion below is based on current conceptual designs of HLW facilities, and considers only those rock types currently under consideration for geologic repositories. It may not apply directly for greatly different designs, or sites with local geologic anomalies. The approach demonstrates that the above phenomena can conservatively be assumed to be contained within a certain distance from the emplaced waste. The interactions of complex processes that would be considered in identifying the spatial extent of intrinsic permeability and porosity changes have not yet been sufficiently studied to provide guidance in estimating their effect on the extent of the disturbed zone.

<u>Stress Redistribution</u>

Rock permeability may be significantly altered in the region immediately surrounding repository openings as a result of stress redistribution caused by the removal of rock previously supporting a load. The immediate vicinity around the opening is most affected by the presence of the opening. The effect gradually decreases with distance back to its pre-excavation

condition. Site-specific experimental results, predominately on small scale laboratory samples, relate permeability changes to stress changes. There are no universal relationships, however, which can be applied to all rocks under wide ranges of stress changes. Lacking a relationship between stress change and permeability change, it is assumed that permeability will not change in the volume of rock beyond the surface of no stress change. Therefore, this boundary can be used to define the region of no permeability change, i.e., the limit of the disturbed zone resulting from stress redistribution.

The distance to the contour of no stress change from the edge of the opening will vary depending on the size and shape of the opening and its orientation in the stress field. For a circular or semicircular opening in an isotropic, homogeneous medium, a reasonable estimate of this distance for the idealized case will be about three times the diameter of the opening[5]. For a noncircular opening, a reasonable estimate is roughly five times the height. Other considerations such as anisotropy of the rock, and the degree of fracturing and subsequent yielding can potentially increase this distance[6,7].

Taking the envelope of the above stress distributions for a reasonable range of anticipated field conditions, the no-stress-change contour could be conservatively estimated in many cases to be about 5 diameters for circular openings or 5 times the opening height for noncircular openings. However, site-specific information must be utilized in order to gain a realistic estimate of the extent of the disturbed zone for a given site based on stress redistribution.

Typical openings in the repository are in the range of about 1 to 10 meters in width, as illustrated in the example presented in Fig. 2. Based on calculations for homogeneous, isotropic, and linearly elastic media, and taking into consideration the effects of host rock anisotropy, in-situ stress conditions, fracturing and yielding, it is estimated that the disturbed zone caused by stress redistribution for the

simplified example described above may extend to a distance of 5 times the opening diameter, or 5 to 50 meters, from the edge of the opening depending on the opening size.

The mechanical properties of salt are significantly different from other rocks and therefore a separate discussion is warranted. A unique feature of salt is its ability to creep into and close excavated openings over periods of only a few years to hundreds of years depending on the salt's mechanical properties, its depth, prevailing stresses, and other geologic phenomena and anomalies. The shape of the openings and the position of the emplaced waste could change over time as a result of salt creep. The extent of these changes should be considered in delineating the boundaries of the disturbed zone in salt media.

A second important difference between salt and other rocks is the applicability of the concept of ground water flow. Traditional concepts of ground water flow through porous media and jointed rocks do not appear applicable to pure salt. However, changes in permeability for the flow of brine or gas may occur as a result of excavation, stress redistribution, and creep.

For repositories constructed in salt, the staff considers that the 50-meter envelope around repository openings encompasses a sufficiently large zone to prevent the reliance on the portion of the host rock immediately adjacent to the underground facility (i.e., within fifty meters of any opening) as the exclusive natural geologic barrier to radionuclide release. If geologic anomalies in the salt (e.g., gas pockets, brine cavities) are present, site specific analyses of their potential impact on the size of the disturbed zone should be provided.

Construction and Excavation

The zone of mechanical damage caused by construction-induced effects is usually smaller than

that due to stress redistribution (with perhaps the exception of massive unjointed rocks). The extent of this zone depends on three factors: (1) the method of excavation (blasting or boring); (2) the type of rock; and (3) the extent of discontinuities in the rock. Porosity and permeability changes caused by dewatering of the facility should also be considered on a site-specific basis. The extent of damage due to controlled blasting rarely extends more than 1.5 meters or greater than half the opening diameter from the edge of the opening[8]. Tunnel and shaft boring results in little damage to the surrounding rock. Therefore, the approximately 50 meter distance from the edge of the opening, established as the minimum distance to the boundary of the disturbed zone resulting from stress redistribution, should also conservatively encompass any effects of construction-induced changes in rock permeability.

