

A SITE-SPECIFIC APPROACH FOR DEFINING A CONTROLLED AREA FOR THE YUCCA MOUNTAIN REPOSITORY

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ABSTRACT

The site-specific EPA public health and radiation protection standards (40 CFR Part 197) for the candidate Yucca Mountain geologic repository include the concept of a controlled area surrounding the geologic repository. Defining a site-specific controlled area must consider the projected pathway of releases toward the “accessible environment”, as well as the design and performance of the repository (its underground configuration and performance expectations). Analyses described here examined potential contaminant plumes, considering dispersion effects and the hydrologic characteristics of the highly fracture-flow dominated flow regime at the site. This ground-water flow and contaminant transport conceptualization is based upon the best available data that includes field characterization tests, literature values and expert elicitation. Assuming various proposed repository inventories, thermal loadings and engineered barrier system (EBS) performance projections, the envelope of transport pathways around the repository was determined. Contaminant transport to the north and west of the site through the saturated zone is not possible for the site’s hydrologic setting, and therefore the northern and western controlled area boundaries can be defined by the repository underground layout and a modest buffer zone (for example, one kilometer from the repository border). Flow through the saturated zone to the east of the repository is expected. The eastern controlled area boundary would be determined by the envelope of potential transport paths in that direction and the uncertainties in projecting these transport paths. To the south, the controlled area boundary has been defined by a conservative resource protection approach considering the location of the current population and the existing use of the ground-water resource, and is not dependent on repository performance. A controlled area that conforms with the areas of potential contamination would be about 300 km².

INTRODUCTION

The EPA’s proposed Yucca Mountain environmental radiation protection standards (1) presented two alternatives for a controlled area (§197.12); one was essentially the definition used in 40 CFR Part 191 (2), while the other involved the borders of the Nevada Test Site as part of the controlled area boundary. This paper describes several considerations, based upon site-specific information, that were used to determine the maximum size of a controlled area at 300 km² given in the final rule (3).

The controlled area surrounding a deep geologic repository defines the geographic extent of the natural barrier system necessary to contain radionuclide releases to acceptable levels during the

10,000 yr regulatory time period. The natural barrier and engineered barrier systems comprise the disposal system for the repository. Defining the extent of the natural barrier on a site-specific basis requires a knowledge of the expected performance of the repository engineered barrier system (EBS), as well as an understanding of the behavior of the natural barrier system, more specifically the ground-water flow regime around the site. Understanding the ground-water flow system is particularly important in defining a controlled area, since the ground-water pathway is the predominant way radionuclides released from the EBS can be transported to the downgradient population (1). The evolution of the controlled area concept is discussed first, followed by a discussion of the intended functions of a controlled area and then a detailed examination of the site-specific information that was used to define a maximum controlled area size for the Yucca Mountain site.

HISTORY OF EPA'S REGULATORY APPLICATION OF THE CONTROLLED AREA CONCEPT

The Agency's use of the concept of a controlled area was first formalized in EPA's generic standard for the disposal of spent nuclear fuel, high-level and transuranic wastes, 40 CFR Part 191 (2). In Part 191, the term "accessible environment" was used to designate the area outside the controlled area surrounding the repository. In developing the site-specific Yucca Mountain standard (3), the concepts of the accessible environment and controlled area were judged to be useful regulatory concepts and were included in the standard.

In Part 191, a 100 km² size restriction was incorporated into the controlled area definition, with a restriction of no more than a 5 km distance for any direction from the outer boundary of the repository underground location. In framing the controlled area concept, an asymmetric delineation of the controlled area around a repository is permissible, and will more likely be the situation, based upon site-specific considerations about actual ground-water flow directions and uncertainties for any actual repository site. The 100 km² area was essentially a limit on the amount of land, which would otherwise be available for unrestricted use, to be dedicated to the geologic disposal system.

Since contamination can occur within the controlled area, it is also intended as an area where human activities should be restricted by institutional controls so that inadvertent exposures to radionuclides from the subsurface do not occur. The Nevada Test Site (NTS) has been host to weapons testing and other activities that have introduced significant amounts of radionuclides there and it is reasonable to assume that the NTS will remain for the foreseeable future a restricted area in terms of access by the general population. In this sense, the institutional control aspects of the NTS boundaries are equivalent in intent to the institutional control function of a controlled area. The text below further describes the functions of the controlled area and the approach used in this report to examine site-specific considerations involved in defining it.

