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JUL 15 1985

J. J. Linehan
Section Leader
Repository Projects Branch
Division of Waste Management
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

EXPLORATORY SHAFT PERFORMANCE ANALYSIS STUDY

Enclosed, for your information, is a Sandia National Laboratories performance analysis related to determination of quality assurance levels for the exploratory shaft. The enclosed material is supplemental to the information on exploratory shaft conceptual design forwarded to you with my letter of June 7, 1985. Members of your staff have indicated an interest in reviewing these documents prior to the August 27-28, 1985 Exploratory Shaft Design Technical Meeting.

Please contact J. S. Szymanski of my office if you have any questions regarding this matter.

Donald L. Vieth

Donald L. Vieth, Director
Waste Management Project Office

WMPO:JSS-1259

Enclosure:
As stated

cc w/encl:
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V. F. Witherill, WMPO, DOE/NV
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D. T. Oakley, LANL, Los Alamos, NM
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J. R. Tillerson, SNL, 6313, Albuquerque, NM

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Sandia National Laboratories

Albuquerque, New Mexico 87185

July 2, 1985

Dr. Don Oakley
Los Alamos National Laboratory
MS F-671
Los Alamos, NM 87545

Dear Don:

Subject: Performance Analysis Studies to be Used in Determining Quality Assurance Levels for the Exploratory Shaft Design and Construction Activities

This letter constitutes SNL's updated response (original response 2-20-85, Hunter to Oakley) to letter WX-4-6482 from D. C. Nelson to T. O. Hunter on August 2, 1984. It is our intent that the position presented in this cover letter and attachments be accepted as a NNWSI Project position. The attachments to this letter have been changed based on the comments received during the presentation to the Technical Project Officers (TPOs) on February 22, 1985, and the comments from LANL and LLNL following the TPO meeting. It is SNL's intent to combine the contents of this letter and attachments and publish this study as an SNL report.

Three items were identified in D. C. Nelson's letter which requested performance analysis studies:

1. "Rock Damage During ES Construction - A performance analysis study is required to assess the potential for radionuclides to reach the accessible environment via construction caused fractures around the ES. Of concern is what effect increased rock fracturing has on the escape of radionuclides. We need to know what extent of rock damage is acceptable so that proper construction controls can be established, adequate sealing techniques can be implemented, or other corrective action can be taken. This analysis should consider the distance of the repository waste from the shaft and both the upward travel of airborne or vaporborne radionuclides and the downward travel of waterborne radionuclides."

2. "Shaft liner - A performance analysis is required that addresses the role of the ES in the repository, the performance required of the liner during the operational or post-closure phase, and whether the concrete liner is expected to contribute to the success of the sealing of the repository."

3. "Shaft internals - A performance analysis is required that addresses whether the shaft internals installed in the ES(s) during the site exploration phase will be used in the repository. If so, what will the function of the shaft be and what are the consequences of failure as far as radionuclide containment is concerned."

This cover letter summarizes Items 1, 2, and 3. Detailed analyses for Items 1 and 2 are reported in the attachment. The significance of the penetration of the exploratory shaft into the Tuffaceous Beds of Calico Hills is not assessed in detail here.

Approach to Items 1 and 2

Perspective for Performance Assessment at the Yucca Mountain - Any conclusions about the performance of selected components of the Yucca Mountain Disposal System should only be made after considering how the overall isolation system performs. Conceptually, the system at Yucca Mountain can be idealized as shown in Figure 1 (Section 6.4.2 NNWSI Environmental Assessment). Isolation relative to ground-water transport is provided by an unsaturated region of the Topopah Springs and Calico Hills units varying between 150 m and 300 m in vertical thickness. A reference value of thicknesses chosen for bounding performance assessments has been assumed of 50 m of the Topopah Springs and 150 m of zeolitized Calico Hills. If moisture contents of 0.10 and 0.28 are assumed with a flux of 0.5 mm/yr, the travel time to the water table is approximately 83,000 years. At a flux of 0.5 mm/yr, a region 10.0 m in radius around the shaft would transmit about .16 m^3/year.

The shafts have the potential to change the anticipated transport by changing the rate or volume of water which flows to the storage horizon. In the worst case, the shaft would act as a short circuit for surface waters to the repository level. In one of the scenarios analyzed, waters from a 500-year flood are collected by the drainage areas in the vicinity of the exploratory shaft and focused to the waste disposal area. Such a scenario would allow flow into the repositroy at the rate controlled by the hydraulic conductivity of the shaft backfill and the damaged zone. In Appendix A, a preliminary system performance assessment is presented. In this assessment, it is assumed that all of the water from twenty, 500-year floods is allowed to enter the shaft and flow into the repository rooms. It is shown in the analysis that this water would result in a release of radioactivity which is less than the NRC allowable release rates and less than the EPA standard for the accessible environment even if no transport through the unsaturated zone is considered. Consequently, even if no engineering measures are taken to prevent flow into the shaft, no significant consequence would result from this flooding scenario.

Nevertheless, in order to assure even better system performance, shaft sealing (surface barrier and station plugs) will provide additional protection against water intrusion.

Three conceivable scenarios were investigated by the International Technology Corporation (ITC) at SNL's request to answer Items 1 and 2. In each scenario, extreme cases were analyzed. The detailed results are reported in Appendix B.

Surface-Water Drainage Down the Exploratory Shaft - Calculations were made to (1) bound the water inflow that could occur in the shaft following severe flooding, (2) determine if water build-up in the shaft (hence potential lateral flow to the waste disposal area) would be anticipated under these conditions, and (3) determine if the damaged zone would influence whether or not water could flow past the waste. To establish an upper bound for surface waters that could conceivably enter the shaft, the 100 and 500-year floods were computed. The surface water collected by the watersheds associated with Coyote Wash (the proposed site for the exploratory shaft) and the wash immediately south of Coyote Wash were assumed as the source of water entering the shaft. The results from this computation indicated that large volumes of surface water 86,000 m^3 could be collected by these watersheds under extreme rainfall conditions. If water drainage out of these watersheds was blocked by landslides or by flood debris, then some or all of these waters could enter the shaft.

It was shown from this flood calculation, the flow of water through the shaft backfill, and the flow through the base of the exploratory shaft that the outflow from the base of the shaft (for the entire range of shaft backfill materials considered) is less than the volume of water entering the shaft at the surface assuming a rock damage zone around the ES (Figure 4, Appendix B). This implies that for the cases analyzed water build-up can occur in the shaft. Even if no damaged zone is present, it would be necessary for the hydraulic conductivity of the shaft backfill to be less than approximately 10^{-3}cm/s to avoid water build-up in the shaft. This value corresponds to a very fine sand, silts, or mixtures of sands, silts, and clay; these materials are less permeable than those being considered as shaft backfill.

It is, therefore, concluded that to control the lateral migration of water to the waste disposal area, assuming a build-up of water at the base of the shaft, it may be more effective to emplace a surface barrier and/or drift plugs rather than emplace a shaft backfill having an effective hydraulic conductivity comparable to the undisturbed tuff (assumed in these analyses to be 10^{-5} cm/s). It is suggested by this conclusion that the presence of engineered components will be used to control water that may potentially enter the waste disposal area.

Subsurface-Water Inflow into the Repository from a Discrete Fault - This series of calculations sought to determine if water orginating from a discrete fault zone could migrate laterally from the waste storage area through mined openings to the exploratory shaft. If waters could reach the ES, then the impact of the damaged zone and the quality of the liner would have to be further investigated. Conversely, if no waters reach the shaft, using engineering measures in the drifts, then the quality of the liner and the disturbed zone below the repository station would not be significant from a sealing perspective. It is implied in this approach that if waters from a discrete-water-producing zone reached the ES, radionuclides could also potentially be transported to the ES by these waters.

In developing this scenario, it was assumed that the fault penetrating through the repository (Ghost Dance Fault) extends to the surface and is fully saturated. The calculations presented in the attachment show that relatively simple engineering measures, such as emplacing dams, can be implemented to encourage drainage through the drift floor prior to reaching the ES.

Airborne Release of Radionuclides Through the Exploratory Shaft - This scenario was analyzed by comparatively evaluating the effect of air flow with and without a disturbed zone in the shaft. Calculations investigating convective transport of repository air were performed. A temperature gradient can develop between the base of the exploratory and the shafts or ramps outside the prospective repository area. A comparatively higher temperature can be reached at the base of the exploratory shaft due to the heat generated from the waste packages as compared to the shafts outside the prospective repository boundary. This temperature difference provided the driving mechanism for convective transport.

Air flows through the shafts, ramps, and the emplacement and access drifts were computed assuming no airflow through the rock mass. In these calculations the air permeability of the shaft and drift backfill was varied. The air flow was also computed assuming no damaged zone and a damaged zone extending one radius from the edge of the shaft. These calculations are considered particularly conservative because the peak temperature in the repository will probably occur well before the expected waste-package lifetime in the Yucca Mountain environment is reached.

As shown by the analyses, the flow rate for all cases analyzed is low. "When the backfill air conductivity is relatively high [10 ft/min or 0.1 ft/min], the effect of the damaged zone is negligible. When the air conductively is relatively low [10^{-5}ft/min], the relative effect of the damage zone is greater but the absolute flow rates are very low [10^{-3} to 10^{-5} cfm] and probably negligible." (Page 39, Appendix B). The results from Appendix A illustrate that the presence of a damaged zone

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does not significantly impact the potential gaseous releases of I-129 and C-14, and hence, do not detrimentally affect the ability to meet the EPA performance criteria.

Approach to Item 3

No performance analysis was considered necessary to respond to this item. Messrs. Stinebaugh and Robb of SNL's Geotechnical Design Division have identified the function of the exploratory shaft and the six-foot diameter emergency exit shaft associated with the exploratory shaft. Their responses are summarized below.

The exploratory shaft will be used as the primary source of intake air for the waste emplacement operations. All shaft internals will be removed prior to these operations and the concrete liner will remain. The six-foot diameter, emergency-exit shaft will be used as an air supply during repository operations to ventilate the repository shop facilities that support the waste emplacement operations. Because the volume of air supplied by the six-foot diameter shaft will be minimal, the internal features and the hoist hardware can be left in place without hindering its intended function during repository operations. Additionally, if the shaft internals for the six-foot diameter shaft are left in place, then the shaft could continue its use as an emergency exit. Therefore, there are no radionuclide containment issues identified at this time related to the planned usage of either the ES or the six-foot diameter shaft.

CONCLUSIONS

Ability of the repository to meet NRC and EPA criteria is not significantly affected by the degree of damage which can be anticipated near the ES using controlled excavation methods or by the quality of the liner. Therefore, from a sealing perspective, public health and safety is not compromised during the post-closure period by the presence of a damaged zone near the ES.

Surface barriers in the shaft and station plugs in the repository drifts may be used to control the volume of surface water entering the waste disposal area; therefore, detailed analyses of the performance of these engineered components will be made to evaluate needed QA levels for their design and construction. Additional areas of the repository, such as the shop area, will be evaluated for their potential to enhance drainage of waters entering the repository.

With respect to needed field data, experiments in the exploratory shaft that assess the drainage capacity of the Topopah Spring Member, confirm the extent and hydraulic conductivity of the damage zone, and quantify the water inflow from discrete sources (if any), remain the highest priority in the sealing program.

RECOMMENDATIONS

The construction controls implemented during shaft excavation need be no stricter from a sealing perspective than from short-term stability viewpoint.

SNL should be on future distribution lists to review proposed blasting procedures to assure that excavation plans are consistent with construction controls recommended above.

Overbreak that occurs while excavating the exploratory shaft should be recorded.

The shaft liner placed below the repository station may be removed at decommissioning to enhance the drainage through the base of the exploratory shaft. Written assurance should be provided to us indicating that the proposed construction methods will not preclude nor unnecessarily complicate the removal of the liner below the repository.

If you or your staff have any questions of the contents of the attahcment, please contact Joe Fernandez (FTS 844-2365) or Joe Tillerson (FTS 844-5575).

Sincerely,

Joe R. Tillerson for

Thomas O. Hunter, Manager
NNWSI Project Department, 6310

JRT:6314:wb

Copy to:

LANL	Dean Nelson
LANL	Wes Meyers
WMPO/DOE	D. L. Vieth
WMPO/DOE	V. Witherill
WMPO/DOE	L. Skousen
WMPO/DOE	J. Szymanski (with additional copy for transmittal to NRC)*
WMPO/DOE	M. Valentine
WMPO/DOE	D. Irby
SAIC	M. E. Spaeth
SAIC	M. Glora
LLNL	L. D. Ramspott
WES	J. Wright
USGS	W. W. Dudley
USGS	W. E. Wilson
USGS	P. Montazer
ITC	Dev Shukla
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6314	R. E. Stinebaugh
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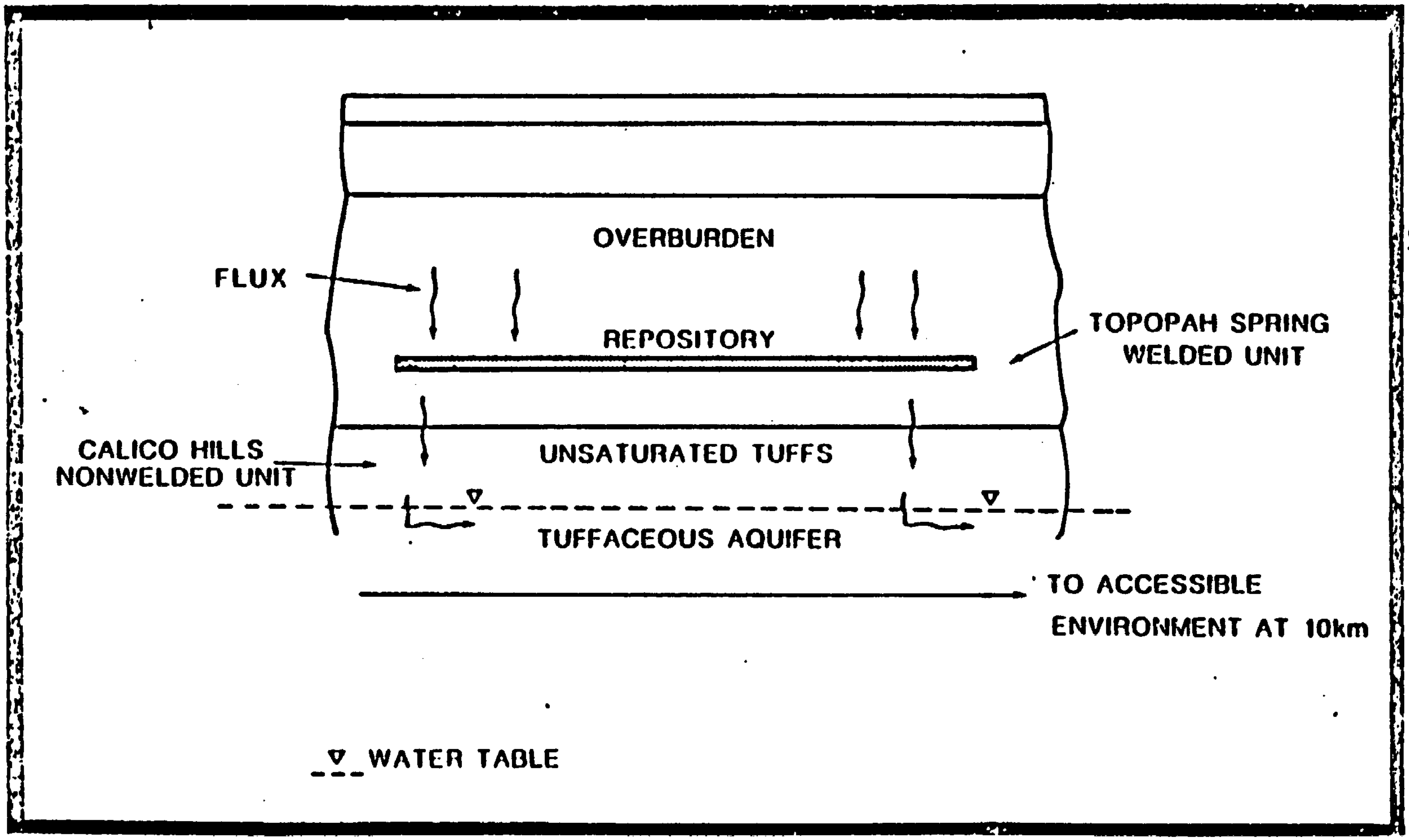

Figure 1. A simple model of proposed waste-disposal system at Yucca Mountain.

Appendix A

Performance Assessment of Radionuclide Release in the Vicinity of the Exploratory Shaft

Introduction

The purpose of this appendix is to illustrate the significance of the damaged zone associated with the exploratory shaft on the release of radionuclides in the unsaturated tuff at Yucca Mountain. This objective is achieved by evaluating the potential radionuclide releases due to (1) water contacting bare spent fuel and dissolving radionuclides and (2) air moving through the drifts and shafts and removing gaseous radionuclides within the waste disposal drifts. Because the volume of water and movement of air control the radionuclide release and release rates, it was necessary to determine how the damage zone influences water transport down the shaft into the waste disposal area and air transport from the waste disposal area to the accessible environment.

The volume of water assumed is an extreme, bounding event occurring at the surface (a 500-year flood). Air movement is assumed to be caused by the temperature difference at the surface and at the base of the exploratory shaft following emplacement of waste. This convective air movement is assumed to transport gases that may be available in the drifts. The emphasis of this assessment, however, is on release of radionuclides following the flooding of the repository downgrade from repository station at the exploratory shaft. This assessment explicitly includes (1) the influence of both shaft backfill and the damaged zone assumed to surround the shaft on the quantity of water contacting the waste and subsequently on the annual, fractional release rate for uranium-238 and (2) the influence of various water volumes on the total radionuclide releases for specific radionuclides and on the EPA ratio (summation of specific radionuclide releases to their respective release limits). The radionuclide releases are computed at the edge of the waste package. It is recognized, however, that the EPA criteria are meant to be applied to the accessible environment. The EPA criteria are presented only for comparison purposes.

This appendix contains the following:

- A discussion on the perspective of radionuclide transport mechanisms in the unsaturated zone.
- Descriptions of the scenario used, the radionuclide release model selected, and the input to the radionuclide release model.
- An evaluation of the water volume that could be associated with major flooding events.
- A discussion of the analyses performed and their results, including radionuclide releases due to waters from flood events and convective air movement.
- A comparison of these results with the EPA and NRC criteria.
- Conclusions and recommendations.

Perspective Into Radionuclide Transport

While several mechanisms can be postulated for transport of radionuclides from a nuclear waste repository in the unsaturated zone at Yucca Mountain, most can be shown to have little significance on radionuclide release. Nevertheless, it is worthwhile to examine the potential for radionuclide transport due to these mechanisms. They include: downward water movement by gravitational forces, gaseous diffusion, convective gaseous transport, upward water movement by matrix and fracture capillarity, and solid-solid diffusion. Some of these transport mechanisms are more significant than others. The results of travel-time calculations described below are intended to provide perspective on the more important mechanisms that should be considered when assessing the significance of the damaged zone associated with the exploratory shaft. Additional explanations of the calculational results presented below will be presented in future issues of this study.

- Downward water transport due to gravitational forces can occur in the matrix or fractures. Assuming a saturated hydraulic conductivity of 2×10^{-11} m/s for both the Topopah Spring and zeolitic, nonwelded Calico Hills unit (Peters, et al., 1984, p. 61) and a thickness of 200 meters to the water table, the transport time through the rock matrix would be about 400,000 years. A more complete evaluation of ground-water travel times through the unsaturated zone to the water table was computed by Sinnock, et al., (1984) considering variable fluxes and the effective porosity of the media. Ground-water travel times assuming matrix flow ranged from 10^4 to 10^5 years and assuming fracture flow ranged from 5 to 200 years.

- Upward transport of water due to capillary forces or major changes in saturation within the rock matrix is unlikely. The water table is generally more than 200 m below the repository. As previously reported (U.S. DOE, 1984, p. 6-126), the zone of continuous fully saturated voids is not expected to extend more than about 30 m above the water table, according to data on pore-size distribution and relationships between pore size and capillary pressure. Furthermore, it is likely that this zone could extend no higher than the top of the Calico Hills nonwelded unit in any event, because the contrast between the fractured, Topopah Spring welded unit and the porous Calico Hills nonwelded unit is likely to cause a capillary barrier between the two units. Additionally, it is estimated that the maximum rise in the water table during pluvial conditions has been only 130 m above the existing level (U.S. DOE, 1984, p. 6-200)

- Upward transport of water in fractures due to capillarity was computed using the formula $h = 2\sigma \cos\theta / \rho g b$ (Lohman, 1972, p. 2), where σ = surface tension of water against air, θ = contact angle between the water in the fracture and the tuff, ρ = density of water, g = acceleration due to gravity, and b = aperture of the fracture. This situation could be applied to fractures penetrating saturated zones such as the water table or a shaft containing water at the base. For fractures having aperture widths of 71μm and 25 μm, the rise in the fractures was computed to be approximately 0.2 m and 0.6 m, respectively. Because of the limited extent that capillary forces within a fracture can transport water upward, radionuclide transport upward by this mechanism is considered to be insignificant.