Thermomechanical Effects

Heat generated by the radioactive decay of emplaced waste may thermally stress the host rock and surrounding media. Thermal stresses can cause changes in permeability by creating new cracks and open or close existing joints. In the far field, thermal stresses may cause uplift and eventual subsidence effects. The resulting permeability changes may be more significant in salt than in hard rocks due to salt creep and a relatively high coefficient of thermal expansion.

Experimental assessment of changes in rock permeability as a result of heat application has shown that permeability increases with temperature because of thermal cracking[9]. However, confining pressure can strongly reduce permeability increases caused by heat. In a repository environment, permeability increases close to the repository wall may largely diminish as confining pressure increases in the surrounding rocks. In jointed rock, some or all of the thermal expansion may be absorbed by the closure of microcracks and joints resulting in overall reduction in the permeability.

Considering the above discussion, the disturbed zone which covers the effect of stress redistribution may generally be expected to include the zone of significant thermomechanical effects on permeability.

Thermochemical Effects

Thermochemical reactions include alteration of pre-emplacement minerals, dehydration, and precipitation of secondary minerals. A change in porosity and permeability of the host rock may result from alterations of pre-emplacement minerals caused by increased temperature and/or altered ground water composition. These reactions can result in either increases or decreases in solid volume.

Dehydration reactions may result in a net increase in porosity of the host rock, especially for hydrous minerals, and in the region surrounding the HLW canisters where temperatures are highest. This will be of particular importance to a repository located in the unsaturated zone. Dehydration of zeolites can occur at temperatures as low as 85°C.

Redistribution of solid phases (e.g., dissolution close to the waste and precipitation at a distance) results in porosity increases in one portion of the repository and decreases in another. The net effect on the flow may be favorable or unfavorable. Generic calculations for the redistribution of silica[4, 10], a common mineral found at at least two of the HLW sites currently under consideration, indicate that dissolution is not likely to be significant beyond the previously discussed distance of 50 m for mechanical disturbance[4, 10]. It is apparent, however, that the distance to the edge of the thermochemically disturbed zone is strongly dependent on the thermal loading of the repository and the ground water flux in the host rock. The staff recommends that analyses of thermochemical effects be performed with site-specific values of the hydrological, mineralogical and chemical parameters for the repository system. These calculations will roughly indicate the suitability of the suggested minimum distance based on stress

redistribution in encompassing the zone of thermochemical changes at the site.

Summary for Disturbed Zone

The NRC staff considers that establishment of generic and easily evaluable guidance on the disturbed zone is desirable in order to simplify the demonstration of compliance with the ground water travel time criterion. Based on the information provided above, it appears that a distance of five opening diameters from any underground opening, excluding surface shafts and surface boreholes, would be a reasonably conservative distance for the extent of the mechanically-disturbed zone in some cases. Given current conceptual designs for underground HLW facilities, this would imply a distance of roughly fifty meters from the underground openings. The limit of one process (silica dissolution) contributing to the thermochemically disturbed zone, based on a simplified evaluation, appears to be less than the mechanically-disturbed distance from the underground facility. However, the thermochemically disturbed zone at a site should be calculated on a site- and design-specific basis, taking into account the hydrochemical, geochemical, hydrologic and thermal conditions for each site. The impact of stress redistribution, construction and thermomechanical effects should also be considered on a site- and design-specific basis where practicable.

INTERPRETATION OF GWTT OBJECTIVE

Assessment of the GWTT objective requires (1) proper characterization of the pre-waste-emplacement environment and its potential spatial and short-term temporal variabilities, (2) identification of the paths of likely radionuclide travel, (3) calculation of the appropriate travel time along the likely paths, and (4) picking the fastest travel time. Compliance with the objective requires a demonstration that the fastest GWTT exceeds 1000 years. The steps necessary to demonstrate compliance are discussed below.