FUNCTIONS OF A CONTROLLED AREA

A controlled area has three functions: as a regulatory compliance measure; as an institutional

control boundary; and as a repository design constraint. The regulatory applications are most important for standards development and regulatory decision making.

The controlled area as a regulatory compliance measure. This is its most obvious and prominent function. It provides a location where calculations of radiation doses to the individual, or radionuclide concentrations in ground water, must be shown to comply with the limits given in regulatory standards. More specifically, a point must be determined on the boundary of the controlled area where the projected radionuclide concentrations in any ground water are calculated to be highest. As commonly understood from the initial framing of the controlled area concept (2), the regulatory standards are not applied inside the controlled area since this area is recognized as an integral part of the disposal system.

The controlled area as an institutional control mechanism. In Part 191, the controlled area location is designated by institutional controls (such as surface markers). The intent of such controls is to preserve the knowledge of the site and its contents so that future generations are aware of the disposal effort and the potential hazards associated with waste disposal. This institutional control aspect is intended to provide a mechanism to restrict access during the period when active institutional controls are effective and preserve the knowledge of the disposal system (both the repository and natural barrier system location) for as long as possible thereafter.

The controlled area as a repository design constraint. As a repository design constraint, the size of the controlled area can be used as way to show where emphasis may be needed in the repository development effort. By identifying a controlled area boundary, a constraint is placed on the repository development efforts. Should radionuclide release projections show that the standard would be exceeded during the regulatory time period, the repository developer must decide if one or more of the following improvements are necessary: enhancements to the engineered barrier to reduce potential releases, a better understanding of the disposal system's anticipated performance to more reliably project releases, or more reliable and realistic modeling capabilities to more defensibly project disposal system performance. A controlled area size establishes a benchmark that can be used by the repository developer to prioritize efforts among the alternatives mentioned above, so that an optimized disposal system can be developed and carried through the licensing process.

EPA APPROACH TO DEFINING THE LIMITS OF A SITE-SPECIFIC CONTROLLED AREA FOR YUCCA MOUNTAIN

In defining a controlled area size limit for the candidate site in the final standard, the focus was on the first two functions described above, i.e., as a regulatory compliance measure and as an institutional control measure. The controlled area must contain any contamination plumes from failed waste packages that have the potential to result in individual exposures or ground water contamination above the limits set in the standard.

The approach relied heavily on integrating three kinds of information described below: the variations in proposed areal lay outs for the repository; the projection of ground-water and

contaminant transport pathways from these repository layouts and the uncertainties that exist in defining them and; the projected performance of the repository engineered barrier design, both for anticipated and “off-normal” conditions reasonably expected to occur over the regulatory time period.

The repository’s underground waste emplacement areas are, of course, the initial source of any projected radionuclide releases and, as such, a controlled area should at a minimum contain these areas within its borders. The controlled area should also contain the location of the repository surface facilities so that institutional controls include these areas, since they are not located directly over the repository underground excavations (4).

Once radionuclide releases from the engineered barriers occur for any reason, they first enter the unsaturated zone surrounding the repository, moving generally downward and to the east to some extent, along the eastwardly dipping contacts between rock units in the unsaturated zone (4). After traversing the unsaturated zone, releases enter the saturated zone portion of the ground-water flow path and mix with ground waters moving through the regional flow system below the repository. In the saturated zone, radionuclide releases would disperse into the ground water as a function of the hydrologic properties of the flow system and along the transport path in the downgradient direction. To understand how radionuclides would be transported through the flow system, the site characterization data collected around the repository location and in the downgradient direction would be used to model the transport.

The final consideration in the approach is an understanding of the anticipated performance of the repository EBS under both anticipated and “off-normal” conditions. As with projecting contaminant transport paths, projecting EBS performance involves uncertainties, both in the performance under anticipated conditions, as well as unanticipated waste package failures due to undetected manufacturing defects for example - the typical “off-normal” failure scenario. The sources of information available to address the factors described above (repository layout, ground-water flow paths, and EBS performance projections) are described below, followed by the detailed analysis of these factors for the Yucca Mountain site.