- Of all the radionuclides that can be released in the gaseous phase following the containment period, two, I-129 and C-14, may be important. Using the formula, $N = ED\,(dC/\tau dz)$, (Froment and Bischoff, 1979, p. 167), migration of the gaseous forms of these radionuclides through gaseous diffusion can be computed. In this formula, N = moles of gas diffusing per unit per cross-section, E = porosity of the material through which the gas is diffusing, τ = tortuosity factor, and dC/dz = change in concentration per change in distance. The minimum time to release 1% of the I-129 as I_2 and 0.3% of the C-14 and CO_2, CO, or CH_4, assuming a transport distance of 600 m through the drift and shaft, was computed as 110,000 and 80,000 years for I_2 and CO_2, respectively. The effect of the damaged zone on the release times for both open and backfilled drifts was minimal, i.e., < 0.5% reduction in the total transport time to the accessible environment.

- The transport time for radionuclides by means of solid state diffusion through the tuff matrix is computed to be 10^{16} years using a modification of Fick's law, $D = x^2/2t$, a diffusion coefficient of 10^{-15} cm^2/s and a distance of 300 m. This diffusion coefficient is at the higher end of diffusion coefficients of some solid systems given in Bird, Stewart, and Lightfoot (1960, p. 505).

The calculations reported above illustrate that some transport mechanisms are more significant than others when considering gaseous, liquid, or solid transport times. Release of radionuclides due to downward water transport is considered to be the most realistic dominant mechanism. Convective air transport of gases through the drifts and shafts, although not addressed in the calculations above, was determined as important to evaluate because of thermal energy differences within the repository. The calculations in this appendix therefore focus primarily on downward transport of radionuclides in the aqueous phase and air transport of gases due to convection. The rates of air movement due to convection are given in Appendix B. These rates are used in this appendix to determine the release of potential gaseous radionuclides.

Scenario

The annual, fractional release rates and total radionuclide releases for each radionuclide are computed for the following three cases. These cases deal with water transport and differ in the amount of water entering the waste disposal areas. The cases evaluating air transport through backfilled drifts and shafts are presented in Appendix B, pages 29 to 41.

Case I: The amount of water reaching the waste disposal areas is equal to that occurring from the 500-year flood.*

The annual, fractional release rate for U-238 is computed assuming that the quantity of water that reaches the waste containers is limited by the amount of water than can drain through the shaft backfill and the damaged zone in 100 days and in 365 days. After 100 days or 365 days, it is assumed that the impoundment of water at the surface no longer exists due to evaporation or evapotranspiration. The 365-day scenario is equivalent to an infinite supply of water because the release standards are expressed in quantity released in any one-year period.

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*The assumed volume of water associated with this 500-year flood is equal to the peak discharge of 24 m^3/sec lasting for one hour or approximately 86,000 m^3.

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The total radionuclide release resulting from all of the water from 20, 500-year floods is also computed so that the release can be compared to the EPA release limits and the EPA ratio. This total release of radionuclides is, therefore, twenty times the radionuclide release caused from the waters contacting the waste during one event.

Case II: The amount of water reaching the waste disposal area is equal to that occurring from the 500-year flood plus a matrix flow of 1 mm/year. (As discussed by Sinnock, et al. (1985, pp 13-16), the likely upper limit for flux through Yucca Mountain is 0.5 mm/year).

The annual radionuclide releases are computed assuming that the waters from one 500-year flood plus the matrix flow during one year can contact the waste package. The total release for each radionuclide is computed assuming that the waters from 20, 500-year floods plus all of the matrix flow (1 mm/year over 9,700 years) enters the waste disposal areas.

Case III: The maximum amount of water from an event occurring once every 500 years that can contact the waste canisters and not exceed the NRC or EPA guidelines.

The scenario used in each of the three cases presented above is one in which surface waters are able to enter the waste disposal area which is at a lower elevation than the elevation of the repository station at the exploratory shaft. The source of the surface water is an extreme event, a 500-year flood. The waters from this 500-year flood are collected by the drainage area associated with Coyote Wash (the proposed site for the exploratory shaft) and the drainage area immediately to the south of Coyote Wash. It is assumed that the volume of water occurring from the flood is equal to the peak discharge lasting for one hour. This corresponds to a 7-in rainfall. It is further assumed that débris from this event is deposited or a landslide occurs immediately below the location of the exploratory shaft. The occurrence of a major flood together with debris deposition or a landslide immediately below the exploratory shaft location followed by impoundment of flood waters is considered most unlikely. Additionally, there is no evidence of massive landsliding at Yucca Mountain. This unlikely scenario is used only to obtain a maximum amount of surface waters that could potentially be focused to the waste disposal area.

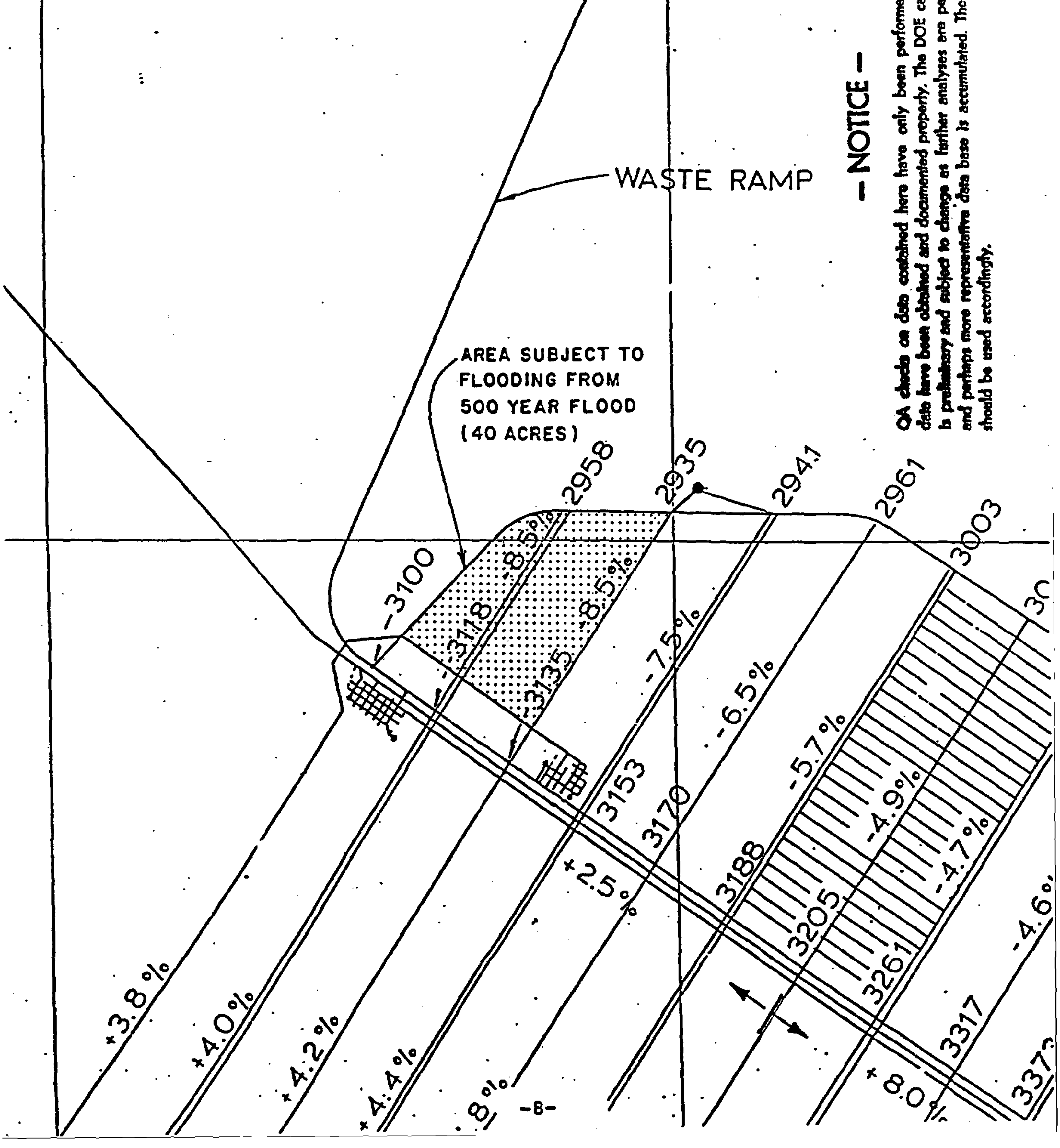
It is then assumed that all the waters captured from this event would then flow through the shaft backfill and the damaged zone to the base of the exploratory shaft. These waters then flow laterally to the waste disposal area and uniformly contact the waste packages. A preliminary drawing (Figure 1) has been prepared by Parsons Brinckerhoff Quade and Douglas which illustrates the grades of the access drifts in the vicinity of the exploratory shaft. As can be noticed from this drawing, the drifts that are basically north and east of the exploratory shaft have a downward grade. It is assumed that the drifts north of the exploratory shaft and east of the main access drifts can be flooded (see Figure 1). Figure 2 schematically illustrates the scenario discussed here.

Radionuclide Release Model

As documented by Oversby and McCright (1984), radionuclides exist in four distinct locations within the spent-fuel assembly and all locations must be considered in order to develop a comprehensive waste-package source-term model. These locations include the uranium matrix (which contains the majority of the radionuclides), the pellet-cladding gap, the spacers and grids, and the fuel cladding. This assessment considers this distribution of radionuclides when computing the radionuclide releases.

In this study, a congruent matrix dissolution mechanism was assumed. This mechanism limits the fractional release rate of radionuclides to the fractional dissolution rate of the matrix. It is further assumed that the uranium dioxide will become saturated with the water contacting the waste and therefore the UO_2 dissolution rate is determined by its solubility limit coupled with the quantity of water. Therefore, the fractional release rate

Figure 1. Diagram of the Grades of the Access Drifts for the Prospective Nuclear Waste Repository in Tuff (Preliminary Drawing)



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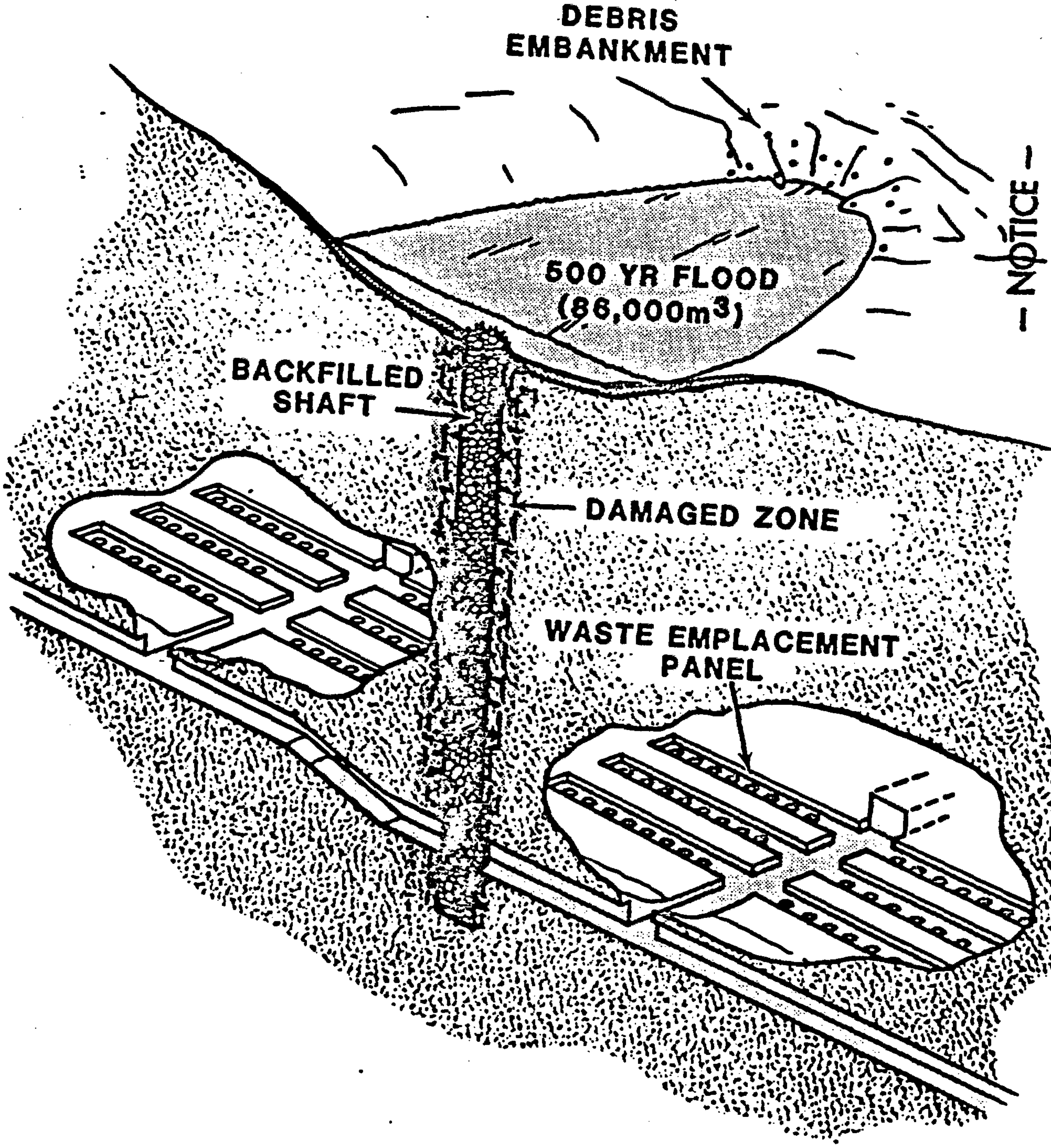

Figure 2. Schematic Diagram of Impoundment of Surface Water in the Vicinity of the Exploratory Shaft Following Deposition of Flood Debris or the Occurrence of a Landslide Immediately Downgradient from the Exploratory Shaft

for U-238 will control the release rate for other radionuclides that have a solubility-limited fractional release rate greater than that of U-238. This approach is similar to that presented in Braithwaite and Tierney (1985), Kerrisk (1984), and the draft environmental assessment (Section 6.3.1.2.3, U.S. DOE, 1984). It is conservatively assumed that no waste canister exists and that the fuel cladding is cracked to permit contact of water with the bare fuel. The formula for computing the fractional release rate and the radioactive release for each radionuclide are presented below.

$$F_i = Q \cdot \min \quad \frac{SW}{RIG}_{i} \quad \frac{SW}{RIG}_{U-238}$$

where:

F_i = fractional release rate of radionuclide "i" (1/year)

Q = annual quantity of water passing the horizontal cross-section of vertically emplaced waste packages (liters/year/1,000 MTHM) (see next section)

S = solubility of specific element (moles/liter)

W = atomic weight (grams/mole)

RIG = radionuclide inventory at 1060* years for spent fuel (grams/1,000 MTHM)

and:

$$RR = (F_i)(SA)(RIG)$$

---

*1,060 years after emplacement into reactor (or 1,000-year inventory following waste emplacement) and selected so that comparison to NRC criteria could be made.

where:

RR = radionuclide release (curies/year/1,000 MTHM)

SA = specific activity for the radionuclide (curies/gram).

The solubilities (at 25°C) for various elements are indicated in Table 1. Radionuclide inventory in grams per 1,000 MTHM are also listed in Table 1. These inventories were computed using the inventory values given for 1,060 years in the environmental assessment (U.S. DOE, 1984, p. 6-305) and (U.S. DOE, 1979, pp. 3.3.20, 3.3.21, 3.3.22, 3.3.25, and 3.3.26) and the specific activity of each radionuclide.

Seven radionuclides that exist in some proportion outside the matrix include: Tc-99, C-14, Cs-135, Cs-137, I-129, Ni-59, and Zr-93. As reported in Van Koynenburg (1984), the percentage of the C-14 inventory in the structural parts of the fuel assembly could be 67% for BWR and 61% for PWR spent fuel assemblies. In U.S. DOE (1979) the percentage of C-14 in the Zircaloy cladding hulls is approximately 7% of the total C-14 inventory. Oversby and McCright point out that some radioactive species can become segregated during reactor operations and can be released at a faster rate than the matrix fuel dissolves. The species of concern include cesium, iodine, and possibly technetium and their initial release rate is generally less than 1% of the inventory of the pin (Oversby and McCright, 1985, p. 10). Because the remainder of the inventory is believed to be within the matrix, cesium and similar species should dissolve at the same rate as the matrix. C-14, Ni-59, and Zr-93 are located within the fuel cladding in the following percentages: 67% (Van Koynenburg, et al., 1984, p. 2), 100% (U.S. DOE, 1979, Volume 1, p. 3.3.40), and 5% (U.S. DOE, 1979, Volume 1, pp. 3.3.20 and 3.3.21).

For these radionuclides that are located in part outside the matrix, their annual radionuclide releases and total radionuclide releases (up to 10,000 years) are computed as follows. The radionuclide releases (for a single event) for Cs-135, Cs-137, and Tc-99 aré equal to that portion released from the matrix plus 1/9,700 times 1% of their 1,060-year inventory. This latter input assumes that the waste package remains intact for the first 300 years following initial emplacement and that containment due to the spent fuel cladding fails linearly over the next 9,700 years. Again, one percent is believed to be that portion of cesium and similar species that are highly mobile in the fuel pin and exist in the pellet-cladding gap (Oversby and McCright, 1984, p. 10).The total radionuclide releases (up to 10,000 years following closure of the repository) for these radionuclides will be that portion released by matrix dissolution for 20 events (as defined above) plus 1% of their 1,060-year inventory.

For C-14, Ni-59, and Zr-93, it was assumed that their release was controlled by the uniform corrosion of the Zircaloy cladding. Because zirconium and Zircaloy cladding are extremely corrosion resistant (Uhlig, 1967, p. 324; Woodley, 1973, p. A-3; Rothman, 1984, pp. 1, 11; Oversby and McCright, 1985, p. 6), the release rate of the radionuclides contained within the fuel cladding is expected to be extremely low. Rothman used Hillner's equation for long-term oxidation behavior and computed the depth of oxidized Zircaloy to be 17 µm at a constant temperature of 180°C for 10,000 years. If the minimum thickness for Zircaloy cladding is assumed to be 600 µm (Rothman, 1984, p. 2 and Woodley, 1983, p. 12) and the release of radionuclides contained within the cladding was controlled by uniform corrosion; it would take approximately 350,000 years to release all of the radionuclides contained within the cladding. The time to release all the radionuclides would be longer if temperatures are lower. Using Hillner's long-term oxidation equations at a temperature of 100°C, the depth of oxidized Zircaloy after 10,000 years is calculated to be 0.0451 µm. If we assumed that the release of radionuclides were controlled by this uniform corrosion, then the release rate per year for radionuclides contained within the full cladding would be approximately 1×10^{-8} of the total inventory. This factor is used in the computation of yearly radionuclide release rate and the total radionuclide release up to 10,000 years following closure of the repository. The corrosion rate of the fuel cladding (1×10^{-8} of the inventory (in the cladding)/year) should not be affected by the sporadic nature of the water flows assumed in these analyses.

Quantity of Water Contacting the Waste Packages

The quantity of flow into the shaft has been calculated as follows. Using the formula developed by Squires and Young (1984) and the tributary area associated with Coyote Wash and the wash immediately to the south of Coyote Wash, the combined peak discharge for a 500-year flood is 24 m^3/s. If the duration of this peak discharge was one hour, the calculated volume of water would be approximately 86,000 m^3.

To determine the amount of water that will contact the waste packages, it is also necessary to compute the number of waste packages that are in the assumed flooded area of the repository. The flooded area, north of the exploratory shaft and east of the main access drifts, (outlined in Figure 1) is approximately 40 acres assuming that the drifts are backfilled with a material having a porosity of about 35%.* If we assume vertical emplacement of the waste packages and associate an extraction ratio of 24% (Dravo Engineers, Inc., 1984), then the floor area that would be flooded would be approximately 40,000 m^2. The number of canisters that could be placed in this 40-acre portion of the repository is 516. This number was computed assuming that the total number of canisters to be emplaced in the repository is 21,000 (70,000 MTHM). These canisters are distributed uniformly over 1,630 acres (the current size of the repository assumed in the conceptual design activity). Therefore, the amount of waste in 516 canisters would be 1,720 MTHM. The horizontal, cross-sectional area of a vertically emplaced waste package is 0.34 m^2 (U.S. DOE, 1984). The total cross-sectional area of these 516 waste packages would be 175 m^2.

While it is assumed that all of the flood water can enter the shaft, only a portion of it will contact the waste packages. It is assumed the water entering the shaft is uniformly distributed over the waste emplacement drifts in the subject area and only the water that covers the horizontal, cross-sectional area of the emplacement boreholes will be available to contact the

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*The backfilled assumption was used to maximize the area flooded in the repository.

spent fuel area. The amount of the water contacting the waste package would therefore be the cross-sectional area of the waste packages (approximately 175 m^2) divided by the floor area flooded (approximately 40,000 m^2) times the quantity of flood water. The total amount of water contacting 1,000 MTHM would be 2.26×10^5 liters.