Identification of Pre-Waste-Emplacement Environment

Pre-waste-emplacement pertains to conditions which exist prior to significant disturbance of the hydrological setting by construction activities and major testing activities capable of seriously disturbing the geologic setting. Restriction of the GWTT requirement to pre-disturbance conditions is consistent with the original intent of 10 CFR 60 to establish a straightforward criterion which is easily defined and determined. The staff recognizes the importance of post-waste-emplacement effects. Evaluation of ground water and radionuclide movement under post-waste-emplacement conditions will be required as part of the demonstration of overall compliance of the repository with the EPA standards as implemented by NRC.

The determination of GWTT will be for present day environmental conditions only. Short-term changes to the environment, (e.g., tens of years) which can be reasonably inferred from records in the vicinity of the site and any other factors that may explain transient responses in the hydrologic system should be considered when developing the conceptual model(s) for determining GWTT whenever practicable. For example, decreases in ground water levels caused by pumping for irrigation may explain transient responses in nearby aquifers. Other examples include cycles of wet and dry years, local flooding and changes in land use.

If present-day conditions have changed markedly over the period of record, the investigator must question whether inappropriate credit is being taken for increased ground water travel times caused by these changes. For example, if a cone of depression has formed as a result of large ground water withdrawals, it could reduce or even reverse the direction of an unfavorable hydraulic gradient. This could lead to the possibility that GWTT calculated on the basis of present-day gradients are overly optimistic and not representative of the geologic setting. In this case, it would be prudent to consider the effects of an otherwise-likely hydraulic gradient absent the effect of the cone of depression. The rationale behind this

philosophy is to avoid the appearance of taking credit for processes for which there could be no assurances of long-term reliability, e.g., continued ground water withdrawals maintaining the favorable gradient.

Identification of Paths of Likely Radionuclide Travel

The paths from the disturbed zone to the accessible environment are to be described in a macroscopic sense. Paths must be potentially capable of carrying a significant quantity of ground water. In the sense employed here, "significant" is relative to the absolute quantity of ground water moving by the site. In crystalline or fractured rocks, paths may consist of fractured, weathered, brecciated or porous zones. In porous media, paths will generally consist of layers of porous, permeable sediments. Paths may also consist of fractured zones in consolidated porous media. In a uniform medium, a distinct conduit for radionuclide transport may not be evident, in which case the path will be defined by the considering the hydraulic gradient and hydraulic conductivity.

Data from the site could support several alternative conceptual models for the repository setting, each of which might determine a different path for radionuclide transport. For example, limited borehole information might indicate the presence of permeable zones, but the investigator may be unable to determine whether or not these zones were connected in such a way that they represent a path.

The analysis of GWTT, therefore, should consider all paths for radionuclide transport defined by alternative conceptual models, unless they can clearly be demonstrated to be unlikely or insignificant. Collection of data at the site must be directed to identifying these paths, establishing the validity of the conceptual models for interpreting and simulating the hydrogeology, and making a reasoned determination that potentially faster paths have not been overlooked.

Underground facilities located in saturated media will usually be emplaced in a rock unit of low

permeability. More permeable units may underlie and overlie the repository horizon, however, as shown in Fig. 3. Some of these horizons may intersect the disturbed zone. While there may be little movement of ground water in the host rock under natural conditions, factors which could cause the movement of radionuclides from the disturbed zone to these more permeable horizons should be taken into account. Paths of transport between horizons could occur via fracture or porous flow under natural hydraulic gradients.

Identification of paths for repository sites in unsaturated media, as illustrated in Fig. 4, will differ from those in saturated media. The flow is likely to be predominantly in the downward direction until the water table is reached. In some cases, the path may be defined in terms of the direction of the gradient, unless there are barriers to flow such as contrasts in hydraulic conductivity leading to perched water tables. The possibility of perched water under reasonably conceivable conditions (e.g., a series of wet years that could occur under present climatic conditions) should be considered, even if such conditions currently do not exist at the site. Possible connections of perched water to fractures or other structural features of the site, which would provide preferential pathways for radionuclide migration through the unsaturated material in which the repository would be placed, should also be considered.