INFORMATION AVAILABLE AND ASSESSMENTS RELATIVE TO DEFINING A SITE-SPECIFIC CONTROLLED AREA FOR THE YUCCA MOUNTAIN SITE

Repository Layout Alternatives

The DOE Draft Environmental Impact Statement (DEIS), Appendix I (5) presents a number of alternative repository waste emplacement layouts based upon assumed possible waste inventories and assumed repository thermal loadings. These alternative configurations of the repository are shown on Figure 1, along with the location of the surface handling facilities to the east.

The final decisions on the repository thermal loading and eventual waste inventories for emplacement have not been made as yet. The alternative layouts presented in the DEIS were used as endpoints for the repository configuration alternatives-from smallest to largest. The

potential repository designs are discussed in greater detail in the DEIS (5), and are summarized in Table I. The Proposed Action alternative described in Table I uses all or part of blocks 1, 5 & 6 depending on the repository areal loading, while alternative waste inventories may use all of the repository areas shown on Figure 1.

Ground-Water Flow and Contaminant Transport Paths From The Repository

Potential contaminant transport pathways through the ground water below the repository have been described extensively in a number of DOE documents describing the projected performance of the site, particularly the DOE Viability Assessment (4) and the DEIS (5), and other documents supporting DOE's preliminary site suitability evaluation (6, 7, 8 and 9). The data used in the analyses described in this report were taken from these documents (summarized in (10)).

After considerable site characterization efforts, there is still uncertainty in the flow reflecting the significant technical difficulties in characterizing ground water movement through the unsaturated zone at the site (10), and the inherent uncertainties involved in characterizing flow paths in highly fractured rocks in general. Extremely reliable projections of potential ground-water flow paths are not possible because of these inherent uncertainties; however, there is a sufficient body of information available to make reasonable projections of flow paths from the repository, as described in more detail below. Using the repository layout alternatives as a starting point, an "envelope" of potential flow paths from the repository and southward can be projected (as shown on Fig. 1). These potential envelopes can then be combined with projections of repository EBS performance to further define areas of the natural barrier that could contain levels of contamination in excess of regulatory standards.

Spatial distributions of chemical and isotopic data were used by DOE to infer (i.e., constrain) flow paths in the region. The analysis inferred flow paths by connecting upgradient areas that have distinct chemical compositions to downgradient areas that have similar chemical compositions (7). DOE indicates that the map of the potentiometric surface was used to guide, but not to determine, the selection of which downgradient areas potentially could be linked by a flow path to an upgradient area. There are, however, anomalies in the chemical composition of waters along the inferred flowpaths. DOE believes that these are probably due to the wide range of sampling depths and geologic units. The flow-path analysis assumed that the delta deuterium, delta oxygen-18, chloride, sulfate, sodium, and calcium composition of ground water along a flow path did not change because of interactions between rocks and the ground water, local recharge of water with a different composition, or vertical mixing between aquifers (see Appendix VI.2.1.4 of (10) for a more detailed discussion). Because flow-path analyses trace ground water in two dimensions, the possible effects of local recharge and vertical mixing between aquifers are not considered. Neglecting the effects of recharge and aquifer mixing in DOE's simple two-dimensional (2-D) analysis causes the estimated flowpaths to be diverted away from areas where the ground-water composition changes as a result of these processes. In reality, recharge and vertical mixing between aquifers also could divert ground water upward or downward beneath the affected areas, as well as laterally away from these areas.

Table I
 Repository Layouts for Thermal Loads and Waste Inventory Options Presented in the Draft
 Environmental Impact Statement (DEIS) for Yucca Mountain (DOE 99)

Repository Alternatives (DEIS - DOE 99)	Repository Blocks Shown on Figure 1	Thermal Load MTHM*per acre
<u>Proposed Action**</u> (70,000 MTHM)		
• high thermal load	5	85
• intermediate thermal load	5	60
• low thermal load	1, 5, 6	25
<u>Expanded Inventory Options</u>		
Modules 1 & 2 (DEIS)***		
• high thermal load	5, 6	85
• intermediate thermal load	1, 5, 6	60
• low thermal load	1-6	25

*MTHM - metric tons of heavy metal

** Proposed Action - total repository inventory = 70,000 MTHM (~ 65k MTHM spent fuel, ~ 5k MTHM of high-level radioactive wastes (HLW), ~ 8 k canisters)

*** Expanded Inventory Modules - Module 1 = ~ 108 k MTHM spent fuel + ~ 22 k canisters of HLW; Module 2 = Module 1 + ~ 6.1 k m³ of other wastes

Various flow paths beneath and around Yucca Mountain are shown on Figure 2 (from (7))

Ground water beneath the potential repository flows southeast towards Fortymile Wash, but then moves south-southwest parallel to, and west of, the wash until it reaches the Amargosa Valley (Figure 2, flow path #6). This flow path is constrained by (i.e., flows between) flow path #2 in Fortymile Wash and flow path #5 in eastern Crater Flat. DOE's assumption that chloride concentrations are not altered by water/rock interaction is based on the absence of chloride-bearing minerals in the volcanic aquifer.