Water Volume Evaluation

The volume of water used in this analysis was the peak discharge for a 500-year flood lasting for one hour. The duration of peak discharge, in fact, is extremely temporary. A hydrograph for the Yucca Mountain site would probably be similar to that shown in Figure 3. The shape is identical to that reported for the Eldorado Canyon, Nevada, flood of September 14, 1974 (Clancy and Harmsen, 1975, p. 15). The drainage area for this flood was much larger than the combined drainage area of Coyote Wash and the wash immediately to the south, 22.9 mi^2 compared to 0.19 mi^2. Because of this smaller drainage area, the duration of this flood would probably be shorter than the 3 hours observed for the Eldorado Canyon flood. The hydrograph assumed in this analysis is also compared with the probable hydrograph in Figure 3.

As illustrated in Figure 3, the hydrograph used in this assessment overestimates the amount of water that would be associated with a major flooding event. A more realistic volume of water for major flood events, i.e., the 100-year flood, the 500-year flood, and the potential maximum floodflow is computed below. The peak discharges are:

$Q_{100} = 186\ ft^3/s$ (Computed from formula in Squires and Young, 1984, p. 1)

$Q_{500} = 843\ ft^3/s$ (Computed from formula in Squires and Young, 1984, p. 1)

$Q_{\text{Potential Maximum}} = 1{,}900\ ft^3/s$ (Crippen and Bue, 1977, p. 15)

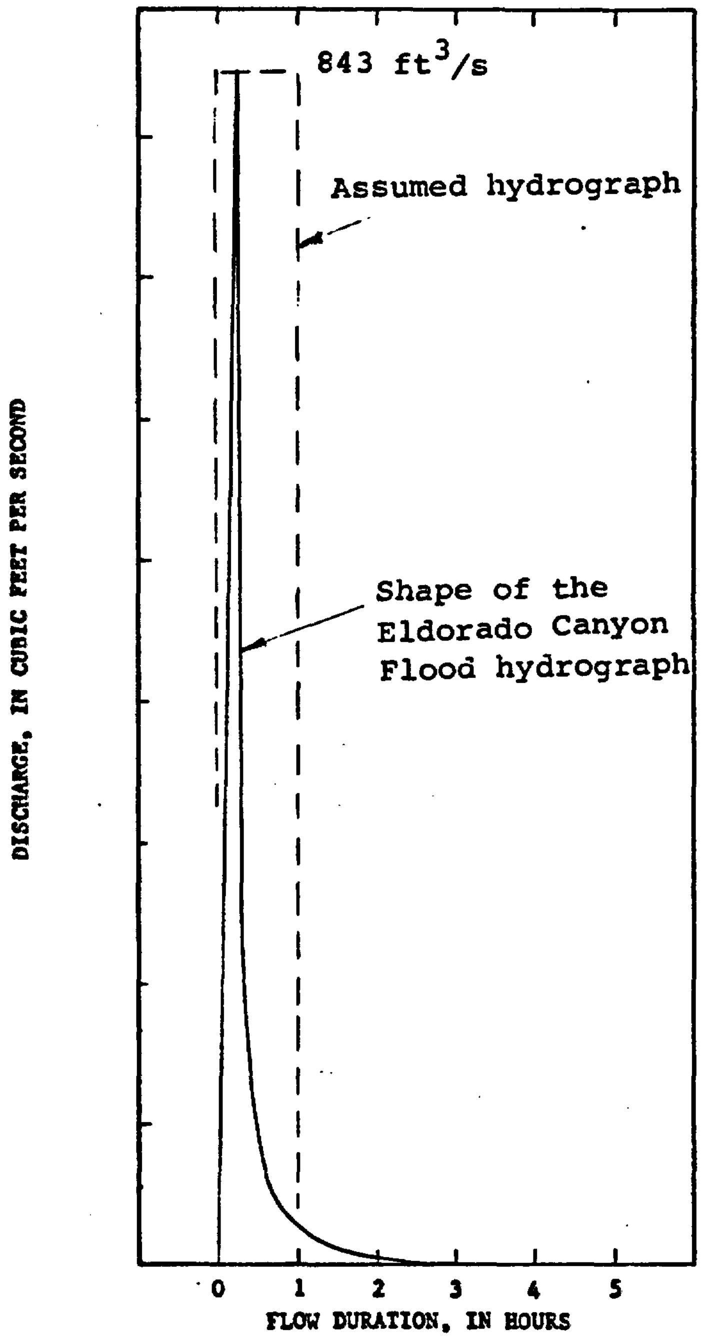

Figure 3. Comparison of the Assumed Hydrograph Used in This Study With the Eldorado Canyon Flood Hydrograph

Using these peak discharges and the shape of the Eldorado Canyon flood hydrograph, the total amount of water collected from the drainage area associated with the exploratory shaft would be:

$$Q_{100,\text{Total}} = 1.67 \times 10^{5}\ \text{ft}^{3}\ (4.73 \times 10^{3}\ \text{m}^{3})$$

$$Q_{500,\text{Total}} = 7.57 \times 10^{5}\ \text{ft}^{3}\ (2.14 \times 10^{4}\ \text{m}^{3})$$

$$Q_{\text{Potential Maximum,Total}} = 1.71 \times 10^{6}\ \text{ft}^{3}\ (4.83 \times 10^{4}\ \text{m}^{3})$$

The total flow from these events up to 10,000 years would be 9.4×10^{5} m^3 assuming 97, 100-year floods; 20, 500-year floods, and 1 potential maximum flood. This total volume can be slightly reduced assuming that water entering the sump can be drained through the base of the shaft prior to the recurrence of a second event. This initial volume of 9.4×10^{5} m^3 could be reduced to approximately 9.2×10^{5} m^3. This reduced volume of water is approximately one order of magnitude greater than the volume of water assumed for the 500-year flood used in this performance assessment.

Discussion of Results and Comparison With the EPA and the NRC Criteria

The primary criteria applied to the release of radionuclides are the annual release rates at the engineered-barrier system boundary specified by U.S. NRC (1983) and the cumulative release limits at the accessible environment given by U.S. EPA (U.S. EPA, 1984; working draft no. 5). The release criteria given by U.S. NRC in Section 60.113 of 10 CFR 60 is:

> "(B) The release rate of any radionuclide from the engineered-barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided that this requirement does not apply to any radionuclide

— NOTICE —

QA checks on data contained here have only been performed to determine that these data have been obtained and documented properly. The DOE cautions that any information is preliminary and subject to change as further analyses are performed or as an enlarged and perhaps more representative data base is accumulated. These data and interpretations should be used accordingly.

which is released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be of part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay."

The criteria provided in Appendix A of 40 CFR 191 (U.S. EPA, 1984) gives the release limits of some radionuclides in total release (curies) up to 10,000 years after emplacement. For most radionuclides the release limit is 100 curies. For unspecified alpha-emitting radionuclides the release limit is 100 curies. For unspecified radionuclides that do not emit alpha particles the release limit is 1,000 curies.

The calculated release rates and limits are compared in this assessment with the U.S. EPA and U.S. NRC criteria. It must be emphatically stated that this is only a comparison to obtain a perspective of the significance of the damaged zone. A direct application to the NRC criteria and EPA regulations is inappropriate. For example, the NRC criteria applies to "anticipated processes and events." The scenario presented in this assessment is considered by the author to be an unanticipated event and extremely unlikely. The EPA regulations apply to the accessible environment not the edge of the waste package as assumed in this assessment.

Radionuclide Releases From Flood Events

Figure 4 and Table 1 are presented to enable a comparison with the NRC release rates whereas Figures 5, 6, and 7 and Table 2 are presented to enable a comparison with the EPA criteria.

Figure 1 illustrates the fractional release rate of U-238 as a function of the hydraulic conductivity of the backfill assuming the presence of a damaged zone and alternatively no damaged zone (Case I only). Because the fractional release rate of any radionuclide cannot be greater than the fractional release rate of U-238, the fractional release rate of U-238 was plotted to represent

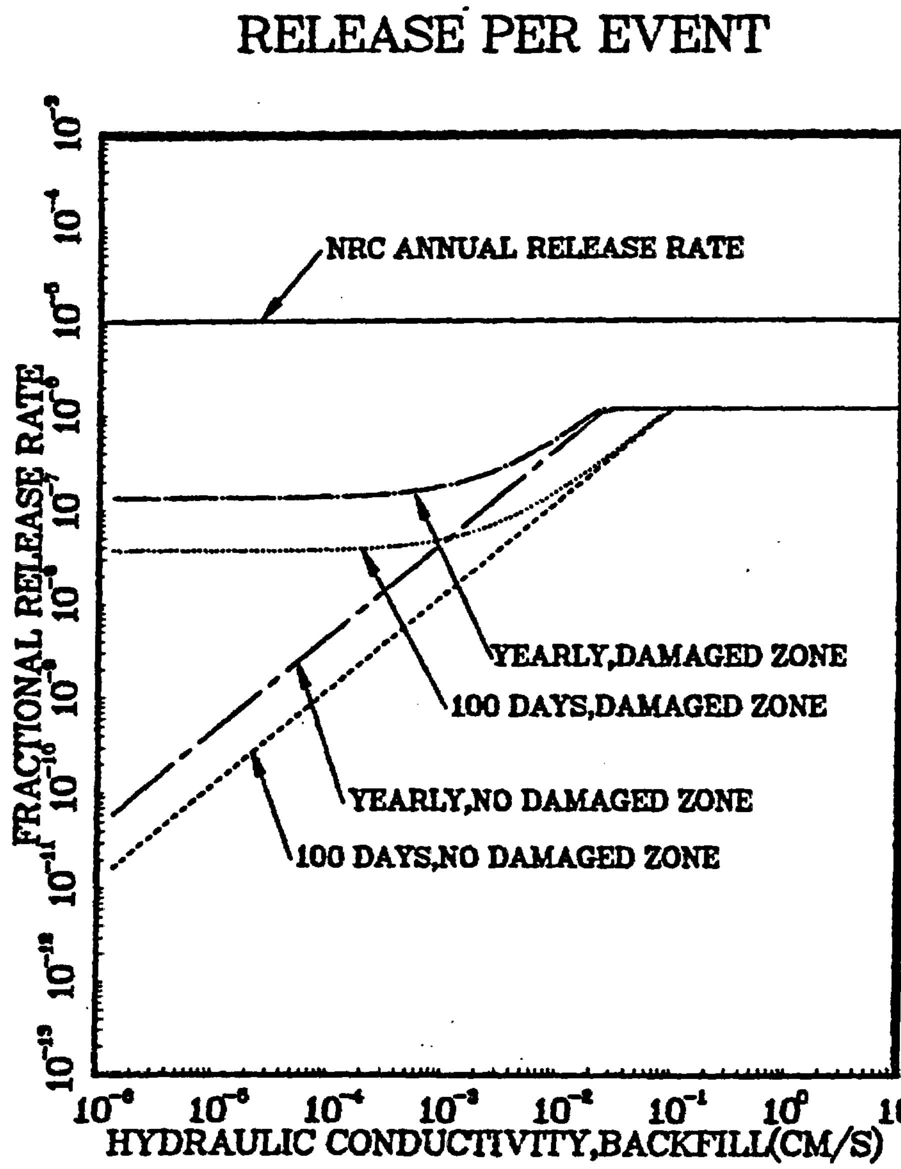

Figure 4. Fractional Release Rate for All Radionuclides (except Zr-93 which will have a lower fractional release rate) Assuming No Damaged Zone and the Presence of a Damaged Zone for Varying Hydraulic Conductivities of Shaft Backfill, Case I (Host rock hydraulic conductivity equals 10^{-5} cm/s)

Table 1. Fractional release rate and total radionuclide release for various volumes of water entering the waste disposal area

Radionuclide Reference Number	Radio-nuclide	Specific Activity (Ci/g)	Radionuclide Inventory at 1060 years[a] (Ci/1000 MTHM)	Radionuclide Inventory (g/1000 MTHM)	Solubility[b] (moles/liter)	NRC Annual Radionuclide Release Rate[c] (Ci/1000 MTHM)	Radionuclide Release for Varying Volumes of Water (liters) per 1000 MTHM: Case I $2.26x10^5$	Case III $6.15x10^5$
1	Pu-240	0.23E+00	0.41E+06	0.18E+07	0.18E-05	0.41E+01	0.48E+00	0.13E+01
2	Pu-239	0.61E-01	0.28E+06	0.46E+07	0.18E-05	0.28E+01	0.33E+00	0.90E+00
3	Am-243	0.19E+00	0.13E+05	0.70E+05	0.10E-07	0.13E+00	0.15E-01	0.42E-01
4	Np-239	0.23E+06	0.13E+05	0.56E-01	0.30E-02	0.13E+00	0.15E-01	0.42E-01
5	Tc-99	0.17E-01	0.13E+05	0.76E+06	0.10E+11	0.13E+00	0.29E-01	0.55E-01
6	Zr-93	0.40E-02	0.17E+04	0.42E+06	0.10E-08[e]	0.17E-01	0.86E-04	0.23E-03
7	Pu-242	0.39E-02	0.16E+04	0.41E+06	0.18E-05	0.16E-01	0.19E-02	0.51E-02
8	Sn-126	0.28E-01	0.48E+03	0.17E+05	0.10E-08	0.73E-02	0.56E-03	0.15E-02
9	U-238	0.33E-06	0.32E+03	0.96E+09	0.21E-04[h]	0.73E-02	0.38E-03	0.10E-02
10	Cs-135	0.88E-03	0.27E+03	0.31E+06	0.10E+11	0.73E-02	0.59E-03	0.11E-02
11	Np-237	0.71E-03	0.27E+03	0.38E+06	0.30E-02	0.73E-02	0.32E-03	0.86E-03
12	U-236	0.63E-04	0.23E+03	0.36E+07	0.21E-04[h]	0.73E-02	0.27E-03	0.74E-03
13	Cm-245	0.16E+00	0.17E+03	0.11E+04	0.40E-08[e]	0.73E-02	0.20E-03	0.54E-03
14	Am-241	0.32E+01	0.83E+06	0.52E+02	0.10E-07	0.73E-02	0.97E+00	0.27E+01
15	Pu-241	0.11E+03	0.17E+03	0.15E+01	0.18E-05	0.73E-02	0.20E-03	0.54E-03
16	C-14	0.44E+01	0.69E+03	0.16E+03	0.10E+11	0.73E-02	0.27E-03	0.73E-03
17	U-234	0.62E-02	0.75E+02	0.12E+05	0.21E-04[h]	0.73E-02	0.88E-04	0.24E-03
18	I-129	0.17E-03	0.33E+02	0.19E+06	0.56E+01[f]	0.73E-02	0.39E-04	0.11E-03
19	Cm-242	0.33E+04	0.32E+02	0.96E-02	0.10E-08[e]	0.73E-02	0.38E-04	0.10E-03
20	Pu-238	0.18E+02	0.32E+02	0.18E+01	0.18E-05	0.73E-02	0.38E-04	0.10E-03
21	Cm-246	0.26E+00	0.31E+02	0.12E+03	0.10E-08[e]	0.73E-02	0.36E-04	0.99E-04
22	Am-242	0.97E+01	0.31E+02	0.32E+01	0.10E-07	0.73E-02	0.36E-04	0.99E-04
23	Ni-59	0.76E-01	0.30E+02	0.40E+03	0.10E-08[g]	0.73E-02	0.30E-06[i]	0.30E-06[i]
24	U-235	0.21E-05	0.16E+02	0.75E+07	0.21E-04[h]	0.73E-02	0.19E-04	0.51E-04
25	U-233	0.95E-02	0.13E+01	0.14E+03	0.21E-04[h]	0.73E-02	0.15E-05	0.42E-05
26	Pb-210	0.76E+02	0.72E+00	0.94E-02	0.10E-04[e]	0.73E-02	0.84E-06	0.23E-05
27	Ra-226	0.99E+00	0.67E+00	0.68E+00	0.10E-06	0.73E-02	0.79E-06	0.21E-05
28	Th-230	0.19E-01	0.66E+00	0.34E+02	0.40E-08[e]	0.73E-02	0.77E-06	0.21E-05
29	Pa-231	0.45E-01	0.37E+00	0.82E+01	0.10E-08[g]	0.73E-02	0.43E-06	0.12E-05
30	Ra-225	0.39E+05	0.67E-02	0.17E-06	0.10E-06	0.73E-02	0.79E-08	0.21E-07
31	Th-229	0.21E+00	0.66E-02	0.31E-01	0.10E-08	0.73E-02	0.77E-08	0.21E-07
32	Cs-137	0.87E+02	0.22E-02	0.25E-04	0.10E+11	0.73E-02	0.48E-08	0.92E-08
33	Sr-90	0.14E+03	0.65E-03	0.47E-05	0.94E-03	0.73E-02	0.76E-09	0.21E-08
34	Th-232	0.11E-06	0.12E-04	0.11E+03	0.10E-08[e]	0.73E-02	0.14E-10	0.38E-10

(a) From U. S. DOE, 1984.
(b) From Kerrisk (1984) unless otherwise noted.
(c) From U.S. NRC (1983) and Sinnock, Lin, and Brannen (1985).
(d) Fractional release rate (FRR) greater than that for U-238 for all radionuclides except Zr-93; therefore, fractional release rate for U-238 assumed.
FRR using $2.26x10^5$ liters = $1.2x10^{-6}$
FRR using $6.151x10^5$ liters = $3.2x10^{-6}$
For Zr-93 FRR (for Zr-93 in matrix only) = $5.0x10^{-8}$, $6.1x10^{-8}$, and $1.4x10^{-7}$, respectively, for the cases analyzed.
(e) Estimated solubilities used include: Zr, 10^{-4}, ppm; Cm, 10^{-3} ppm, Pb, 2ppm;; Th, 10^{-3}ppm (from Krauskopf (1982)).
(f) From Handbook of Chemistry and Physics assuming I in I_2O_5.
(g) Assumed value.
(h) From U.S. EPA (1984) and Sinnock, Lin, and Brannen (1985).
(i) Assumed to be the radionuclide release from fraction of cladding corroded in one year. Corrosion computed from Hillner's equation given in Rothman (1984, p. 9) and Woodley (1983, p. A.3).

the upper bound of release rates. In this figure, the hydraulic conductivity of the shaft backfill is varied, while the hydraulic conductivity of the damaged zone is held constant. The damaged zone is modelled as extending one radius from the edge of the shaft wall and possessing a hydraulic conductivity two orders of magnitude higher than the undisturbed host rock. The hydraulic conductivity of the undisturbed host rock is assumed to be 10^{-5} cm/s. A more detailed description of the disturbed zone model is given in Appendix B. Figure 1 also shows the impact of the flood waters being impounded for 100 days at the surface and 365 days at the surface. It is believed that ponding of water at the surface beyond 365 days is unlikely due to the high evaporation and evapotranspiration rates at Yucca Mountain. Even if impoundment was longer than 365 days, the annual, fractional release rate would be no greater than shown in Figure 4 for Case I.

When the hydraulic conductivity of the shaft backfill is greater than approximately 2×10^{-2} cm/s, all of the water impounded at the surface could flow through the shaft backfill and the damaged zone in less than one year. As the hydraulic conductivity of the shaft backfill decreases, the flow will also decrease. In other words, even though a water supply may be available at the surface, the water flow to the waste disposal area is controlled by the shaft backfill or the disturbed zone hydraulic conductivities. When no damaged zone is present, the amount of water reaching the base of the shaft will decrease proportionately as the hydraulic conductivity of the shaft backfill decreases. Because the fractional release rate is directly proportional to the quantity of water passing the waste package, the fractional release rate will also decrease as the hydraulic conductivity of the shaft backfill decreases. This trend is observed in Figure 1. Where a damaged zone is present, a leveling of the fractional release rate is observed in both figures. This occurs because the hydraulic conductivity of the damaged zone is held constant (at 10^{-3} cm/s) and the flow to the base of the exploratory shaft will be dominated by the flow through the damaged zone when the hydraulic conductivity of the shaft backfill is less than about 10^{-3} cm/s.

In Figure 1, when noticeable differences occur between the fractional release rate for the case considering a damaged zone and the case considering no damaged zone, the fractional release rate is well below the release rate of 1 part in 100,000 established by the NRC. Radionuclide releases are not given for Case II because the effect of adding matrix flow is negligible. The fractional release rate for Case III is still less than 1 part in 100,000 for the 1,060-year inventory.

Figures 5, 6, and 7 illustrate the total release up to 10,000 years of the specific radionuclides given in Table 2. Radionuclide releases are given for each of the three cases presented in the introduction. The controlling factor in meeting the EPA criteria is not the release of an individual radionuclide exceeding its limit but rather the ability to meet the EPA ratio restriction. This is illustrated by comparing the EPA release limits and total release for each radionuclide in Table 2. For example, when the EPA ratio is one as in Case III, the largest individual radionuclide ratio is 0.53 for Am-241. Additionally, the EPA ratio appears to be controlled predominately by the release of Pu-240, Pu-239, and Am-241 as indicated in Table 2. If total corrosion of the fuel cladding occurred at 60,000 years, the release of radionuclides in the fuel cladding, i.e., C-14, Ni-59, and Tc-99, together with Pu-240, Pu-239, and Am-241, will dominate the ability to meet the EPA ratio criteria.