Determination of Travel Time

Ground water travel time must be determined for each of the likely paths determined in the previous step. The GWTT is a distributed variable rather than a fixed quantity. Several reasons exist for the distributed nature of travel time. These are mechanical dispersion, molecular diffusion, data uncertainty, the distributed nature of the source and accessible environment, and the transient nature of ground water flow. These phenomena are discussed below. It is helpful in the following discussion to introduce the concept that GWTT may be determined by simulating the

release and migration of inert, infinitesimal tracer particles which behave identically to the molecules of water:

- Dispersion - Ground water travels only in the open spaces (pores, fractures) in the rock. There would be numerous possible particle trajectories within each path, each with a different travel time. In any real situation, natural spatial variability in the properties of the medium such as porosity and hydraulic conductivity, will cause the tracer particles to disperse. Tracer particles moving in the ground water will follow trajectories governed by the hydraulic properties of the medium at their location. The less uniform the medium, the less parallel will be the trajectories and the greater the range of the arrival times of the tracer particles at the boundary of the accessible environment.

- Molecular diffusion - Random movement on a very small scale allows water and solute molecules to diffuse into openings in the rock where there may be little or no net flow of the water. Molecular diffusion may be important in cases where there is appreciable matrix porosity and generally slow movement of ground water[11].

- Uncertainty - Measurement error and limits of data necessary to characterize the site add uncertainty to the hydrologic parameters used to calculate GWTT, which is translated into uncertainties in the GWTT estimates. This uncertainty can be combined into the probability distribution of arrival times for tracer particles.

- Distributed source - The disturbed zone and accessible environment are defined as surfaces rather than points. Tracer particles released at different points along the disturbed zone surface will reach the boundary of the accessible environment at different times.

- Temporal variability - Hydrologic and hydrogeologic data within recorded history of the site might indicate that the ground water velocities are fluctuating. This fact might be particularly important at sites built in unsaturated media. For example, it is conceivable that a period of unusually heavy precipitation for several years (unreleated to a global climatic change) could increase hydraulic heads, decreasing travel times along a normally slow pathway. A transient GWTT should be weighted according to its frequency and duration. In addition, a path which changes direction or length over time as a result of variable fluxes of ground water should be considered to be a single path for the purposes of GWTT calculations. This allows the low probability, fast GWTT's to be fairly weighed with the high probability, slow GWTT's.

Analysis of the GWTT for a repository must depend on methods of indirect inference from observations of hydrogeologic data at the site. Artificial tracers are useful in some cases, but the time (thousands of years) and distance (kilometers) scales are too great for direct characterization of GWTT at HLW repository by such methods. Naturally occurring isotopes and those produced from atmospheric weapons testing and nuclear reactors can be used for ground water age dating to support estimates of travel time distributions for real sites. Such techniques should be used whenever practicable, although investigations must usually resort to mathematical models of the repository for predictions of performance.

Values of travel time from the disturbed zone to the accessible environment are usually obtained from mathematical models consisting of the equations governing the hydraulic potential, flow of ground water, and transport of a tracer. There are many models for ground water flow in various media which are based on the equations at steady state or transient conditions in one, two or three dimensions[12]. Currently, the most prevalent method of determining the GWTT distri-

bution is by the use of deterministic models with inputs generated randomly[13 14].

Deterministic models consist of equations whose solution is based on the assumption of known parameters, e.g., hydrogeologic properties, initial conditions and system geometries. Uncertainties and variabilities of the data are usually taken into account by obtaining many solutions, each one based on a different statistical realization of the parameter set. Such techniques are generally known as "Monte Carlo" simulations.