DOE believes that the regional flow paths constructed on the basis of the hydrochemical and isotopic data are generally consistent with flow paths that could be inferred from the potentiometric surface but have a stronger north-south component. DOE observes that the stronger north-south component could reflect the general north-south structural fabric of the rock, the inability of the method to account for chemical mixing due to recharge or upwelling from the carbonate aquifer, or simply the sparseness of the data in certain areas. DOE also notes

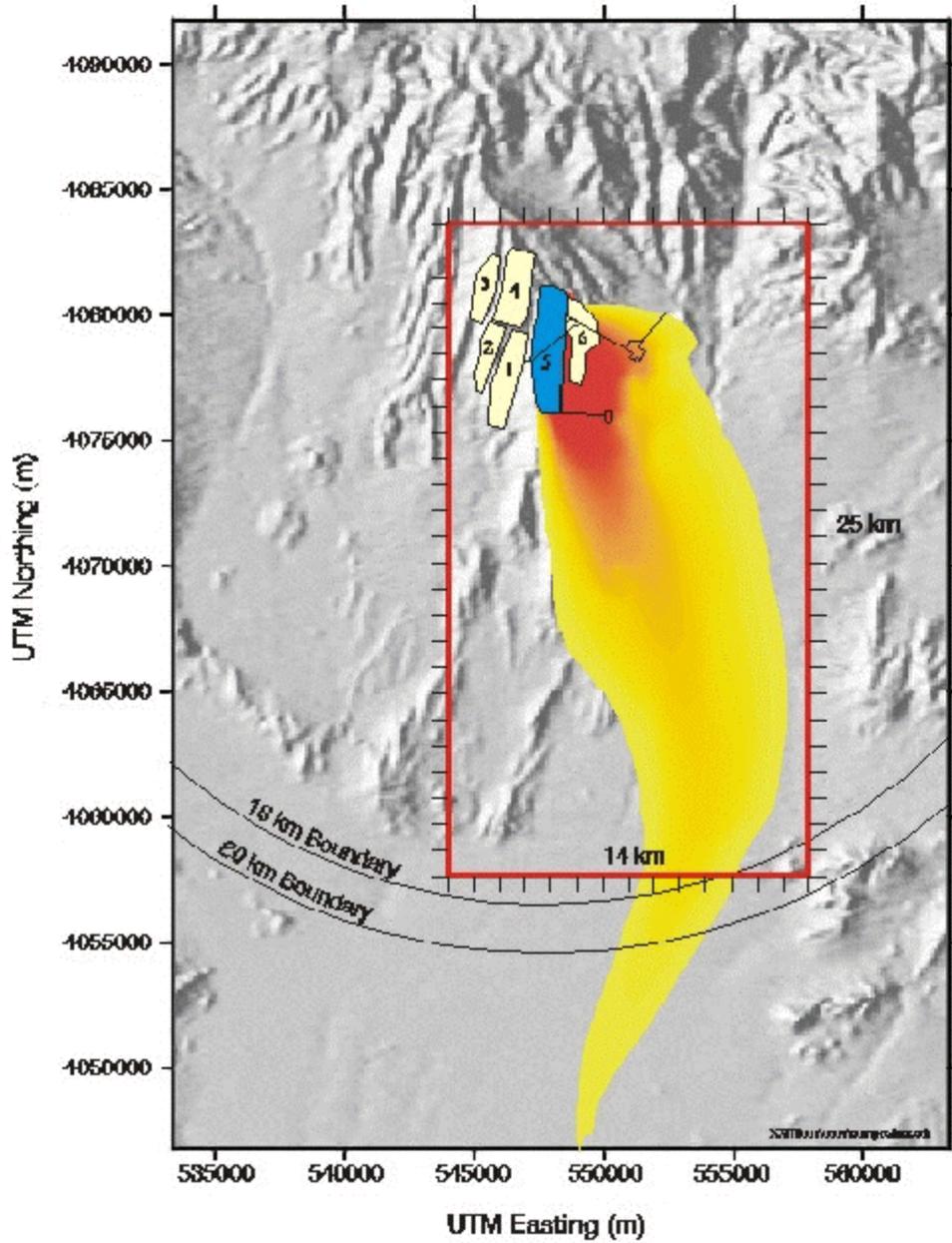


Fig. 1. Site-Specific Controlled Area (showing potential contaminant transport paths and repository configurations)

that although it is not possible to conclusively identify the reason for the differences, the flow paths are bounded by the two representations of the flow system (both of which rely on different and independent sets of assumptions, and both of which are consistent with the potentiometric surface).

Importantly, DOE believes that the chloride data, as well as other chemical and isotopic data, suggest that ground water from beneath the potential repository area may not flow along the south-trending faults in the southern part of the mountain. DOE believes that this conclusion is consistent with the potentiometric surface map that indicates that ground water in this area probably flows from Crater Flat.

Repository Engineered And Natural Barrier Performance Projections

Information on the projected performance of two EBS designs are is presented in (4) and (8) for an older design, and in (6) for the current EDA II design. The new design includes features intended to increase the time required for corrosion to breach the waste packages, water to contact the wastes, thereby resulting in releases. These new design features include the following.

- A drip shield over the waste packages to deflect any ground water seeping into the emplacement drifts from direct contact with the waste packages.
- A redesign of the bimetal waste container to place the corrosion resistant alloy on the outside of the package rather than the inside.
- The elimination of as much of the concrete supports in the underground emplacement area as feasible and a lower waste thermal loading compared to previous designs.

Performance projections for the EDA II design show releases under expected conditions are essentially zero during the regulatory time frame (6, 9), however the projected waste package lifetimes rely on the extrapolation of short-term laboratory tests to in-service periods of thousands, to tens of thousands, of years. Such extrapolations will remain questionable, and if they cannot be supported releases during the regulatory time period would be expected. For defining a maximum controlled area size limit in advance of the final repository design and performance assessments, we must assume that releases are possible and then examine the potential pathways for radionuclide transport through the ground-water system.

Assuming a long-lived waste package, potential releases during the regulatory period may well be dominated by “off-normal” conditions. “Off-normal” conditions would include disruptive events, such as roof falls, that could cause releases by inducing containment failures or accelerating failure rates in the EBS. Another “off-normal” condition is the early failure of waste packages as a result of manufacturing defects. Manufacturing defects could also act to accelerate anticipated corrosion processes, leading to earlier failures than predicted from