In comparing Figures 5 and 6, it is noticed that adding matrix flow to the flow from the flood events will have a negligible influence on the total radionuclide release for each radionuclide and a minor influence on the EPA ratio. When comparing the total radionuclide releases for each case, it is also noticed that release from the UO_2 matrix, due to increasing the water volumes, is small in comparison to the initial release assumptions. Increasing the amount of water has negligible influence on the amount of radionuclides released for Tc-99, Cs-135, Ni-59, and Cs-137 and only minor influence on C-14 and Zi-93. Because the remainder of the radionuclides are contained within the UO_2 matrix, their release is directly proportional to the amount of water contacting the waste package.

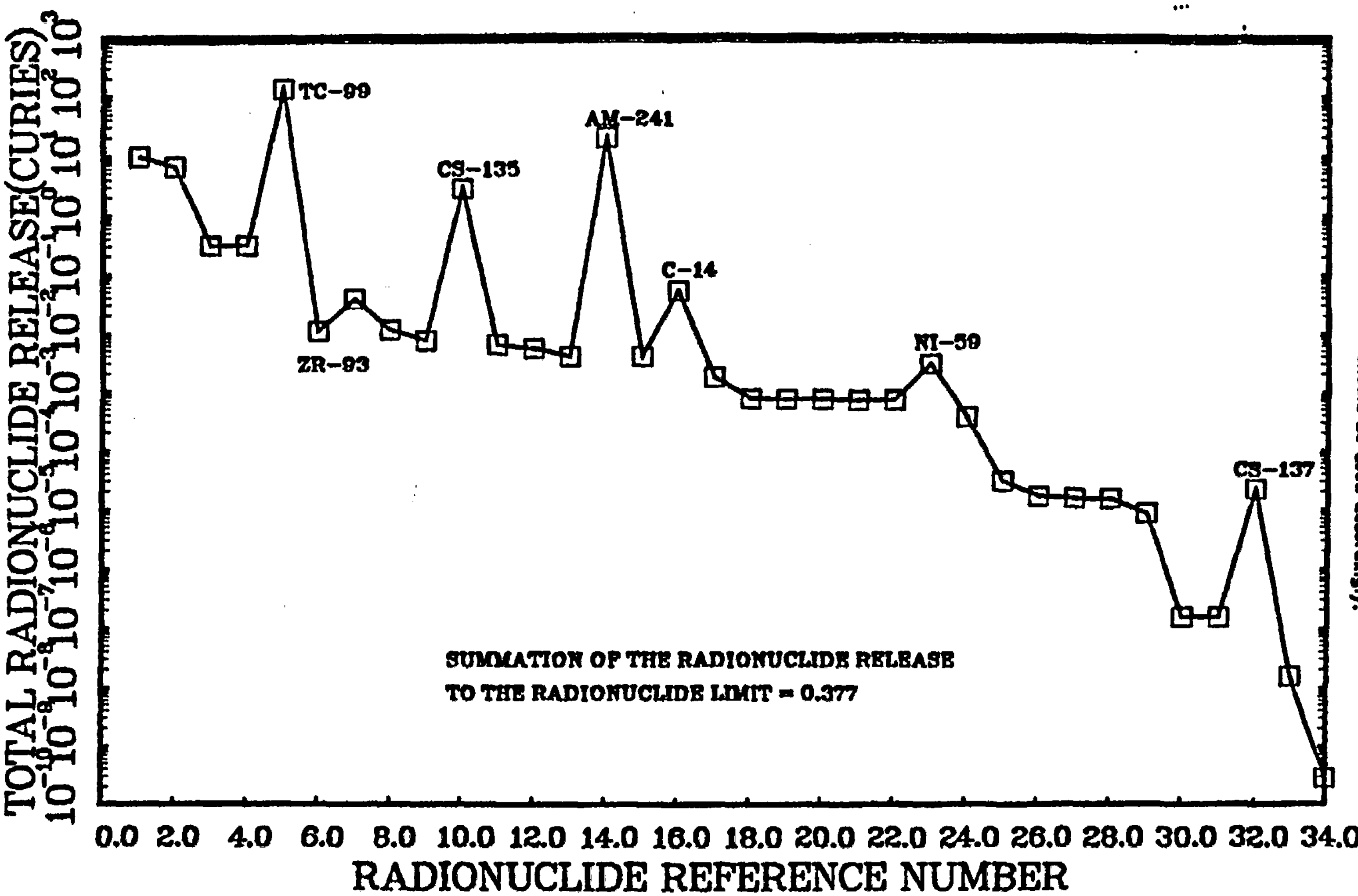

Figure 5. Total Radionuclide Release for All Radionuclides of Concern During the First 10,000 Years Following the Closure of the Repository Assuming the Occurrence of 20 events Having 2.256 x 10^5 Liters of Water Contacting 1,000 MTHM During Each Event (Case I)

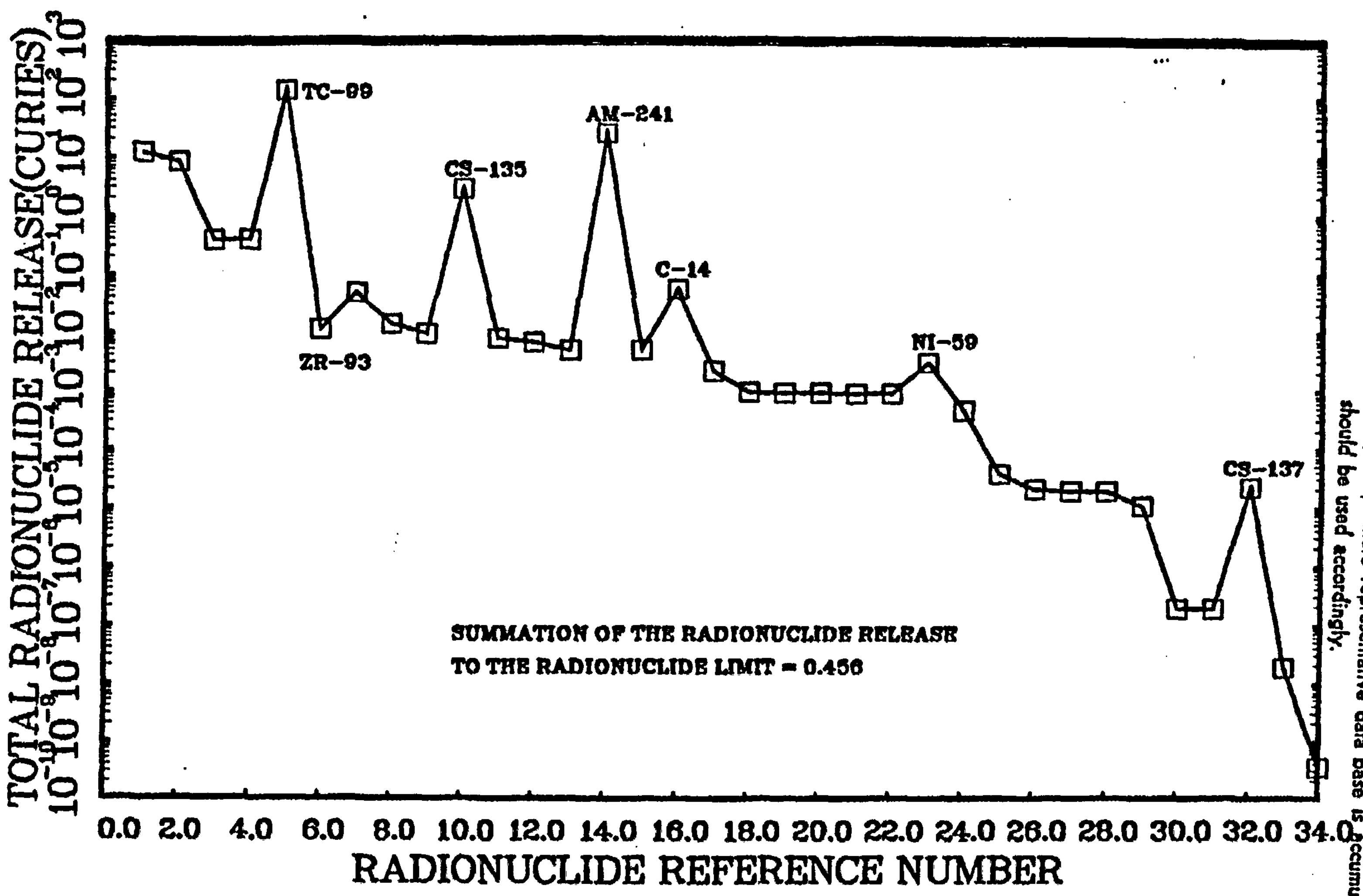

Figure 6. Total Radionuclide Release for All Radionuclides of Concern During the First 10,000 Years Following the Closure of the Repository Assuming the Occurrence of 20 Events Having 2.751 x 10^5 Liters of Water Contacting 1,000 MTHM During Each Event (Case II)

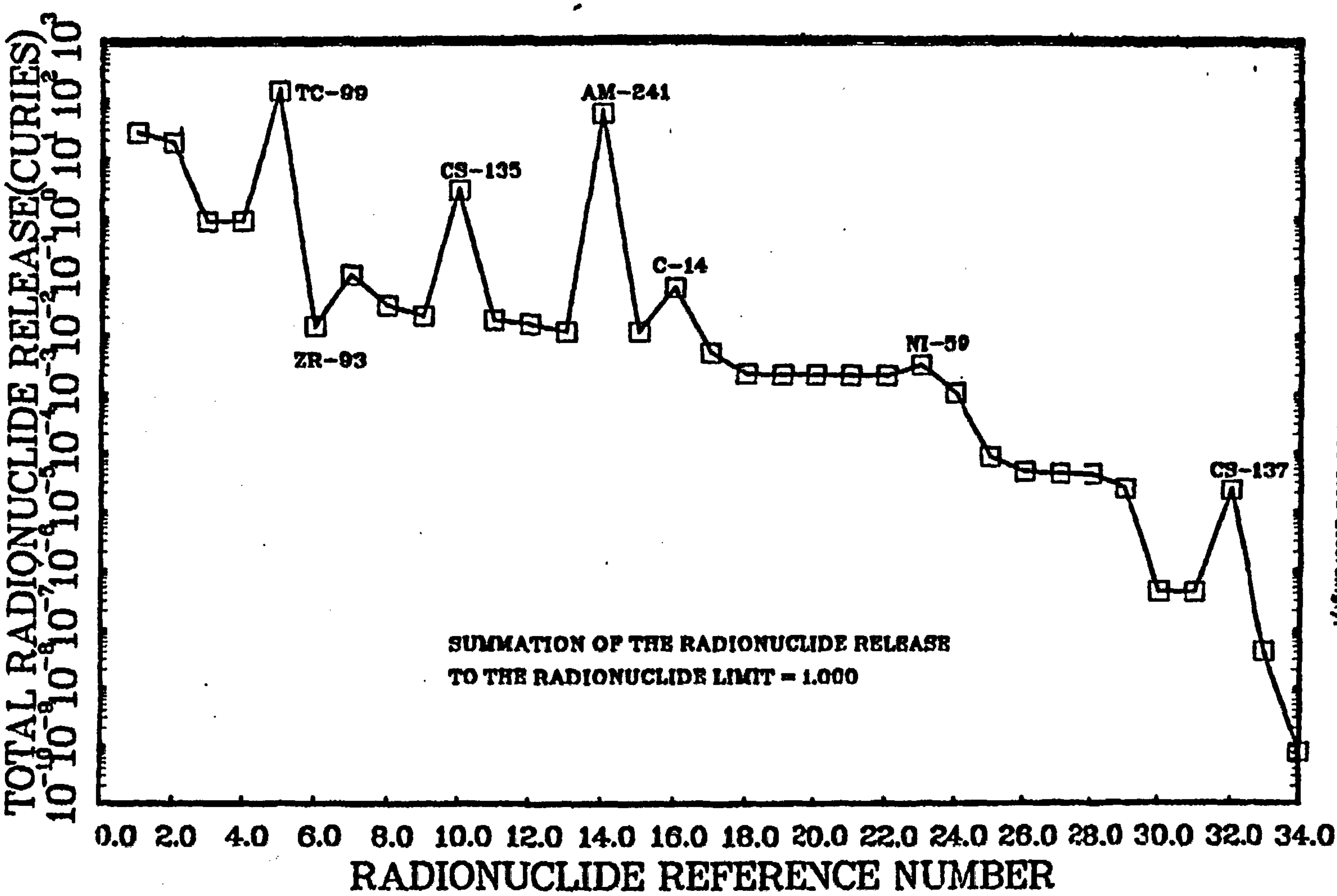

Figure 7. Total Radionuclide Release for All Radionuclides of Concern During the First 10,000 Years Following the Closure of the Repository Assuming the Occurrence of 20 Events Having 6.151 x 10^5 Liters of Water Contacting 1,000 MTHM During Each Event (Case III)

Table 2. Comparison of the EPA release limits resulting from varying water flow[a]

Radionuclide Reference Number	Radio-nuclide	EPA Cumulative Release Limit at Accessible Environment at 10,000 years[b] (Ci/1000 MTHM)	Total Radionuclide Release Assuming the Following Volumes of Water (liters) per 1000 MTHM			Ratio of Radionuclide Release to the EPA Limit for Various Volumes of Water (liters) per 1000 MTHM		
			$4.51x10^6$ (c)	$5.50x10^6$ (c)	$1.23x10^7$ (c)	Case I $4.51x10^6$ (c)	Case II $5.50x10^6$ (c)	Case III $1.23x10^7$ (c)
1	Pu-240	100	0.95E+01	0.12E+02	0.26E+02	0.95E-01	0.12E+00	0.26E+00
2	Pu-239	100	0.66E+01	0.80E+01	0.18E+02	0.66E-01	0.80E-01	0.18E+00
3	Am-243	100	0.31E+00	0.37E+00	0.83E+00	0.31E-02	0.37E-02	0.83E-02
4	Np-239	1,000	0.31E+00	0.37E+00	0.83E+00	0.31E-03	0.37E-03	0.83E-03
5	Tc-99	10,000	0.13E+03	0.13E+03	0.13E+03	0.13E-01	0.13E-01	0.13E-01
6	Zr-93	1,000	0.11E-01	0.11E-01	0.14E-01	0.11E-04	0.11E-04	0.14E-04
7	Pu-242	100	0.38E-01	0.46E-01	0.10E+00	0.38E-03	0.46E-03	0.10E-02
8	Sn-126	1,000	0.11E-01	0.14E-01	0.31E-01	0.11E-04	0.14E-04	0.31E-04
9	U-238	100	0.75E-02	0.92E-02	0.20E-01	0.75E-04	0.92E-04	0.20E-03
10	Cs-135	1,000	0.27E+01	0.27E+01	0.27E+01	0.27E-02	0.27E-02	0.27E-02
11	Np-237	100	0.63E-02	0.77E-02	0.17E-01	0.63E-04	0.77E-04	0.17E-03
12	U-236	100	0.54E-02	0.66E-02	0.15E-01	0.54E-04	0.66E-04	0.15E-03
13	Cm-245	100	0.40E-02	0.49E-02	0.11E-01	0.40E-04	0.49E-04	0.11E-03
14	Am-241	100	0.19E+02	0.24E+02	0.53E+02	0.19E+00	0.24E+00	0.53E+00
15	Pu-241	100	0.40E-02	0.49E-02	0.11E-01	0.40E-04	0.49E-04	0.11E-03
16	C-14	100	0.52E-01	0.53E-01	0.61E-02	0.52E-03	0.53E-03	0.61E-03
17	U-234	100	0.18E-02	0.21E-02	0.48E-02	0.18E-04	0.21E-04	0.48E-04
18	I-129	100	0.77E-03	0.94E-03	0.21E-02	0.77E-05	0.94E-05	0.21E-04
19	Cm-242	100	0.75E-03	0.92E-03	0.20E-02	0.75E-05	0.92E-05	0.20E-04
20	Pu-238	100	0.75E-03	0.92E-03	0.20E-02	0.75E-05	0.92E-05	0.20E-04
21	Cm-246	100	0.73E-03	0.89E-03	0.20E-02	0.73E-05	0.89E-05	0.20E-04
22	Am-242	1,000	0.73E-03	0.89E-03	0.20E-02	0.73E-06	0.89E-06	0.20E-05
23	Ni-59	1,000	0.30E-02	0.30E-02	0.30E-02	0.30E-05	0.30E-05	0.30E-05
24	U-235	100	0.38E-03	0.46E-03	0.10E-02	0.38E-05	0.46E-05	0.10E-04
25	U-233	100	0.31E-04	0.37E-04	0.83E-04	0.31E-06	0.37E-06	0.83E-06
26	Pb-210	1,000	0.17E-04	0.21E-04	0.46E-04	0.17E-07	0.21E-07	0.46E-07
27	Ra-226	100	0.16E-04	0.19E-04	0.43E-04	0.16E-06	0.19E-06	0.43E-06
28	Th-230	10	0.15E-04	0.19E-04	0.42E-04	0.15E-05	0.19E-05	0.42E-05
29	Pa-231	100	0.87E-05	0.11E-04	0.24E-04	0.87E-07	0.11E-06	0.24E-06
30	Ra-225	100	0.16E-06	0.19E-06	0.43E-06	0.16E-08	0.19E-08	0.43E-08
31	Th-229	100	0.15E-06	0.19E-06	0.42E-06	0.15E-08	0.19E-08	0.42E-08
32	Cs-137	1,000	0.22E-04	0.22E-04	0.22E-04	0.22E-07	0.22E-07	0.22E-07
33	Sr-90	100	0.15E-07	0.19E-07	0.42E-07	0.15E-09	0.19E-09	0.42E-09
34	Th-232	10	0.28E-09	0.34E-09	0.77E-09	0.28E-10	0.34E-10	0.77E-10
					EPA Ratio	0.38	0.46	1.00

(a) The following assumptions were made:
- 1% immediate release of Tc-99, Cs-135, and Cs-137.
- Uniform corrosion up to $1.3x10^8$ years for Zircaloy cladding.
- U-238 solubility of 2.1E-05 moles/liter.
- C-14 (cladding) 67% of total 1,060 years out of reactor.
- C-14 (matrix) 33% of total 1,060 years out of reactor.
- Zr-93 (cladding) 5% of total 1,060 years out of reactor.
- Zr-93 (matrix) 95% of total 1,060 years out of reactor.
- Ni-59 (cladding) 100% of total 1,060 years out of reactor.

(b) From U.S. EPA (1985) and Sinnock, Lin, and Brannen (1985).

(c) The total volume of water used to compute the total radionuclide release is 20 times $2.256x10^5$ liters ($4.51x10^6$ liters); 20 times $2.256x10^5$ liters ($4.51x10^6$ liters) plus 102 liters per year for 9,700 years (matrix flow, 1 mm/year); and 20 times $6.151x10^5$ liters ($1.23x10^7$ liters).

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QA checks on data contained here have only been performed to determine that these data have been obtained and documented properly. The DOE cautions that any [illegible] is preliminary and subject to change as further analyses are performed or as an [illegible] and perhaps more representative data base is accumulated. These data and interpretations should be used accordingly.

Radionuclide Releases Due to Convection Air Movement

The results presented above are for water transport of radionuclides. An additional concern is the influence of the damaged zone on the release of airborne radionuclides. Potential gaseous species, Xe isotopes, Rn, Kr-85, and H-3, can be eliminated from concern due to their short half-life assuming that the containment period will be 300 to 1,000 years. The radionuclides that could potentially enter into the gaseous state are C-14 and I-129 (Van Koynenburg, et al., 1984, p. 1). As indicated by Van Koynenburg, 0.3% of the C-14 inventory in a stored canister of spent fuel might be released as a gas. One percent of I-129 could be released rapidly if the cladding failed (Oversby and McCright, 1984, p. 11).

To compute the impact of the damaged zone on the release of I-129 and C-14, it was assumed that immediate release of 1% of I-129 and 0.3% of C-14 occurs. These radionuclides are then assumed to be uniformly distributed in the drifts. The total volume of air present in the drifts containing 1,000 MTHM would be 4.8×10^4 m^3 (1.7×10^6 ft^3) for backfilled drifts (porosity of backfill about .35) and 1.4×10^5 m^3 (4.9×10^6 ft^3) for an open drift. As shown in Table 2 of Appendix B, the presence of a damaged zone influences the air flow rate through the disposal areas when the air conductivity of the shaft backfill is 10^{-5} ft/min.