Each Monte Carlo run requires the solution of the hydraulic head and velocity field for the values of parameters and boundary conditions chosen randomly, but following certain statistical rules based on the data. The solution is generally accomplished by solving the partial differential equations (PDE's) that describe ground water flow using techniques such as finite differences or finite elements. Once the velocity field is known, travel time distributions can be calculated by simulating the release of tracer particles from single or multiple locations along the disturbed zone boundary and counting their arrival times as they reach the accessible environment[14 15].

Stochastic models deal with the variability and uncertainty of the data in a more direct way[16]. The coefficients and variables of the equations are treated as random fields rather than deterministic quantities. The PDE's are solved indirectly in terms of the moments of the dependent variables (e.g., mean and variance). This technique has the advantage of requiring only one solution rather than the numerous Monte-Carlo solutions for the deterministic approach. Direct stochastic approaches to modeling are much less developed than Monte Carlo techniques, although it is an area of rapid development.

With either type of model, the computations must be performed with parameters inferred from the available data in order to generate the GWTT distribution. The types and quality of data available will determine

how the computations are to be performed. For example, if only a few data points are available for a particular parameter, a conservative estimate of that parameter may have to be made and carried through the calculations. With more data, a mean and variance of the parameters can be calculated and used with a simple sampling approach. If the site is well-characterized, spatially varying properties of the parameters can be employed[17].

Ground water travel time can be represented as a distribution for each of the paths in terms of a Cumulative Distribution Function (CDF), shown in Fig. 5. This CDF combines all spatial variability, temporal variability and quantifiable uncertainty of the GWTT into a single curve for each of the likely paths. The CDF itself, however, is assumed to contain no uncertainty. It is important to note that the CDF does not exclude the existence of uncertainty, but that all quantifiable uncertainty is incorporated into the CDF. Compliance with the 1000 year GWTT objective would be demonstrated if it could be shown that along any of the paths, a tracer particle leaving the disturbed zone has a (100-X)% or greater probability of arriving at the accessible environment in a time greater than 1000 years, where X is a small number. The choice of X is discussed in the next section.

The GWTT computed using this general guidance will be sensitive to the degree of characterization of the site. That is, investigators of poorly-characterized sites will be forced to use conservative or at least overly wide distributions to represent the large uncertainties in the input parameters. Sites that have been characterized on the basis of defensible conceptual models will facilitate the development of a more defensible GWTT distribution function by reducing the variance of parameter distributions.

<u>Percentile (X) Criterion for GWTT Distribution</u>

At the upper and lower limits of the GWTT distribution for each of the paths, there will be ground water travel times which, although possible, are so

unlikely that they are inappropriate measures of GWTT. As an example, consider the two hypothetical cases shown in Fig. 6 for which (1) all particles arrive at the same time, t' or (2) the particles arrive gradually after t'. Case 2 would obviously be more favorable in terms of repository performance, but this fact could not be determined if the "first particle" or zero percentile criterion for the GWTT distribution had been chosen. The choice of a higher percentile would give proper credit to Case 2.

A finite percentile also avoids some of the difficulties caused by model inaccuracies and inadequacies. For example, calculations for solute concentrations are frequently made using the convective-diffusion equation. This equation can predict small but non-zero concentrations of solute appearing instantaneously at any point in the computational field, in violation of the laws of physics. Similar inaccuracies can be caused by approximations made in the numerical solution of the equations. These extremely small concentrations are recognized as erroneous and are not usually cause for concern, but the "first particle" criterion would present difficulties which could be easily avoided by the choice of a larger percentile.

A choice for the percentile which is too high, say the median, would be undesirable because it may be insensitive to the variance of the GWTT distribution. This can be demonstrated for the hypothetical example depicted in Fig. 7. The two CDF curves of GWTT in this figure have the same median of 1000 years, but different variances. Under the median GWTT criterion, sites which exhibit a wide variance of the travel time distribution for reasons such as great spatial variability, dispersion, matrix diffusion, or uncertainty, would be treated as equals. This leaves open the possibility that in the case of the curve with the wider variance, a substantial fraction of the tracer particles could arrive at the accessible environment in less than 1000 years. A smaller percentile justifiably favors the site which has the smaller variance in the GWTT distribution. If the wider variance is due to

substantial changes from last draft

quantifiable uncertainty (e.g., lack of data), the smaller percentile would serve as an incentive to further characterize the site. A smaller percentile favors the site which has the smaller variance in the GWTT distribution.