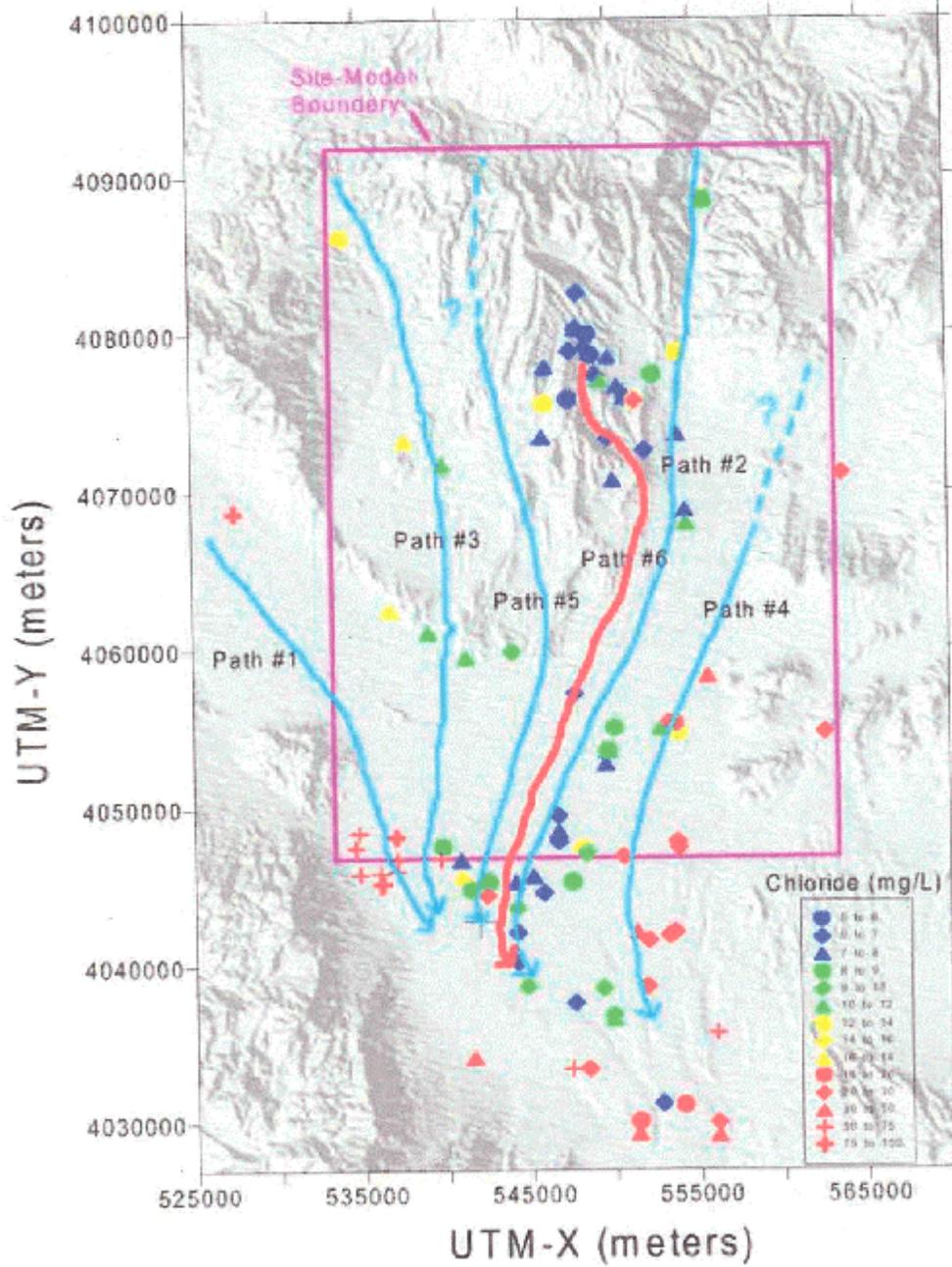


Fig. 2. Groundwater Flow Paths Near Yucca Mountain.

laboratory corrosion testing data alone. The important aspect of these “off-normal” failures is that they could occur at any time and at any place within the repository, and releases would then be possible anywhere within the envelope of ground water flow paths from the repository. Estimates of ground-water travel times in the saturated zone from the repository to a location 20 km downgradient have been reported as varying between approximately 15 and 31 m/yr, depending on the parameter values used and conceptualization of the flow system (11), suggesting that any releases into the ground-water flow system could reach the location of current populations if the releases occurred early enough in the regulatory period.

As noted in the discussion above, DOE’s particle tracking analysis did not address the degree to which a plume of contamination may spread laterally due to transverse dispersion. DOE, however, has performed advective-dispersive transport simulations that do incorporate transverse dispersion, and resulted in the plume shown in Figure 1 (12).

In order to provide an independent assessment of the effects that transverse dispersion may have on a potential plume of contamination emanating from Yucca Mountain, a model simulation was performed by EPA with a modified version (13, 14) of the computer codes MODFLOW and SURFACT. MODFLOW is a widely used flow code developed by the United States Geological Survey. SURFACT is a companion transport code to the MODFLOW code. The model domain used was 8 km by 30 km, divided into 18 layers that reach to a depth of 350 meters. There are 110,700 elements in the grid that are uniformly spaced at 200 m. Model input parameters for MODFLOW result in a seepage velocity of 31.5 m/yr. Values for longitudinal, transverse and vertical dispersion were obtained from the Saturated Zone Expert Elicitation Panel (which made estimates of these parameters which were used in later performance assessments (4)), and were assigned values of 100, 10 and 5 m, respectively. The source term was assumed to be 200 m long in the direction perpendicular to ground-water flow.

The plume width that corresponds to a two order of magnitude decrease in concentrations at 18 kilometers is 3400 m. This width is consistent with that predicted by DOE at the 18-20 K boundary (Figure 1). The effects of transverse dispersion were added to the projected ground water flow paths developed by DOE (12) and the total envelope of transport pathways is shown on Fig. 1.