The flow rate assuming shaft backfill of 10^{-5} ft/min and open drifts was shown to be 2.2×10^{-3} cfm. Using this airflow rate, it would take approximately 4,200 years to replace the air associated with 1,000 MTHM. This release rate for C-14 would be 4.9×10^{-4} Ci/year and for I-129 it would be 7.9×10^{-5} Ci/year. Using the airflow rate, 4.2×10^{-4} cfm, in Table 2 (backfilled drifts), Appendix B, it would take approximately 7,700 years to replace the air associated with 1,000 MTHM. The corresponding radionuclide release rates would be 2.7×10^{-4} Ci/year for C-14 and 4.3×10^{-5} Ci/year for I-129. The release rates are given for comparison purposes and to illustrate that the air associated with 1,000 MTHM could be replaced in a period shorter than 10,000 years if no transport upward through the rock occurred.

If we were to add the release of 1% of the 1,060-year inventory of I-129 to the total waterborne release, the effect on the EPA ratio and release limits would be negligible. The EPA ratio would be modestly affected if the 0.3% of C-14 were released within the 10,000-year period following post-closure. This incremental release of C-14 (2.1 Ci) plus the amount released by dissolution of the matrix, is still small when compared to the EPA cumulative release standards. From these calculations, it has been shown that the presence of the damaged zone does not detrimentally impact the ability t meet the performance criteria established by the EPA and does not significan affect the calculated release rates of C-14 and I-129.

Effect of Shaft Penetration Into Calico Hill Unit

An additional consideration beyond the impact of the damage zone on gaseous and waterborne transport of radionuclides is the influence of the damaged zone on the pre-waste emplacement travel time to the accessible environment. We take the position that the depth of the shaft does not determine the "disturbed zone" for purpose of complying with regulation. However, as shown on Figure 8, the thickness of Unit IV, zeolitic Calico Hills nonwelded unit is approximately 125 ft thicker at the exploratory shaft location than the area to the east. Because the penetration of the exploratory shaft is not planned to be greater than 125 ft into Unit IV, the pre-waste emplacement travel time should not be less than other areas within the prospective boundary of the repository. Therefore, the presence of the exploratory shaft and hence the associated damaged zone should not impact meeting the pre-waste emplacement ground water travel time criteria of 1,000 years to the accessible environment as given in U.S. DOE guidelines (U.S. DOE, 1983, p. 20) and U.S. NRC criteria (U.S. NRC, 1983, p. 60-12). A more complete evaluation of the potential impacts of the depth of the ES may be performed in later studies.

Conclusions and Recommendations

The performance assessment presented is considered extremely conservative because

- It is assumed that no waste package exists.

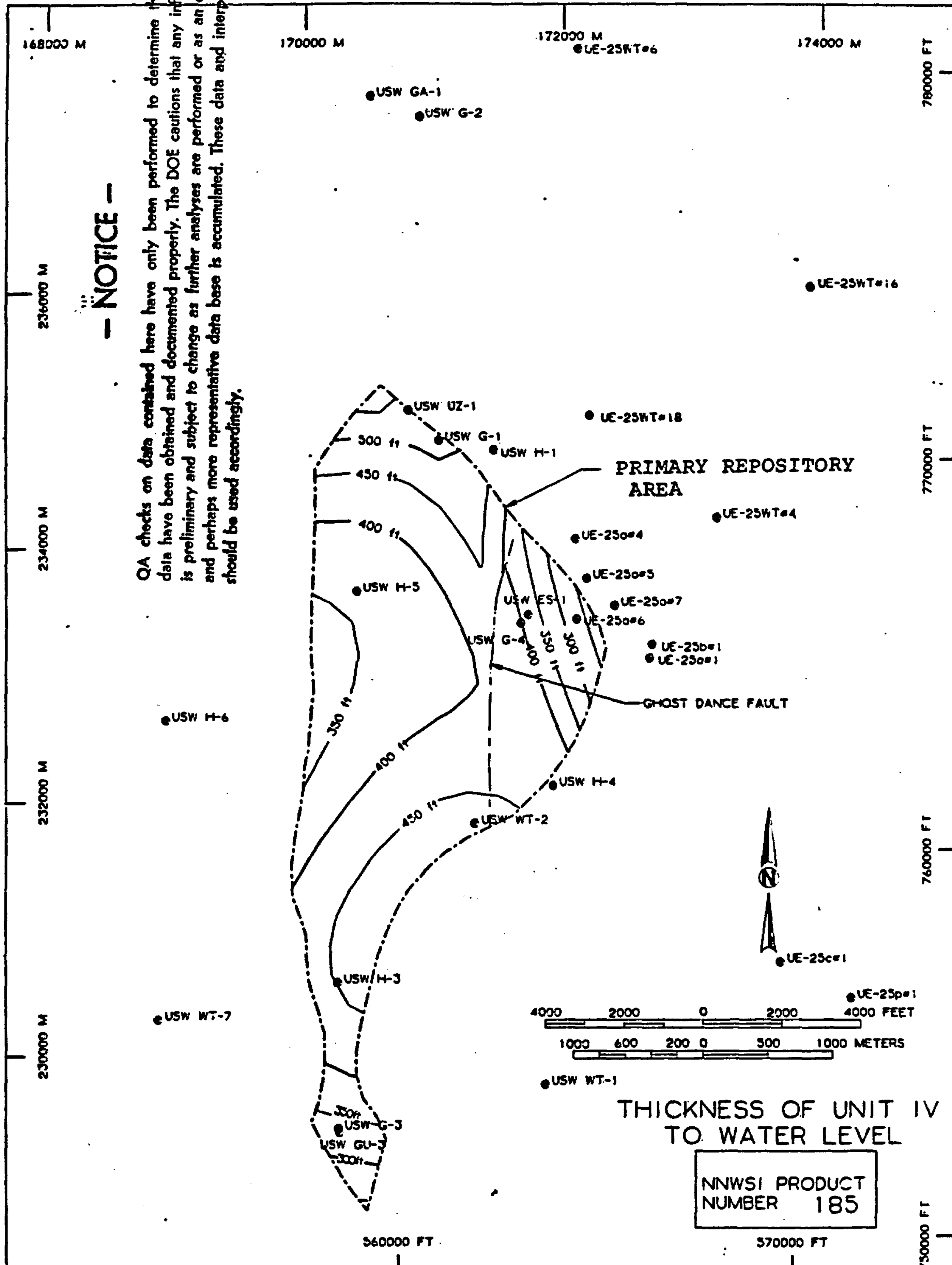

Figure 8. A Contour Map of the Thickness of Unit IV (zeolitic Calico Hills nonwelded unit) to the Water Table

- Decay of the 1,000-year inventory (following emplacement) of all radionuclides has not been factored into these analyses.

- Cladding container failure due to cracking of the cladding is assumed to occur for all fuel pins when the first 500-year flood occurs. This permits contact between the water entering the waste disposal area and the bare fuel.

- The EPA release limits at the accessible environment and the NRC release rates from the engineered barrier system are compared with the results presented in this assessment. The results are for radionuclide release limits and release rates applied at the edge of the waste package. Transport of the radionuclides through the waste package, the engineered barrier system, and the geologic setting has not been factored into these analyses.

- The probability of a landslide or flood debris deposition occurring immediately downgradient from the exploratory shaft is believed to be extremely low, although no calculations have been performed. Further, no evidence currently exists at Yucca Mountain suggesting an occurrence of a massive landslide or a debris deposit sufficient to impound waters from a 500-year flood.

- All the water collected by the drainage area is assumed to be impounded at the surface and available for transport through the shaft backfill and damaged zone. Infiltration through the alluvium is considered not to occur. Percolation through a debris and/or slide deposit is also not assumed. Particle-size distribution sampling of the debris deposits following the Eldorado Canyon flood showed that the bulk of nonorganic deposits were coarse in nature, 1 percent boulders, about 60 to 80 percent gravel, about 10 to 30 percent sand, and less than 3 percent salt and clay (Clancy and Harmsen, 1975, p. 14). A deposit having these particle size distributions would have a high permeability and would be ineffective in impounding water.

From the results presented, it can be concluded that:

- When the presence of a damaged zone influences the fractional release rate of U-238 and subsequently all of the radionuclides except Zr-93 which has a lower fractional release rate, the NRC release rate is not exceeded (Figure 4). Therefore, the presence of a damaged zone does not impact meeting the NRC release rate.

- The presence of a damaged zone for a broad range of shaft backfill hydraulic conductivities clearly does not impact the ability to meet the EPA release limits for all radionuclides (see Table 2, Case I) because all of the waters from 20 of the assumed 500-year floods could contact the waste packages and still not exceed the EPA criterion. Further, if we consider the more realistic volume of water as discussed earlier, i.e., 9.2×10^5 m^3 for all of the major flooding events, all of this water could pass the waste package and still not exceed the EPA and NRC criteria at the waste package boundary (see Table 2, Case III which assumes a total volume of 1.23×10^7 m^3).

- The presence of a damaged zone surrounding the exploratory shaft does not significantly affect the calculated release rates of C-14 and I-129 and does not detrimentally impact the ability to meet the performance criteria established by the EPA.

While the presence of a damaged zone can influence the fractional release rate and the cumulative release of radionuclides under certain conditions, the U.S. NRC and the U.S. EPA criteria are generally not exceeded for even the most extreme cases postulated for surface water inflow into the exploratory shaft. However, it is prudent to restrict the inflow to the waste disposal area by emplacement of a surface barrier and/or a station plug. Although not investigated in this study, it is believed that emplacement of these sealing components will be more cost effective in restricting flow to the waste disposal area than eliminating or severely restricting blast damage associated with mining of the exploratory shaft. Further, data may be needed from the exploratory shaft study to confirm the extent of the region in which the hydraulic conductivity is modified and to quantify the magnitude of the change in the hydraulic conductivity.

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APPENDIX B

RESPONSE TO QUESTIONS FROM LOS ALAMOS NATIONAL LABORATORY REGARDING QUALITY ASSURANCE LEVELS FOR EXPLORATORY SHAFT DESIGN AND CONSTRUCTION FEATURES

1.0 STATEMENT OF PROBLEM

Sandia National Laboratories (SNL) has been requested by Los Alamos National Laboratory (LANL) to assess the performance of the exploratory shaft (ES) so that quality assurance levels for various exploratory shaft design and construction features can be established. Three items have been identified by LANL that may pertain to the licensing process. These items are:

1. "Rock damage during ES construction - A performance analysis study is required to assess the potential for radionuclides to reach the accessible environment via construction-caused fractures around the ES. Of concern is what effect increased rock fracturing has on the escape of radionuclides. We need to know what extent of rock damage is acceptable so that proper construction controls can be established, adequate sealing techniques can be implemented, or other corrective action can be taken. This analysis should consider the distance of the repository waste from the shaft and both the upward travel of airborne or vaporborne radionuclides and the downward travel of waterborne radionuclides."

2. "Shaft liner - A performance analysis is required that addresses the role of the ES in the repository, the performance required of the liner during the operational or post-closure phase, and whether the concrete liner is expected to contribute to the success of sealing the repository."

3. "Shaft internals - A performance analysis is required that addresses whether the shaft internals installed in the ES(s) during the site exploration phase will be used in the repository. If so, what will be the function of the shaft and what are the consequences of failure as far as radionuclide containment is concerned."

ITC has been requested by SNL to assist in responding to items 1 and 2 above.

LANL's questions require assessment of how the damage zone around the shaft or the shaft liner could affect the isolation of radionuclides within the repository. Should it be found that either the damage zone or the liner could affect isolation, then it will be necessary to institute additional quality assurance controls during design and construction of the ES. Should it be found that neither the damage zone nor the liner can affect isolation then the additional quality assurance controls will not be required with respect to future sealing considerations. This report does not address reasons for limiting the damage resulting from shaft excavation or for controlling liner construction other than those related to sealing.

The technical approach adopted in this letter report is to evaluate the influence of the damage zone and the shaft liner on successful sealing of the shaft. The objective will be to show either that the damage zone and liner have no significant effect on air or water flow through the shaft, or that the effect of the damage zone or liner can be alleviated by simple engineering. Worst case scenarios and limiting values for input parameters will be used where appropriate.

2.0 BACKGROUND DATA

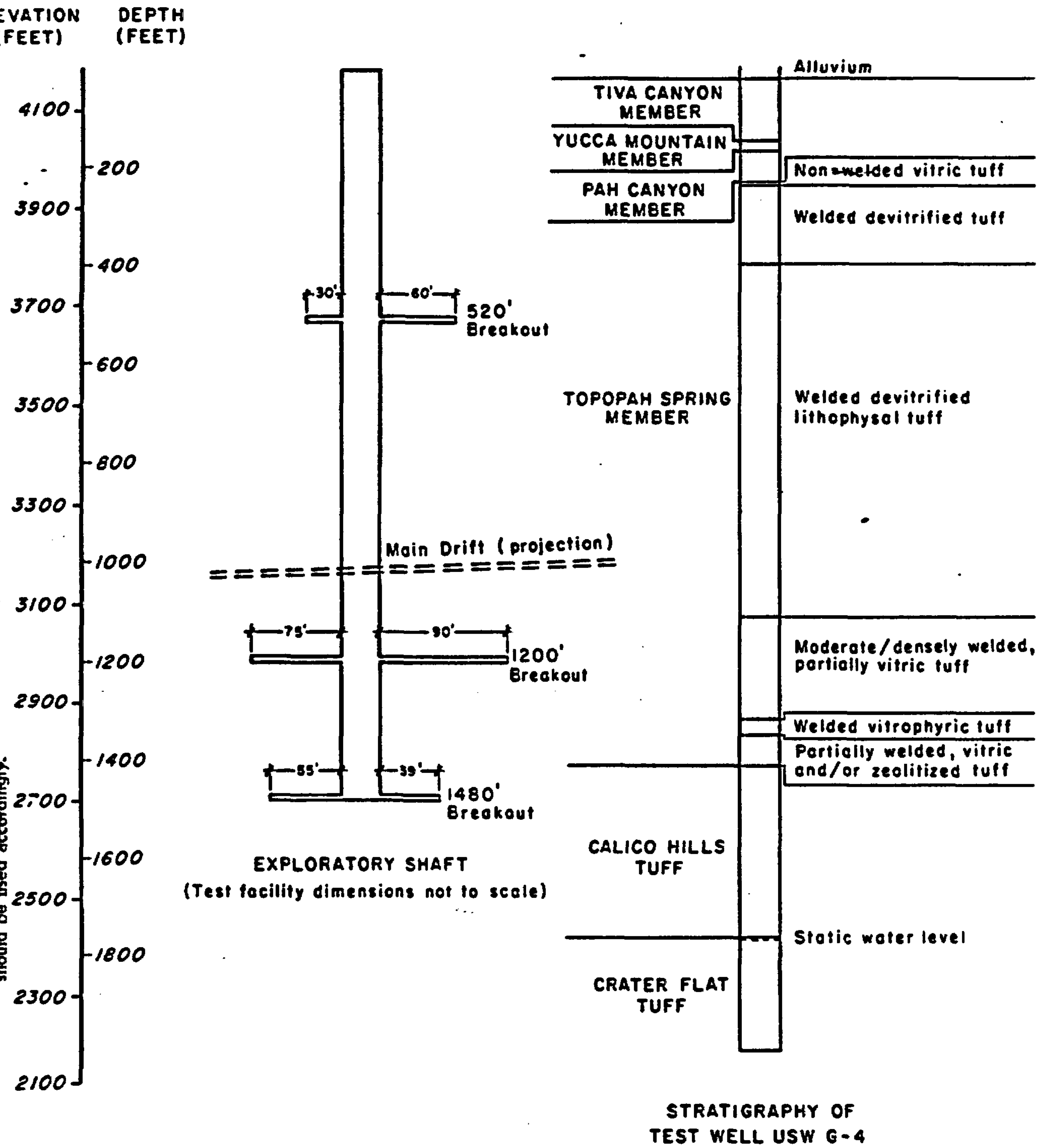
2.1 ES AND REPOSITORY DESIGN

A conceptual design of the ES has been prepared by LANL (1984). The proposed shaft is 1480 ft (451m) in total depth and will penetrate approximately 70 ft (21.3m) into the Tuffaceous Beds of Calico Hills (Calico Hills). The breakout to the repository will be at about 1000 ft (305m) depth in the lithophysal poor unit of the Topopah Spring Member (Figure 1). The shaft will have a diameter of 12 ft (3.7m) and it will be concrete lined. The conceptual design for the repository has not been completed as of December 1984. The repository layout used in this study has been obtained from the conceptual design work in progress (Parsons Brinckerhoff, 1984) and is referred to as the preconceptual design.

2.2 ROCK DAMAGE RESULTING FROM ES CONSTRUCTION

Three processes may contribute to formation of a damage zone around an underground opening: stress redistribution, damage by the excavation process - especially if blasting is used, and weathering or interaction between the rock and groundwater. Of the three processes, only one is directly related to the excavation method. Also, the effects of stress redistribution apply to all openings and excavation methods although the magnitude of the effects depends greatly on site-specific conditions. Accordingly, it is not appropriate to consider the damage zone solely as a blast-damaged zone that does not exist if mechanical excavation methods are used.

In a fractured rock with relatively high intact strength, such as welded tuff, the major mechanisms for affecting the rock mass permeability are blasting and stress r ... l be to create new fractures in a z ... : as well as to open pre-existing fr ... f may be to open pre-existing fractur ... from the shaft wall.

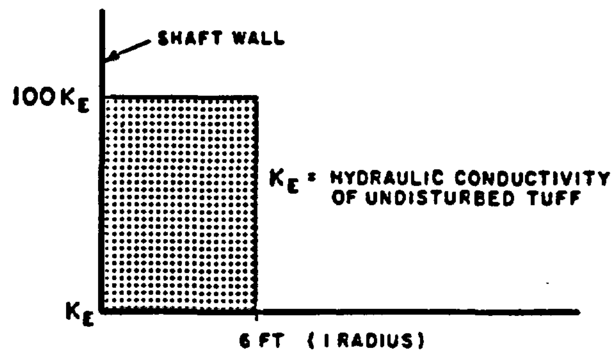


References: Bentley, 1984
Los Alamos National Laboratory, 1984

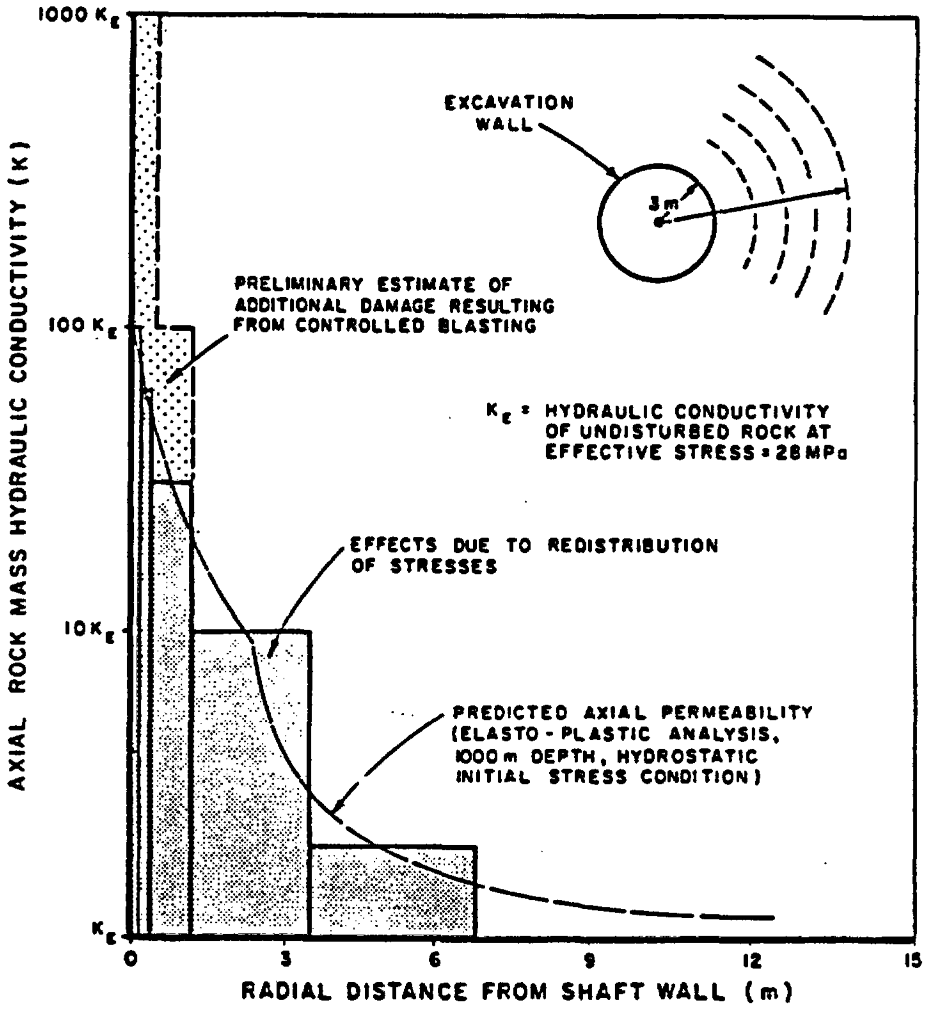
FIGURE 1. Stratigraphy of Exploratory Shaft (showing breakouts for test facility and projection of main repository drift)

There has been no site-specific evaluation of the degree of damage likely to be associated with shaft construction in tuff. For purposes of the present analysis, a simplified model of the damage zone has been used. In this model the rock mass hydraulic conductivity is increased by two orders of magnitude uniformly over a zone extending to one radius from the shaft wall (Figure 2a). For comparison, Figure 2b shows a damage zone model developed by Kelsall et al. (1982) for fractured basalt at a depth of 1000m. This model (2b) allows for both blast damage and stress relief and shows a progressive reduction in hydraulic conductivity away from the shaft as would be expected in reality. The average hydraulic conductivity, weighted for area over the area extending to one radius from the shaft wall, is about 150 times the value for the undisturbed rock.