The percentile for the CDF as the criterion for GWTT is presently unspecified, but the rationale from the above two examples suggests that a value greater than a few percent and considerably less than 50% would be desireable. The determination of the percentile for the GWTT criterion should also be based on considerations of "reasonable assurance". Licensing considerations to be made in connection with GWTT involve substantial uncertainties, many of which are unquantifiable (e.g., those pertaining to the correctness of the models used to evaluate GWTT). Such uncertainties can be accommodated within the licensing process only if a qualitative test such as reasonable assurance is applied for the level of confidence that the numerical performance objective is expected to achieve. Both the quantifiable uncertainties incorporated in the GWTT distribution and the unquantifiable uncertainties which are not included must be considered together in reaching a finding of reasonable assurance. It might, for example, be proper to select a different percentile criterion for a relatively well-understood, easily modeled site (where unquantifiable uncertainties are small) than would be appropriate for a site with larger unquantifiable uncertainties. Stated another way, selection of the percentile criterion is a qualitative judgement, and is part of a larger set of judgements necessary to reach a finding of reasonable assurance that the performance objectives will be achieved.

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Note that the user is not required to generate a detailed CDF of the GWTT distribution. A simplified approach would be acceptable, provided that achievement of the 1000 year GWTT objective could be demonstrated with reasonable assurance. Such a simplified approach could for example, define a conservatively short path along which the travel time of a single particle could be calculated using Darcy's law with

conservatively chosen coefficients of hydraulic conductivity, gradient and effective porosity.

Summary for GWTT

Ground water travel time is a measure of the merit of the geologic setting of a high level waste repository. The staff recognizes that there may be alternative conceptual models of the site because of the inability to completely characterize it with the available data. This inability may lead to a multiplicity of paths for likely radionuclide travel. The ground water travel time along the paths will be a distributed quantity because of spatial variability, temporal variability, the distributed nature of the disturbed zone and accessible environment, and model or data uncertainty. Ground water travel time should therefore be represented as a cumulative distribution, although a single-valued GWTT would be acceptable if it were derived from appropriately conservative models and coefficients. The "pre-waste-emplacement ground water travel time along the fastest path of likely radionuclide travel" should be represented as a percentile of all travel times contained in the Cumulative Distribution Function (CDF) for the fastest of the identified paths. Compliance with the 1000 year GWTT objective would be demonstrated if it could be shown that along any of the paths, a tracer particle leaving the disturbed zone has a (100-X)% or greater probability of arriving at the accessible environment in a time greater than 1000 years, where X is a small number. A numerical value of X has not been specified by the staff at this time.

Pre-waste-emplacement pertains to conditions at the site prior to any significant disturbance of the hydrological or geological setting such as construction activities or the effects of radioactive waste, and whose spatial and temporal variability can be reasonably inferred from historical records at or near the site. Testing activities capable of altering the pre-waste-emplacement environment should be taken into consideration.

CONCLUSIONS

The ground water travel time objective was established as a simple but meaningful measure of the merit of the geologic setting of a high level waste repository. The disturbed zone was defined to avoid the necessity of quantifying complicated processes which are likely to occur close to the emplaced waste, and to prevent reliance on a relatively small thickness of rock to satisfy the GWTT objective.

The staff has endeavored to present a workable definition of the pre-waste-emplacement ground water travel time objective to be used for HLW repository licensing. The definition will assist the staff in evaluating compliance of a specific site with the performance objectives of 10 CFR 60. This paper is however intended to be guidance only. It reflects the staff's current interpretation of the disturbed zone definition and GWTT objective. It does not prevent others from advancing alternative interpretations.

The draft Generic Technical Positions on which the present paper is based[3,4] have not yet been made available for public comment. This paper may not therefore reflect the final NRC positions on the disturbed zone and ground water travel time. The authors encourage comments and suggestions on the topics covered in this paper.

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