Releases from waste package failures are likely to be narrow discrete contamination plumes from individual packages scattered across the repository that fail by “off-normal” causes, such as manufacturing defects or unanticipated accelerated corrosion processes. The fractured nature of the natural barrier rocks along potential transport paths would also suggest that contamination plumes would be narrow in comparison to the behavior of a contamination plume in a flow system governed by porous-flow characteristics. A more widespread release across the repository would only be possible if the extrapolations of long-lived waste package corrosion resistance were not shown to be correct. In this case, the expected degradation of the waste may result in projected failures of many waste packages within the regulatory time frame. Understanding the flow system around and below the repository allows an estimate to be made of the maximum extent of the natural barrier that could be contaminated.

DEFINING CONTROLLED AREA BOUNDARIES

Using the available information on repository configuration alternatives, ground water flow and contaminant transport paths around the repository particularly in the saturated zone, and assumed EBS releases from the repository, it is possible to define a maximum size for the controlled area. The controlled area would assure that unanticipated releases from the repository, which could generate narrow, and perhaps highly concentrated contamination plumes from anywhere in the repository, are contained within it. Since these "off-normal" failures can also occur at early times, the institutional control function of the controlled area suggests that all potential transport pathways should be contained in the controlled area.

Northern Boundary. Hydrologic information shows that contaminants potentially released from the repository will not move northward. Furthermore, transverse dispersion will occur in a direction perpendicular to the ground water flow direction. Therefore, transverse dispersion will cause the plume to spread east and west rather than to the north. Therefore, the northern boundary need only include a buffer zone around the potential repository blocks, assumed to be 1 km here.

Western Boundary. Transverse dispersion effects are not expected to spread the plume to the west beyond the flowline identified as Path #5 in Figure 2. This pathline is also coincident with the western boundary of the controlled area as defined by a 1 km buffer zone around the potential repository blocks.

Eastern Boundary. The eastward flow and transport paths are shown in Fig. 1. The eastern controlled area boundary would include this flow path and a buffer to compensate for remaining uncertainties.

Southern Boundary. The southern controlled area boundary is determined by the compliance point for the individual protection standard in the final rule, i.e., the southern boundary of the Nevada Test Site directly downgradient from the repository. This location was chosen because it is the closest potential location of an exposed population, and is not dependent on the ground water flow system or projected performance of the EBS (3).

These boundaries are shown on Figure 1. The area of the rectangle around the repository blocks and projected flow paths is approximately 350 km², however considerable area within this rectangle will have no contamination potential. A controlled area that corresponds more realistically with the actual envelope of potential transport paths would be about 300 km² in area. It is important to note that while the maximum size of the controlled area in the final rule is 300 km², most of the potential contamination plume is contained within the boundary of the NTS, which actually extends north-south along the eastern flank of Yucca mountain to approximately the 18 km distance shown on Fig. 1. The extent of the controlled area extending beyond the NTS boundary should be considerably less than the 100 km² limit used in the generic standard, Part 191 (2). Since the NTS is already restricted access land without the repository, the actual

commitment of otherwise available land is still consistent with the 100 km² limit given in Part 191.

SUMMARY

The approach discussed here defined the maximum size of a controlled area in the same way as it is likely to be determined from assessments of the final repository configuration and disposal system performance taken into a licensing process. The maximum controlled area size was defined to assure that the two important regulatory functions were met, i.e., an area can be defined as a compliance mechanism consistent with the anticipated behavior of the disposal system, and an institutional control perimeter can be identified to protect against inadvertent intrusions. A smaller controlled area can be defined if EBS performance can be reliably bounded, particularly with respect to radionuclide releases from “off-normal” waste package failures, which have the potential to occur anywhere in the repository.

The controlled area size limit set in the final standards (3) does not mandate that the controlled area defined for licensing must be 300 km² in area, or that the southern boundary must be the NTS boundary. DOE is free to propose a smaller area if EBS performance is as suggested in current assessments. The analyses performed here illustrate the important components of developing a site-specific controlled area for the proposed Yucca Mountain repository site. These analyses have explored a technical approach to framing a maximum controlled area size that is responsive to its regulatory and institutional control functions; i.e., providing a compliance measure and a minimal area for institutional control placement.

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