Model 2a used in the present analyses predicts a lower average increase in permeability than that predicted by the model for basalt. This is considered reasonable given that the maximum depth of the ES (451m) is less than the depth of 1000m used in the basalt model. Model 2a is considered to be a reasonable "best estimate" for the degree of damage resulting from controlled blasting in welded tuff. The degree of damage could be greater if blasting practices are not controlled, but it is reasonable to assume that prudent blasting techniques will be used for a repository shaft.



(a) Simplified Damaged Zone Model Used in Present Study



From Kelsall et al (1982)

(b) Preliminary Damaged Zone Permeability Model for a 3m Radius Shaft in Basalt at 1000m Depth

FIGURE 2. Damaged Zone Models

3.0 SUMMARY AND CONCLUSIONS

3.1 MECHANISMS FOR RADIONUCLIDE RELEASE

Consideration has been given to mechanisms by which the ES and its component parts could affect radionuclide release from the repository. The remainder of this section presents the relevant mechanisms and provides a summary of the major conclusions regarding the potential influence of the damage zone and the shaft liner on release. A more detailed discussion of each of the mechanisms is given in Section 4.0.

Radionuclides could be released from the repository by either waterborne or airborne transport. For a repository located in the unsaturated zone the flow path for waterborne release is for water to enter the repository from above, contact the waste and then flow downwards to the water table. In borehole USW G-4, located adjacent to the ES, the depth to the water table was about 1770 ft (540m); that is, about 290 ft (88m) below the bottom of the shaft (Figure 1). Potential mechanisms for airborne release include convection in response to heat generated by the waste, and diffusion.

Consideration of potential radionuclide release mechanisms reveals three mechanisms involving flow of water or air through the ES:

1. Surface water or groundwater enters the shaft and then migrates to the waste disposal area

2. Groundwater enters the repository through a discrete fault zone, contacts the waste, and then flows to the ES which acts as a preferred pathway towards the groundwater table

3. Airborne transport of radionuclides through the ES

These mechanisms are evaluated in turn in the following sections. Consideration is given to whether the mechanism is credible and can lead to an unacceptable release. In the event that the mechanism is credible, the influence of the damage zone and liner can be evaluated.

3.2 INFLUENCE OF THE ES DAMAGE ZONE AND LINER ON POTENTIAL RADIONUCLIDE RELEASE

Water Inflow Via the ES

Because the ES is located on the side of a wash, there is a potential for runoff to enter the shaft following heavy rainfall. In the short term this occurrence should be prevented by engineered drainage structures which will carry the runoff down the wash past the shaft. Over the longer term these structures could be destroyed by erosion, and landslips and settlement could result in impoundment of water near the shaft. In the extreme case that all of the runoff in the wash should flow into the shaft backfilled with coarse rockfill, much of the northeastern part of the repository downgrade from the ES could be flooded.

The probability of flooding part of the repository by flow through the ES is low but not negligible if the shaft is not sealed in some manner. It will be prudent, therefore, to emplace barriers or seals in the shaft which will limit the inflow. The preferred concept for limiting inflow (Fernandez and Freshley, 1984) is a surface barrier consisting of a shaft cover, a core of low permeability material extending at least through the overburden and, if necessary, a plug at the bedrock surface. Flow into the shaft or damage zone below the barrier would be limited to seepage of surface water around the barrier and to groundwater inflow below the barrier. As shown by Fernandez and Freshley, the groundwater inflow from the matrix should be very small because the backfill will tend to act as a capillary barrier. Any flow that does enter the shaft should drain from the shaft sump rather than enter the repository.

Given that an effective surface barrier is installed, the backfill in the shaft below the barrier has no function other than as support for the shaft walls and it can be relatively permeable. The damage zone and liner in this section of the shaft (i.e., between the bedrock surface and the connection to the repository) should have no significant effect on the volume of water inflow, regardless of the degree of damage (within reasonable limits) or the quality of the liner. It will be beneficial but not essential to remove the liner from the shaft below the repository station in order to increase the drainage capacity of the sump.

Outflow from the ES

Fernandez and Freshley (1984) have reported previously that sand or an equivalent coarse material placed as backfill in the drifts will act as a capillary barrier which will limit inflow to the repository from the rock matrix. The possibility exists, however, that inflow could occur via discrete faults. If unimpeded, this flow could contact the waste and then flow downgrade along the repository floor to the ES.

The locations of faults within the repository block are believed to be well known (Figure 3), but there is little information regarding their hydrologic properties. With regard to the potential for inflow to the repository, the most significant faults are likely to be those underlying washes which could be recharged by rainfall. Faults underlying Drill Hole Wash will intersect the repository ramps but the intersection will be downgrade from the ES. The probability that inflow through these faults will be sufficient to flow past the waste and reach the ES is estimated to be very small. The fault with the greatest lateral continuity within the repository area is the Ghost Dance Fault which intersects seven panels, all upgrade from the ES. Theoretically, the hydraulic conductivity of this fault may be sufficient to cause large inflows. In practice, recharge is likely to be restricted severely because the fault crosses the slope of Yucca Mountain at right angles to the washes.

It is anticipated that some inflow will occur from faults following heavy rainfall. Flow of this water towards the shaft can be impeded by barriers such as small dams constructed at the ends of emplacement rooms

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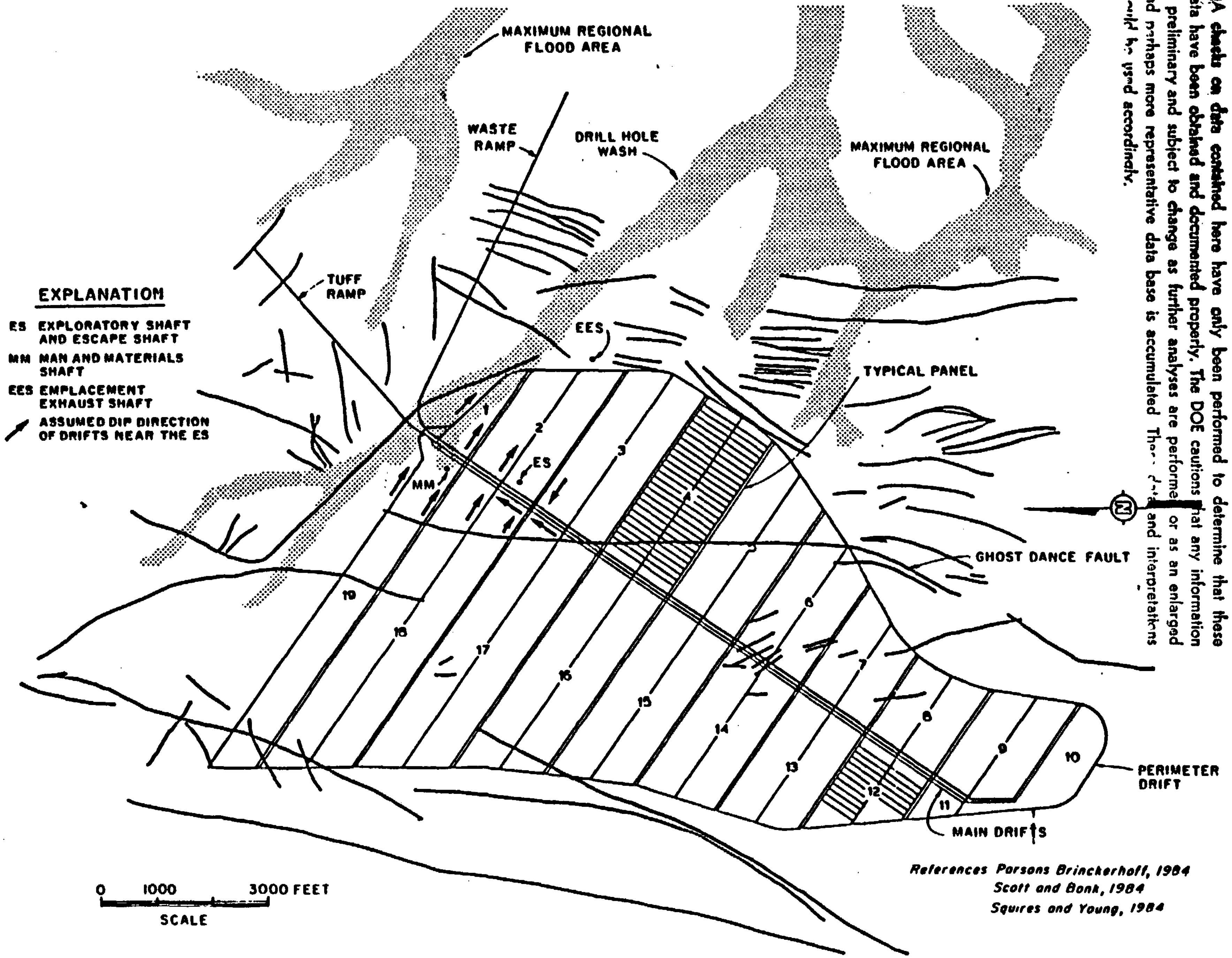


FIGURE 3. Plan of Proposed Yucca Mountain Facility With Faults and Maximum Regional Flood Area

or at intervals in the mains and submains. The inflow will then drain through the repository floor. If no inflow reaches the ES, it is evident that the damage zone and the liner will have no impact on radionuclide release. If some inflow reaches the shaft this should only be a small part of the original inflow, most of which will drain through the floor. If flow is contaminated, the flow through the ES and its damage zone will only be a small part of the total contaminated flow, most of which will occur through the undamaged rock mass. Because of the increased permeability in the damage zone, the travel time through the damage zone to the base of the Topopah Spring may be less than the average travel time through the rock mass. If minimum travel time is a concern (regardless that the flow is small) barriers could be emplaced, impeding flow from reaching the shaft.

Airborne Release

Various mechanisms may contribute to airborne movement of radionuclides within the repository and potentially out of the repository towards the accessible environment. These mechanisms include convective transport through the shafts and ramps or through the host rock, gas expansion due to heating, gas production from the waste, and various types of diffusion.

The potential effect of the damage zone in the ES on airflow rates from the repository has been evaluated by analyses of a single transport mechanism, that involving convective transport through the shafts, ramps and drifts. This analysis indicates absolute flow rates through portions of the repository in the vicinity of the ES, and compares total flow with and without a damage zone. The analyses are believed to be adequate for estimating the effects of the damage zone for all transport mechanisms.

The analysis of airflow has been conducted using a network of resistances in series and parallel representing open or backfilled shafts and drifts. The method is similar to that used in mine ventilation studies. The simplified method does not couple heat transfer and air flow. Temperatures for locations in the repository are obtained from previous work by SNL and are used to calculate the differential air pressure, which is the driving force for air flow. In practice, the air flow may change the temperatures, but this is not taken into account. Conservative values are assumed for temperatures such that the airflows calculated are approximately the maximum values expected.

Analyses have been conducted for shaft backfills with permeabilities to air equivalent to hydraulic conductivities ranging from 10^2 cm/s to 10^{-4} cm/s. For the higher value, corresponding to a coarse rockfill (and also for a value of 1 cm/s), the damage zone in the shafts has a negligible effect on total air flow through the repository. For the lower conductivity, corresponding to a silty sand, more flow occurs through the damage zone in the shafts than through the backfill, but the total flow rate is very low (<.01 ft^3/min). These analyses indicate that the degree of damage associated with the ES will not have a significant effect on airborne release.

3.3 CONCLUSIONS

Three scenarios were identified by which radionuclide release from the repository could be affected by the degree of damage resulting from construction of the ES or by the quality of the liner in the ES. One scenario involves water flow in through the ES, one involves water flow out through the base of the shaft, and the third involves airflow. In each case the effects of the damage zone and the liner have been found to be negligible.

With regards to the damage zone, the overall conclusion is that the degree of damage which can be anticipated using controlled excavation methods should not affect successful sealing of the shaft. The construction controls to be implemented need be no stricter from the point of view of sealing than from the point of view of not compromising the short-term stability of the shaft.

With regards to the liner, the overall conclusion is that the type of liner will not affect successful sealing of the shaft. The liner placed in the shaft sump may be removed at the time of sealing the repository in order to enhance drainage. Other sections of the liner will probably be left in place when the shaft is backfilled. Deterioration of the liner beyond this point in time should not be detrimental to the shaft seal system.

As an overall conclusion, there is no reason related to successful sealing of the repository for imposing additional quality assurance levels during construction.

4.0 EVALUATION OF POTENTIAL RELEASE MECHANISMS

4.1 WATER INFLOW VIA THE ES

4.1.1 Water Sources and Volumes

Potentially, the ES could act as a conduit for surface runoff to enter the repository. If a large volume of water were to enter the shaft, the sump would fill and the excess flow would enter the drift (or drifts) connecting the shaft to the repository. In the present preconceptual design for the repository, the ES joins the waste main via a single drift. This main grades downwards at approximately 2.5% to the northeast and may connect directly to waste panels in the northeast part of the repository which are at a lower elevation than the connection from the repository to the ES. If no measures are taken to divert water at the surface or to provide barriers to flow in the repository, a potential may exist to flood parts of the repository following extreme rainfall.

The proposed site for the ES is in Coyote Wash, an east-west feature which drains off Yucca Crest into Drill Hole Wash (Figure 3). The proposed ES site at elevation 4160 ft msl (1268m) is about 140 ft in elevation (42.7m) above the limits of the maximum probable flood in Drill Hole Wash and its tributaries as defined by the USGS (Squires and Young, 1984). There is a potential, however, for runoff in Coyote Wash following severe rainfall.

The tributary area feeding Coyote Wash is approximately 2.2×10^5 m^2 (2.4×10^6 ft^2, 55.2 acres). The ES site is close to a second unnamed wash south of Coyote Wash which could also feed towards the shaft depending on the precise shaft location. The tributary area for both washes is approximately 4.8×10^5 m^2 (5.2×10^6 ft^2, 119.6 acres).

Squires and Young (1984) examined the flood potential in Drill Hole Wash and other major washes near Yucca Mountain. The following formulae were derived to calculate Q_{100} and Q_{500}, respectively the peak flows in cubic feet per second (ft^3/s) for floods with 100-year and 500-year recurrences:

$$Q_{100} = 482\ A^{0.565} \qquad\qquad (1)$$
$$Q_{500} = 2200\ A^{0.571}$$

where A = tributary area (square miles). For A = 0.19 mi^2 ($4.8 \times 10^5\ m^2$) for the two washes combined, Q_{100} = 186 ft^3/s (5.3 m^3/s) and Q_{500} = 843 ft^3/s (24 m^3/s) for near the ES location. Although these values may appear large, USGS estimates for Q_{100} and Q_{500} for Drill Hole Wash at its confluence with Fortymile Wash are 2,300 and 10,000 ft^3/s (65 and 283 m^3/s), respectively. The regional maximum flood for this wash is estimated by USGS to be 86,000 ft^3/s (2440 m^3/s). Drill Hole Wash includes a drainage area of 15.4 mi^2 (39.9 km^2) and is considerably larger than Coyote Wash and the unnamed wash.

The USGS formulae indicate the peak flow of the flood in a wash but not the duration. Some indication of the duration may be obtained by consideration of the rainfall required to produce the floods predicted by the formulae. For a flood of 843 ft^3/s lasting for one hour, the required rainfall over the area of 0.19 mi^2 is about 7 inches, assuming no storage within the basin and instantaneous time of equilibrium (rainfall rate equals runoff rate). These are reasonable assumptions for a small, simple basin underlain primarily by bedrock (Chow, 1964). By comparison, the maximum expected rainfall for southern Nevada given by the U.S. Bureau of Reclamation (1974) for the design of small dams is 10 inches with a duration of 1 hour. This comparison suggests that the durations of the maximum floods calculated using Equation (1) should not be much greater than one hour.

A preliminary design drawing of the ES surface facilities (LANL, 1984) shows flood control structures in each of the washes to the north and south of the shaft. If one or both of these structures were to be blocked, for example by a small landslide or by flood debris, it is conceivable that some or all of the flood flow from the washes could be diverted towards the shaft. The inflow to the shaft would then be limited by the hydraulic conductivity of materials placed in the shaft. Neglecting any flow through the rock surrounding the shaft the steady-state flow rate through backfill in the shaft assuming a unit gradient can be estimated from:

$$Q_b = K_b \cdot A_s \tag{2}$$

where

Q_b = steady-state flow rate (m^3/s),

K_b = saturated hydraulic conductivity of the backfill (m/s), and

A_s = area of the shaft = $10.5 m^2$ ($113 ft^2$).

For a range of backfill hydraulic conductivity of 10^2 to 10^{-4} cm/s (corresponding approximately to a range from coarse rockfill to silty sand) the calculated flow rate is 10.5 to 1.05×10^{-5} m^3/s (371 to 3.7×10^{-4} ft^3/s). The upper bound value for this calculation (10.5 m^3/s) is approximately the same as the value of 24 m^3/s calculated for the 500-year runoff. The calculations indicate, therefore, that placement of coarse rockfill as backfill in the shaft will not by itself limit the volume of inflow. With an inflow of 10.5 m^3/s and a duration of 1 hour, the volume entering the repository would be about 4×10^4 m^3 (1.3×10^6 ft^3). If no barriers were installed within the repository, this inflow would flood a significant area in the northeastern part of the repository. (In the preconceptual repository design, the area of the repository downgrade from the ES [i.e., to the north of the shaft and east of the mains] is about 40 acres and the volume of the rooms and other drifts in this area is about 6×10^6 ft^3.) Evidently, the probability of such a large volume of water entering the shaft is very small. If the potential maximum volume is reduced by two orders of magnitude or more (i.e., by engineered barriers) it should be relatively straightforward to divert flow in the repository so that it would not contact waste.

If a relatively impermeable backfill was placed, only a small part of the flow rate in the wash could be accepted by the shaft. The total flow into the shaft would also be restricted provided that water could not be impounded near the shaft in a way which would allow the flow into the shaft to continue beyond the duration of the flood in the wash.

Over the long term (i.e., 10,000 years) two mechanisms could result in impoundment of surface water near the shaft. The first mechanism would involve subsidence or settlement adjacent to the shaft and inward collapse of the upper part of the shaft forming a depression. In the preconceptual design for the repository a network of rooms housing decontamination and emplacement equipment is excavated immediately to the south of the ES. The extraction ratio in this area (approximately 40%) may be high enough to provide the potential for collapse and subsidence over the long term. The amount of subsidence would be small, however, if the rooms are backfilled. A more likely mechanism for collapse around the shaft (assuming the underground workings are backfilled) would involve settlement of the shaft backfill and inward collapse of the upper part of the shaft. If the settlement was 50 ft (15m), equivalent to 3.5% over 1480 ft (451m) depth, the area affected would be about 100 ft (30.5m) in diameter assuming an angle of draw of 45°. The volume created within the depression would be 50 ft (15m) times the area of the shaft, i.e., about 5700 ft^3 ($161m^3$).

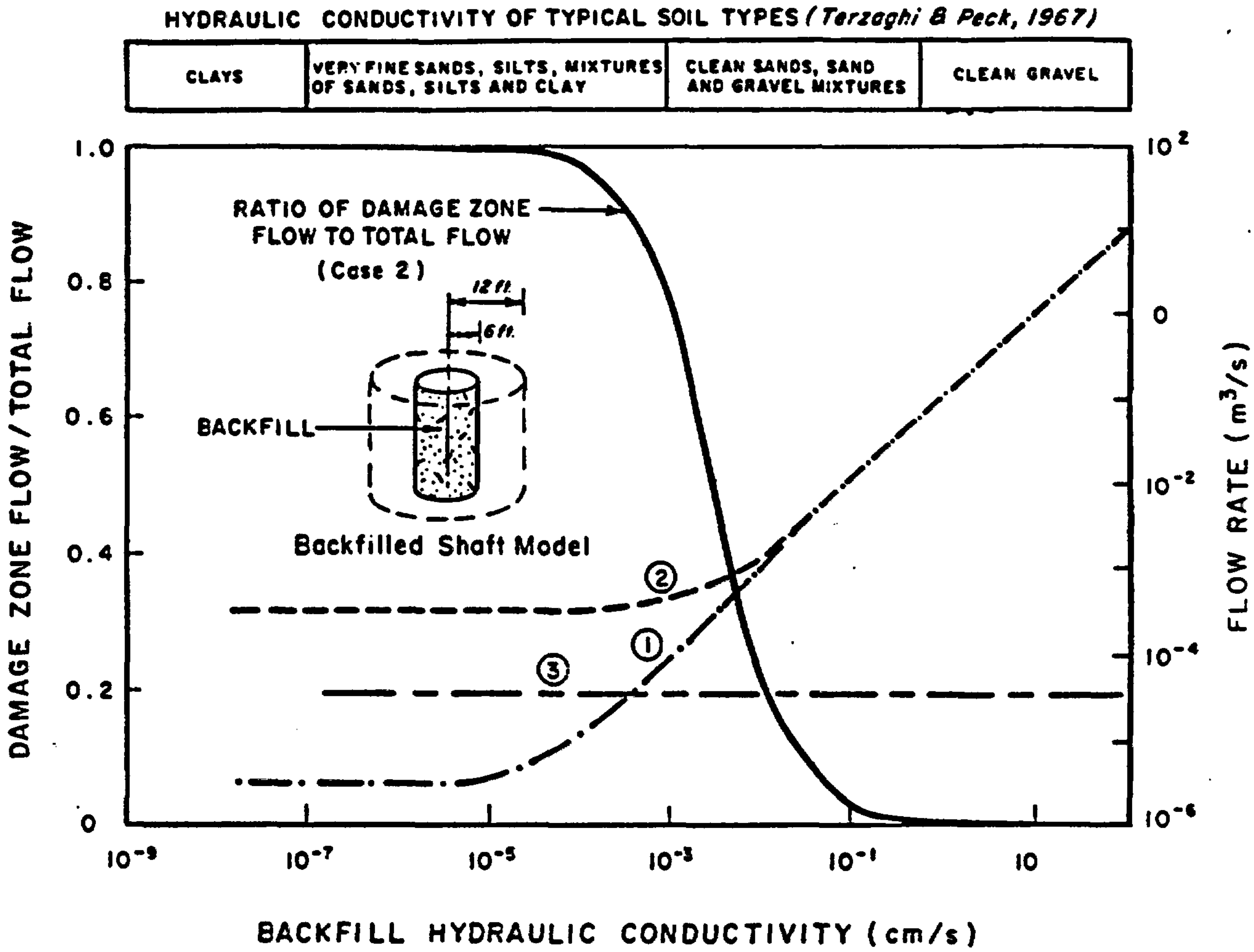
The second mechanism would involve erosion of alluvium in the wash and deposition downstream from the shaft, forming a dam across the wash. The probability of major disruption of the drainage patterns is considered to be low, but the possibility cannot be discounted. Accordingly, the present conclusion is that some combination of subsidence and erosion could lead to channeling of runoff towards the shaft with perhaps some impoundment near the shaft.

The previous discussion has concerned only surface water entering the shaft. As shown by Fernandez and Freshley (1984), the inflow of groundwater should be very small from the fractured tuff because the backfill will tend to act as a capillary barrier. Greater inflow could occur from a fault but, as indicated by the geology of USW G-4 (Bentley, 1984), no faults should be intersected by the ES.

4.1.2 Sealing Concepts for Repository Shafts

The preceding calculations have been presented to demonstrate that there is a potential for large volumes of surface water to enter the shaft under extreme rainfall conditions. In the short term, the likelihood of this occurrence will be greatly reduced by appropriate surface flood control features, but over hundreds to thousands of years these structures could be destroyed by weathering or erosion. If it is necessary to ensure that large volumes of water will not enter the repository, it is apparent that additional barriers will be required. These barriers could include a surface barrier, as suggested by Fernandez and Freshley (1984), a relatively impermeable backfill throughout the shaft, seals or backfills placed in the repository to keep flow out of disposal rooms, or some combination of these.

The significance of the damage zone in the shaft will depend largely on which concept is selected. If a surface barrier is used, or if seals are placed in the repository, the flow through the shaft (and hence through the damage zone) will not be significant. If a relatively impermeable backfill is used to control flow, the damage zone may have a higher effective hydraulic conductivity than the backfill and thus could be significant. This point is illustrated by Figure 4, which shows the effect of a hypothetical damage zone on flow through a 12-foot diameter, backfilled shaft under a nominal hydraulic gradient. In this example, the damage zone extends to one radius from the shaft wall and has a hydraulic conductivity of 10^{-3} cm/s. It can be seen that the damage zone has little effect on total flow when the hydraulic conductivity of the backfill is greater than 10^{-2} cm/s. Conversely, the damage zone



TOTAL FLOW THROUGH 12 ft RADIUS MODEL

① — · — · — *FLOW THROUGH UNDAMAGED ROCK PLUS BACKFILL*
HYDRAULIC CONDUCTIVITY OF UNDAMAGED TUFF = 10^{-5} cm/s

② — — — — *FLOW THROUGH DAMAGED ROCK PLUS BACKFILL*
HYDRAULIC CONDUCTIVITY OF DAMAGE ZONE = 10^{-3} cm/s

DRAINAGE

③ — — — *DRAINAGE FROM BASE OF LINED SHAFT*
(HYDRAULIC CONDUCTIVITY OF TUFF = 10^{-5} cm/s, HEAD = 100 ft.)

, of Damage Zone on Flow Through

dominates the total flow when the conductivity of the backfill is less than 10^{-3} cm/s. In this example, backfill with a hydraulic conductivity less than 10^{-4} cm/s reduces the total flow to about 3×10^{-4} m^3/s (26 m^3/day).

Some or all of the water which infiltrates through the backfill and damage zone may drain into the fractured tuff from the shaft sump. If the drainage capacity of the shaft sump exceeds the infiltration rate through the backfill and damage zone, there should be little or no flow through the shaft station into the repository. If the infiltration through the backfill and damage zone exceeds the drainage capacity of the sump, the sump will fill and the excess water will flow into the repository.

Drainage from the shaft may be calculated for two cases, for a lined sump where flow occurs only through the bottom, and for an unlined sump where flow occurs also through the sidewalls. For the lined case, the drainage rate is estimated using a formula developed by the U.S. Bureau of Reclamation (Stephens and Neuman, 1982) for steady-state flow from the bottom of a cased borehole:

$$Q_s = 5.5\ r\ H\ K_f \qquad (3)$$

where

- Q_s = flow rate (ft^3/s),
- r = radius of shaft = 6 ft (1.83m),
- H = height of standing water in the shaft (ft), and
- K_f = saturated effective hydraulic conductivity of fractured tuff (ft/s).

For a nominal head of 100 ft (30.5m) and an effective saturated hydraulic conductivity of 3.3×10^{-7} ft/s (10^{-5} cm/s, as used for the undamaged tuff in the damage zone model), the calculated flow rate is 1.1×10^{-3} ft^3/s (3.1×10^{-5} m^3/s).

Drainage from the unlined shaft may be estimated from the Nasberg-Terletskata equation (Stephens and Neuman, 1982):

$$Q_s = \frac{K_f \, H^2}{0.423} \, \frac{1}{\log(2H/r)} \qquad (4)$$

where symbols are defined previously. For the same head and hydraulic conductivity used above, the calculated flow is 5.1 x 10^{-3} ft^3/s (1.4 x 10^{-4} m^3/s). These calculations indicate a sump drainage capacity in the range 10^{-4} to 3 x 10^{-5} m^3/s. From Figure 4, the infiltration rate through the shaft may be in the range 10^{-3} to 10^{-4} m^3/s, even if a relatively impermeable backfill is placed. The infiltration through the shaft may thus exceed the drainage capacity of the sump, primarily because of the influence of the damage zone. In other words, if it was decided to limit flow down the shaft by placing a relatively impermeable backfill, it would be necessary to reduce the permeability of the damage zone either by limiting the damage at the time of construction or by treating the damage zone at the time of sealing.

Placing the previous calculations and discussion in perspective, the damage zone around the shaft need not be an issue if the main part of the shaft is not a primary component of the shaft seal system. As noted previously, flow into the shaft can be impeded by a surface barrier. As a redundant backup for the surface barrier, seals or barriers can be placed in the shaft station or barriers can be placed in the repository to keep flow out of the emplacement rooms. An additional point of perspective is that seals or barriers are required only to prevent episodic inflow of surface water. Even if some inflow could bypass the seals, this should occur only at intervals of hundreds of years or longer so that the total flow which could reach the waste would be very low averaged over the life of the repository.

In conclusion, the preferred concept for sealing the shaft is the surface barrier as proposed by Fernandez and Freshley (1984), consisting of a shaft cover, a core of low permeability material extending at least through the overburden and, if necessary, a plug at the bedrock surface. Given that an effective surface barrier is installed, the damage zone and liner in the shaft below the barrier should have no significant effect on the volume of water inflow, regardless of the degree of damage or the quality of the liner. It will be beneficial to remove the liner in the sump below the main station connecting to the repository in order to increase drainage. It may also be advantageous (with respect to construction of a surface barrier) to remove the liner in the alluvium overlying the bedrock. This solution may only be adopted if the alluvium is relatively thin so that the liner could be removed in a safe manner.

4.2 <u>GROUNDWATER INFLOW FROM A FAULT TOWARDS THE ES</u>

In this scenario groundwater enters the repository from a fault zone, contacts the waste and then flows downgrade in the drifts towards the ES. The ES then acts as a preferred pathway for radionuclide migration towards the groundwater table.

The ES is potentially a preferred pathway because much of the repository floor drains towards the shaft, and because the shaft penetrates through the Topapah Spring Member into the Calico Hills Tuff. Because the Topapah Spring Member is fractured and may be permeable throughout, the ES does not represent the only pathway to the groundwater table. Thus, although a pathway through the ES could represent the minimum travel time to the groundwater table, the shaft will not necessarily have a significant influence on flow volume or on the average travel time, which takes into account all possible travel paths.

4.2.1 <u>Groundwater Inflow From the Rock Matrix and From Discrete Faults</u>

Fernandez and Freshley (1984) report analyses performed with the computer code TRUST for groundwater inflow to a drift. Excepting discrete faults, they predicted that the inflow should be small, on the order of 10^{-10} to 10^{-12} m^3/s (approximately 4×10^{-9} to 4×10^{-11} ft^3/s) for a drift backfilled with clay to 10^{-24} m^3/s (3×10^{-23} ft^3/s) for a drift backfilled with sand. In these calculations the assumed flux through the rock mass was 4 mm/year (0.16 in/year) and the saturated permeability of the rock mass was approximately 10^{-17} to 10^{-14} m^2 (10^{-16} to 10^{-13} ft^2; equivalent to 10^{-8} to 10^{-5} cm/s). The analyses showed that the drift backfill acts as a capillary barrier and reduces the groundwater inflow. Sand was found to be a more effective capillary barrier than clay.

Fernandez and Freshley's analyses using TRUST accounted for fracture flow by considering an equivalent porous medium permeability for the tuff. In a separate analysis, Fernandez and Freshley postulated the existence of discrete fault zones which would have a higher effective hydraulic conductivity than the typical rock mass. Such faults have been encountered in tunnels at the Nevada Test Site, and some have produced large inflows at the time of excavation. If these faults connect to the surface they could be recharged by heavy rainfall, particularly if they connect with washes which become flooded.

Figure 3 shows the faults mapped at the surface in the vicinity of the proposed repository location. While a relatively large number of faults are shown, it is reasonable to suppose that many are minor features which may not penetrate to the repository horizon. For purposes of evaluating potential inflow, two faults deserve special attention; the unnamed fault or series of faults in Drill Hole Wash, and the Ghost Dance Fault which runs north-south across the repository to the west of the ES.

The faults in Drill Hole Wash have a major topographic expression in the form of the wash. This presumably reflects a relatively erodable fracture zone that may also possess high vertical permeability. Scott et al. (1984) discussed the nature of the faults in Drill Hole Wash and other northwest-southeast trending washes to the north of the repository and evaluated the possibility that the faults may act as conduits for groundwater flow. A preliminary conclusion was that the groundwater flow characteristics were not significantly different beneath the washes than in the adjacent unfaulted blocks. This preliminary conclusion does not yet disprove the possibility of rapid recharge below the major washes. The faults in Drill Hole Wash may be significant with regards to sealing concepts because they intersect the two ramps and because they underlie an area inundated periodically by flooding (Figure 3). The faults are less significant with regards to sealing of the ES because they intersect the repository workings downgrade from the shaft. A very large inflow (approximately 1.8×10^5 m^3; 6×10^6 ft^3) would be required in order for water to flood the repository downgrade from the ES and reach as far as the shaft.

The Ghost Dance Fault intersects the repository upgradient from the ES and is a potential source for inflow which could drain towards the shaft. The fault dips 84 to 89° to the west and is identified at the surface by small stratigraphic separations and by breccia zones. The fault has little vertical displacement, and it cuts across the east-west trending washes which drain off Yucca Crest. There is no information available regarding the subsurface character of the fault, nor its hydrologic properties. (These properties may be obtained from boreholes drilled from the ES.) For purposes of the present analyses, the significance of the Ghost Dance Fault derives from its continuity and its location. As shown by Figure 3, the fault intersects seven panels in the preconceptual repository layout, including 37 emplacement rooms, all of which are upgradient from the ES. Nine small washes cross the fault on the surface (within the proposed repository block) and could supply water. If recharge occurs only directly below the intersection of the fault and a wash, possibly only nine rooms would experience inflow after rainfall. Because the fault crosses the washes almost perpendicularly, the amount of recharge and subsequent inflow should be significantly less than for a fault which underlies a wash along its length.

The scenario postulated for fracture inflow presupposes there will be rainfall of sufficient intensity and duration to produce runoff-induced flow in the washes for several hours to days. After a period of time, the alluvium beneath the wash becomes saturated and begins to provide water to the fault/fracture system intersecting the wash. Because of the small volume of the fracture, an assumption made is that little time is required to completely saturate the fracture plane. Implicit in this assumption is that the infiltration into the host rock along the fracture is small compared to the flow through the fracture. With the fracture zone completely saturated from the surface to the water table, the discharge from the fracture zone can be estimated by a method given by Freeze and Cherry (1979) for inflow to a tunnel located in the saturated zone:

$$Q = \frac{2\pi K H_o T}{2.3 \log(2H_o/r)} \qquad (5)$$

where

- Q = groundwater inflow from fracture zone (ft^3/s),
- K = effective hydraulic conductivity of the fracture zone (ft/s),
- H_o = hydraulic head (ft),
- r = effective radius of the drift (ft), and
- T = width of fault zone (ft).

This solution also assumes that the drift is infinitely long, that the equivalent porous medium within the fault zone is homogeneous and isotropic, that the pressure heads on the drift wall are atmospheric, and that the water table is maintained at a constant elevation. In reality, it is not likely that the head in the fracture zone will be maintained over significant periods of time, as is implied by a constant water table elevation. It is expected that drift inflows will be transient in nature, not steady, so that the solution may provide the peak rather than the steady-state flow. Another simplification is that the solution implies that flow converges to the tunnel from all directions (i.e., inflow occurs through the floor and walls as well as through the roof) which seems unlikely for a tunnel above the water table. Considering all of the assumptions involved, Equation (5) probably provides a conservative upper limit for inflow.

There are no reported values for the hydraulic conductivities of fault zones in welded tuff. Intuitively, the conductivity might be expected to be relatively low perpendicular to the fault (because of the presence of clay gouge) but higher within the plane of the fault. The present analyses use a range of 10^{-5} to 10^{-2} cm/s (3.3×10^{-7} to 3.3×10^{-4} ft/s), as given by Scott et al. (1983) for the effective rock mass hydraulic conductivity for welded tuff. For this range of hydraulic conductivity, the inflow to a 10 ft (3m) radius tunnel for a 1 ft (0.3m) wide fracture zone under a head of 1200 ft (366m) ranges from 4.5×10^{-4} to 4.5×10^{-1} ft^3/s (1.2×10^{-5} to 1.2×10^{-2} m^3/s). Values for wider fracture zones or other conductivities can be scaled accordingly.

4.2.2 Sealing Concepts for Discrete Fault Zones

Fernandez and Freshley (1984) described several concepts for sealing a discrete fault or fracture zone occurring in a drift. These range in complexity from drains installed in the floor, to small dams built up on the floor, to grouting of the fractured zone, and to external fault seals or bulkheads which would completely seal off the drift on either side of the fault. In theory, each concept may be appropriate for a particular volume and rate of inflow. For example, the small dams will retain a specific volume of inflow before overflowing. From calculations presented above, the maximum estimated inflow rate is 4.5×10^{-1} ft^3/s (1.2×10^{-2} m^3/s). For a horizontal drift 15 ft (4.6m) wide, two 6 ft (1.8m) high dams 20 ft (6.1m) apart will retain an inflow of 4.5×10^{-1} ft^3/s for approximately one hour, even neglecting drainage through the floor. Similarly, dams 200 ft (60m) apart will retain 4.5×10^{-1} ft^3/s for 10 hours. Dams 6 ft (1.8m) high at either end of a horizontal, 1400 ft (427m) long emplacement room (vertical mode) would hold 126,000 ft^3 ($3570 m^3$), equivalent to an inflow of 4.5×10^{-1} ft^3/s lasting about three days. A 6 ft (1.8m) high dam at the lower end of a drift graded at 5% would hold 5400 ft^3 ($153 m^3$), equivalent to an inflow of 4.5×10^{-1} ft^3/s lasting about three hours.

These calculations suggest that relatively simple measures such as dams placed at the ends of emplacement drifts can control water flow along the repository floor and encourage drainage through the floor in the vicinity of the inflow, in the event that periodic inflows do occur through faults. Additional measures such as grouting can be taken in areas where high inflows occur during excavation and where inflow in the future is most likely. Moreover, if exploration holes are drilled ahead of mining, water-bearing zones should be identified and a decision may be made not to mine through these areas.

4.2.3 Flow Through the ES

The calculations in the preceding section indicate that relatively simple engineered barriers can be used to prevent groundwater from reaching the ES. Evidently, if no flow reaches the shaft, then neither the damage zone nor the liner can influence radionuclide release.

Even if some inflow could reach the ES, the shaft represents only one potential flow path since groundwater entering the repository will tend to drain through the floor at all points in the repository provided that the permeability of the floor is not greatly reduced by fines. It is thus important to note that the repository drifts offer a relatively large floor area through which flow can occur, whereas the area of the ES is relatively small, even with a damage zone. The total area of the repository in the preconceptual design is 6.6×10^6 m^2 (1630 acres, or 7.1×10^7 ft^2) and the overall extraction ratio is about 16%, giving a drift floor area of about 9.3×10^5 m^2 (10^7 ft^2). In contrast, the area of the exploratory shaft is 10.5 m^2 (113 ft^2); assuming that the damage zone extends to one radius (see Section 2.2) from the wall the area of the damage zone is 31.5 m^2 (339 ft^2) and the total area of the shaft plus damage zone is 42 m^2 (452 ft^2). The ratio of the floor area in the repository to the area of the shaft plus damage zone is thus greater than 10^4.

The damage zone may have a hydraulic conductivity two orders of magnitude greater than that of the undisturbed fractured tuff (Section 2.2). If this is the case, the ratio of the product of the hydraulic conductivity for the undisturbed tuff and the repository floor area to the product of the hydraulic conductivity of the damage zone around the shaft and the damage zone area is about 10^2. This suggests that the potential for flow through the damage zone should be insignificant relative to that through the floor, provided that flow does not occur freely along an impermeable floor towards the shaft.

The damage zone may have more influence on minimum travel time (considered to be the minimum travel time along any pathway between the repository and the water table), which could be reduced by two orders of magnitude through the Topopah Spring (assuming that the hydraulic conductivity is increased by up to two orders of magnitude within the damage zone). It is noted, however, that the potential flow along the travel path representing the minimum travel time is very small (as determined above) compared with the total flow, because the area of the damaged rock is small. This means that the damage zone in the ES has little effect on the average travel time from the repository to the groundwater table. If minimum travel time is a concern, the drift connecting the ES to the repository could be sealed with a bulkhead so that flow which had contacted the waste would be impeded from entering the damage zone.

4.3 AIRBORNE RELEASE

4.3.1 Mechanisms for Airborne Release

Various mechanisms may contribute to airborne movement of radionuclides from the repository to the accessible environment. In this report the major mechanism considered is convection driven by temperature gradients. Other mechanisms include gas expansion due to heating, gas production from the waste, and diffusion. Various mechanisms for diffusion are discussed by Evans (1984). For simplicity, this report considers only one mechanism for convective air flow, and does not address absolute radionuclide release. The approach will be to estimate in turn the peak air flow due to convection for various backfills, the proportion of flow within the repository which occurs through the disposal areas, and the effect of the damage zone around the ES and other shafts on air flow. Given information regarding gas release rates from the waste, the results of the study could easily be extrapolated to estimate radionuclide release rates.

In mine ventilation studies it is customary to assume that all flow occurs through the entries with no flow lost to the rock formation. This is a reasonable assumption for open shafts and drifts but it may not be reasonable if the openings are backfilled, particularly if the host rock is relatively permeable.

Figure 5 illustrates two mechanisms for convective air flow, occurring when the waste disposal areas are relatively hot. Case 1 assumes that little or no flow occurs through the host rock relative to flow through the drifts. The ES and adjacent Escape Shaft are within the repository area (Figure 3) and the temperature is above ambient. The Man and Materials Shaft, the Waste Ventilation Shaft and the ramps are located outside or just inside the repository perimeter and the temperature is close to ambient. In response to the thermal regime, air will tend to rise in the ES and Escape Shaft and air will be drawn in through the other entries. Case 1 may occur if the shafts and drifts are open, or if the backfill is relatively permeable so that the resistance to flow through the backfill is less than that through the rock. Case 2 in Figure 5 assumes that significant flow can occur through the host rock. The waste disposal areas are relatively hot and the heated air tends to rise vertically through the rock. Air may be drawn in through the peripheral shafts to maintain atmospheric pressure in the rooms.

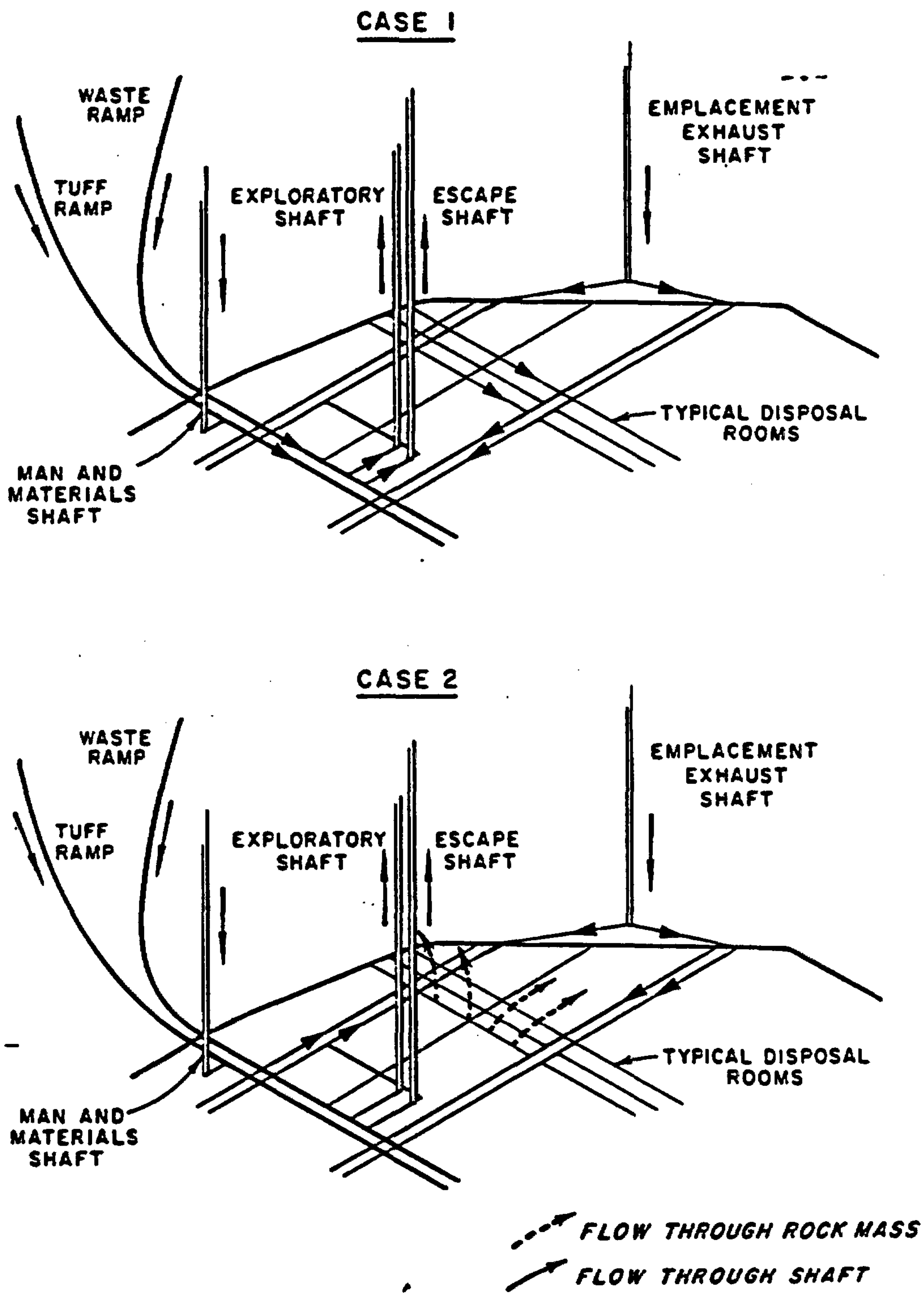


FIGURE 5. Mechanisms for Convective Air Flow

Because the ES and Escape Shaft are located close to the disposal panels, air may escape through these shafts. Case 2 is more likely to occur when the backfill is relatively impermeable such that the resistance to air flow is less through the rock than through the backfill.

4.3.2 Airflow Analysis

This section presents a simplified analysis of convective air flow through a backfilled repository assuming no flow through the host rock (other than the damage zone around the shafts and ramps). The analysis is used to demonstrate the influence of the damage zone around the shafts and ramps relative to the performance of the backfill, and is taken to be representative of the influence of the damage zone for any airborne release mechanism. The analysis does not couple air flow with heat transfer from the rock and does not account for changes in the temperature of the air flowing through the repository. The analysis involves a network flow analysis for part of the repository surrounding the shafts. Prior to conducting the analysis, it is necessary to obtain temperature and pressure differentials which are the driving force for air flow.

Temperature and Pressure Distributions

Movement of air through the repository is caused by the addition of thermal energy to the air by convective heat transfer from the rock. A rigorous solution to the problem would require a coupled heat flow-fluid flow problem. Because of the number of factors affecting heat/air flow, it is an accepted practice in underground mine ventilation analysis to compute natural draft pressures on the basis of differences in air density at inlet and outlet shafts arising from differences in temperature (Hartman, 1961).

In the analysis presented below, the temperature profiles at the potential inlet and outlet points are first determined. The air density profiles at the two locations are then determined from the temperature profiles with a small correction applied for air compressibility. The air pressure profiles at the two locations are then integrated over the height of the column of air to obtain the pressures at the bottoms of the shafts. The difference in pressure between these two locations is taken as the natural draft pressure acting over the entire ventilation network.

No analyses have been conducted to determine temperature histories at the inlet and outlet shaft locations such that temperature profiles at certain times could be obtained. Various unpublished thermal analyses performed by Sandia have been reviewed, and for purposes of the present analyses a peak temperature profile was estimated for the ES based on a peak temperature of 111°C at the repository horizon. At the time at which this peak temperature profile is attained, the temperature at the other shafts outside the repository will be considerably lower. For a conservative analysis, the geothermal temperature profile was adopted, assuming an ambient temperature of 25°C at the repository horizon.

The density of the air as a function of pressure is determined (Cummins and Given, 1973) by:

$$\gamma = 1.327\beta/(460 + t) \qquad (6)$$

where

γ = air density, pounds per cubic foot (pcf),

β = barometric pressure (inches Hg), and

t = temperature (°F).

For the ES, the calculated air density ranges from 0.076 pounds per cubic foot to 0.059 pounds per cubic foot as a function of depth. For the other shafts, the air density calculated from the geothermal profile is approximately 0.076 pounds per cubic foot.

The natural draft pressure was calculated by integrating air density over depth for the ES and the other shaft profiles to determine two pressures at the repository horizon and then taking the difference in these two pressures. The calculated natural draft pressure was 4.9 x 10^{-2} psi (3.4 x 10^{-4} MPa) which corresponds to 1.4 inches of water gage. By comparison, according to Hartman (1961) the natural ventilation pressure generated by thermal energy in mines is usually less than 0.5 inches water gage, and seldom exceeds 3 inches except in extreme cases. The calculated pressure falls within this range and would be expected to be higher than 0.5 inches since the generation of heat in an underground nuclear waste repository results in larger temperature contrasts than those experienced in a typical underground mine.

Flow rates in the backfilled shafts and ramps were determined from Darcy's law for incompressible air flow. The range in conductivity to air for the backfill was from 3.0 x 10^{-6} m/min (10^{-5} ft/min) to 3.0 m/min (10 ft/min), equivalent to a range of hydraulic conductivity from 10^{-4} to 10^{2} cm/s. The upper bound for air permeability corresponds to a coarse aggregate material (gravel) while the lower bound corresponds to an engineered material with fine aggregate (silty sand).

One objective of the analysis was to consider both backfilled and open drifts. For backfilled drifts, the resistance to air flow is calculated using Darcy's law as described above. For open drifts, the resistance to air flow was calculated assuming laminar flow. This assumption* is

*The assumption of laminar flow in the backfill and open drifts was checked by calculating the Reynolds number from the air velocity or specific discharge, air kinematic viscosity, and characteristic dimension. In the case of flow through an open drift, the characteristic dimension is the tunnel diameter and the calculated Reynolds number should be less than 2000 (Daugherty and Franzini, 1965). In the case of flow through backfill, the characteristic dimension is the mean grain diameter and Darcy's law is valid as long as the Reynolds number does not exceed a value between one and ten (Freeze and Cherry, 1979). In both cases the calculated Reynolds numbers were within the specified limits and the assumption of head loss varying linearly with flow rate was found to be justified.

reasonable since the presence of backfill in the shafts and ramps reduces the overall flow rate through the system, resulting in laminar flow and a linear relation between head loss and velocity (Daugherty and Franzini, 1965):

$$h_\ell = \frac{32\mu\ell}{\gamma D^2} V \qquad (7)$$

where

h_ℓ = head loss (ft),

μ = absolute viscosity (lb-s/ft^2),

γ = air density (lb/ft^3),

ℓ = length of drift (ft),

D = effective drift diameter (ft), and

V = velocity (ft/min).

A comparison of the resistances calculated for open drifts and for the backfilled shafts indicates a very large contrast. For practical purposes in calculating total air flow, the resistance to flow from the open drifts may be neglected. However, differences in air flow resistance within the network of underground drifts may affect the distribution of air flow past waste rooms.

The damage zone developed around the shafts is assumed to extend out one radius from the wall (Section 2.2). In this zone, the conductivity to air is assumed to be two orders of magnitude greater than that in the surrounding undisturbed rock. A value of 3.0×10^{-5} m/min (10^{-4} ft/min) was used for conductivity to air in the damage zone. This is equivalent to a hydraulic conductivity for the undisturbed rock of 10^{-5} cm/s, which is the mid-range value for fractured welded tuff quoted by Fernandez and Freshley (1984). For ramps, which have a non-circular section, the damage zone area was calculated from the equivalent radius of a circle with the same area. The areas of the openings and the damage zone for all the entries are shown in Table 1. As shown, a damage zone was not included for the drifts within the repository. The justification for this is discussed below.

TABLE 1.

FLOW AREAS USED IN AIRFLOW ANALYSIS

Entry Description	Entry Area, m^2 (ft^2)	Damaged Zone Area, m^2 (ft^2)
Waste Ramp	26.1 (281)	78.3 (843)
Tuff Ramp	23.2 (250)	69.7 (750)
Tuff Main	23.2 (250)	--
Waste Main	39.5 (425)	--
Panel Access Drift	19.8 (213)	--
Mid-Panel Access	28.3 (305)	--
Emplacement Drift	28.3 (305)	--
Perimeter Drift	25.5 (275)	--
Men & Material Main	15.5 (167)	--
Men & Material Shaft	26.1 (280.7)	78.2 (842)
Exploratory Shaft	10.5 (113.1)	31.5 (339)
Escape Shaft	2.6 (28.3)	7.89 (84.9)
Waste Emplacement Shaft	29.2 (314.2)	87.6 (943)

Reference: Parsons Brinckerhoff, 1984.

Network Analysis

The network used in the analysis is shown in Figure 6 and consists of two waste panels adjacent to the ES, the mains and submains accessing these panels, and the shafts and ramps accessing the repository. The network used in the analysis does not consider the entire repository layout but is sufficient for approximating the distribution of flow past waste emplacement rooms. More remote waste emplacement panels would receive a small portion of the flow and would not affect total flow significantly.

The analytical method used to solve for air flow consisted of assembling a "network stiffness matrix" for the various resistances through the network (Zienkiewicz, 1977). The pressure boundary conditions are applied and a system of linear simultaneous equations in unknown nodal pressures is set up. Solution of the simultaneous equations by the Gauss elimination method results in calculation of the nodal pressures which in turn are used to calculate air flows through the network.

In analyses of a backfilled repository, the differential draft pressure of 4.9×10^{-2} psi as calculated above was applied to the tuff ramp, the waste ramp and two shafts at or outside the edge of the repository. Because there is no contrast in this case between the resistances in the shafts and the drifts, the analysis can be run in one stage. For the case of backfilled shafts/ramps and open drifts, there is large contrast in resistances (as discussed above) and the analysis was performed in two stages. In the first stage a simple network which assumed zero resistance in the repository drifts was used to calculate flows in all shafts and ramps. In the second stage these flows were imposed on the drift network to determine distribution of flow in the repository between the mains and the disposal areas.

Twelve parametric runs were performed with the network model (Table 2), six with a damage zone included (Runs 1-6) and six equivalent runs without the damage zone (Runs 1N-6N). In each set of six runs, three

– NOTICE –

QA checks on data contained here have only been performed to determine that these data have been obtained and documented properly. The DOE cautions that any information is preliminary and subject to change as further analyses are performed or as an enlarged and perhaps more representative data base is accumulated. These data and interpretations should be used accordingly.

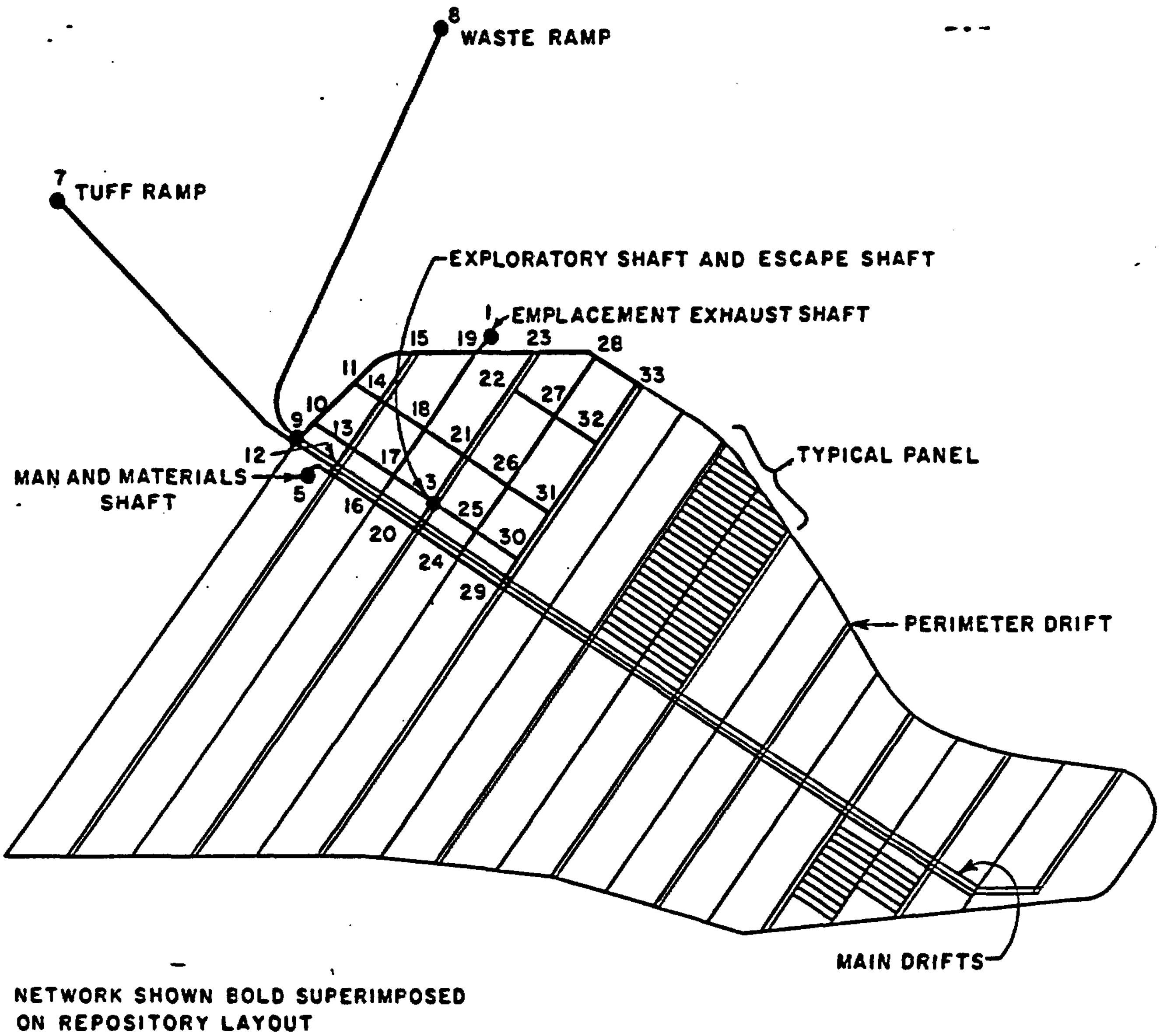


FIGURE 6. Network Used in Analysis of Convective Air Flow

TABLE 2.

SUMMARY OF NETWORK ANALYSIS

Run No.		1 or 1N	2 or 2N	3 or 3N	4 or 4N	5 or 5N	6 or 6N
Backfill Conductivity to Air	10 ft/min		X			X	
	0.1 ft/min	X			X		
	10^{-5} ft/min			X			X
Backfill	drifts open	X	X	X			
	drifts backfilled				X	X	X
Flow rate with disturbed zone (cfm)		0.72	72	2.2×10^{-3}	0.55	55	4.2×10^{-4}
Flow rate without disturbed zone (cfm)		0.72	72	7.2×10^{-5}	0.55	55	5.5×10^{-5}

Flows are flow rates past waste emplacement rooms.

runs were performed for open drifts representing three values for the air conductivity of the backfill in the shafts, and three runs were performed for backfilled drifts covering the same range of conductivity. For analyses with backfilled drifts, the air conductivity of the backfill in the drifts was the same as that for the backfill in the shafts. Table 2 shows the calculated air flow past the waste for each of the runs.

The calculated total air flow for the base case analysis (Run No. 1) is 0.03 m^3/min (1.1 ft^3/min) under the draft pressure of 4.9 x 10^{-2} psi. It is estimated that approximately 35 percent of this flow would pass directly through the mains to the ES. The estimated flow passing through waste emplacement rooms is therefore about 65 percent of the total flow, or 0.02 m^3/min (0.72 ft^3/min). Since the conductivity to air of the backfill in the shafts and ramps is three orders of magnitude greater than that of the surrounding damage zone, the air flow is dominantly through the backfill and the damage zone does not affect flow.

An increase in the shaft backfill conductivity to air to 3 m/min (10 ft/min) in Run No. 2 results in a proportional increase in total air flow to 3.1 m^3/min (111 ft^3/min). However, a reduction in conductivity to air to 3.0 x 10^{-6} m/min (10^{-5} ft/min) in Run No. 3 does not result in a proportional reduction of total air flow because the damage zone becomes the dominant flow path when a relatively impermeable backfill is selected. In Run No. 3, the damage zone is an order of magnitude more permeable than the low permeability backfill.

The presence of backfill in the waste emplacement rooms (Run Nos. 4-6) has a relatively minor effect on total air flow and air flow past waste canisters over the range of backfill permeabilities from 3 x 10^{-2} to 3 m/min (0.1 to 10 ft/min). These results confirm that the main resistance to air flow is in the shafts and ramps with the network of drifts providing little resistance. Therefore, backfilling only the shafts and ramps is effective in reducing overall flow. Also, the damage zone around the drifts (not included in these analyses) will have little effect on flow rate provided high air conductivity backfill materials are emplaced in the drifts. If low conductivity materials are placed, much of the flow may occur in the damage zone but the flow rate will be very low.

The analyses presented above were repeated with the damage zone around the shafts and ramps removed. The resulting flow rates for high permeability backfill (Run Nos. 1N, 2N, 4N, 5N) are nearly the same as for the counterpart runs with a damage zone. A comparison of Runs 3N and 6N with their counterpart runs indicates that the flow through the damage zone is significant relative to flow through the low permeability backfill but the absolute flow rate is low (10^{-4} ft^3/min).

The simplifications and assumptions involved in the airflow analyses have been noted above. Accordingly, it is appropriate to consider the results only as order of magnitude estimates. In this context, the analyses show that the air flow rate is low for all cases considered. The maximum calculated value for flow past the waste was 72 ft^3/min for the case of a very permeable shaft backfill. When the backfill air conductivity is relatively high, the effect of the damage zone is negligible. When the backfill air conductivity is relatively low, the relative effect of the damage zone is greater but the absolute flow rates are very low and probably negligible. From these analyses, it is concluded that the degree of damage resulting from ES construction will not affect performance in terms of airborne radionuclide release.

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