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Rautman, C.,
D.L. South, and
B.C. Whittet, 1987

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Definitions of Reference Boundaries for the Proposed Geologic Repository at Yucca Mountain, Nevada

C. A. Rautman, B. C. Whittet, D. L. South

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DEFINITIONS OF REFERENCE BOUNDARIES FOR THE PROPOSED GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN, NEVADA

C. A. Rautman,
B. C. Whittet, and D. L. South

Geoscience Analysis Division
Sandia National Laboratories
Albuquerque, New Mexico 87185

ABSTRACT

Reference locations are proposed for six boundaries or regions specified by federal regulations related to a proposed high-level nuclear waste repository at Yucca Mountain in southern Nevada. These proposed boundaries establish the limits and extent of (1) the underground facilities, (2) the disturbed zone around those underground facilities, (3) the geologic repository operations area, the restricted area for preclosure radiation protection, the controlled area, and the accessible environment. For each boundary, discussion of the underlying regulations is followed by a description of the proposed location of that boundary. A discussion section describes the rationale for choosing that particular, site-specific location in relationship to the generic regulatory definition.

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INTRODUCTION

The Yucca Mountain site in southern Nevada (Figure 1), has been selected as one of three candidate locations for the first permanent repository for high-level, commercial nuclear waste (DOE, 1986). This paper proposes reference locations for several of the critical boundaries at the Yucca Mountain site. These boundaries establish the limits and extent of:

1. the underground facilities,
2. the disturbed zone around the underground facilities,
3. the geologic repository operations area,
4. the restricted area for preclosure radiation protection,
5. the controlled area, and
6. the accessible environment.

Each boundary is addressed separately below. For each item, information and discussion is provided concerning:

1. the regulatory or policy basis that establishes the need and requirements for a definition,
2. the proposed location of the reference boundary in two- or three-dimensional space*, and
3. the rationale used to locate that particular boundary.

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*The Interactive Graphics Information System, maintained and operated by Division 6315 at Sandia National Laboratories, produced the figures attached to this report, and contains the exact three dimensional (x,y,z) coordinates of all boundaries discussed. Reference to the CAL product numbers found on each figure provides for traceability to the source documents or design drawings used in defining the specific boundaries.

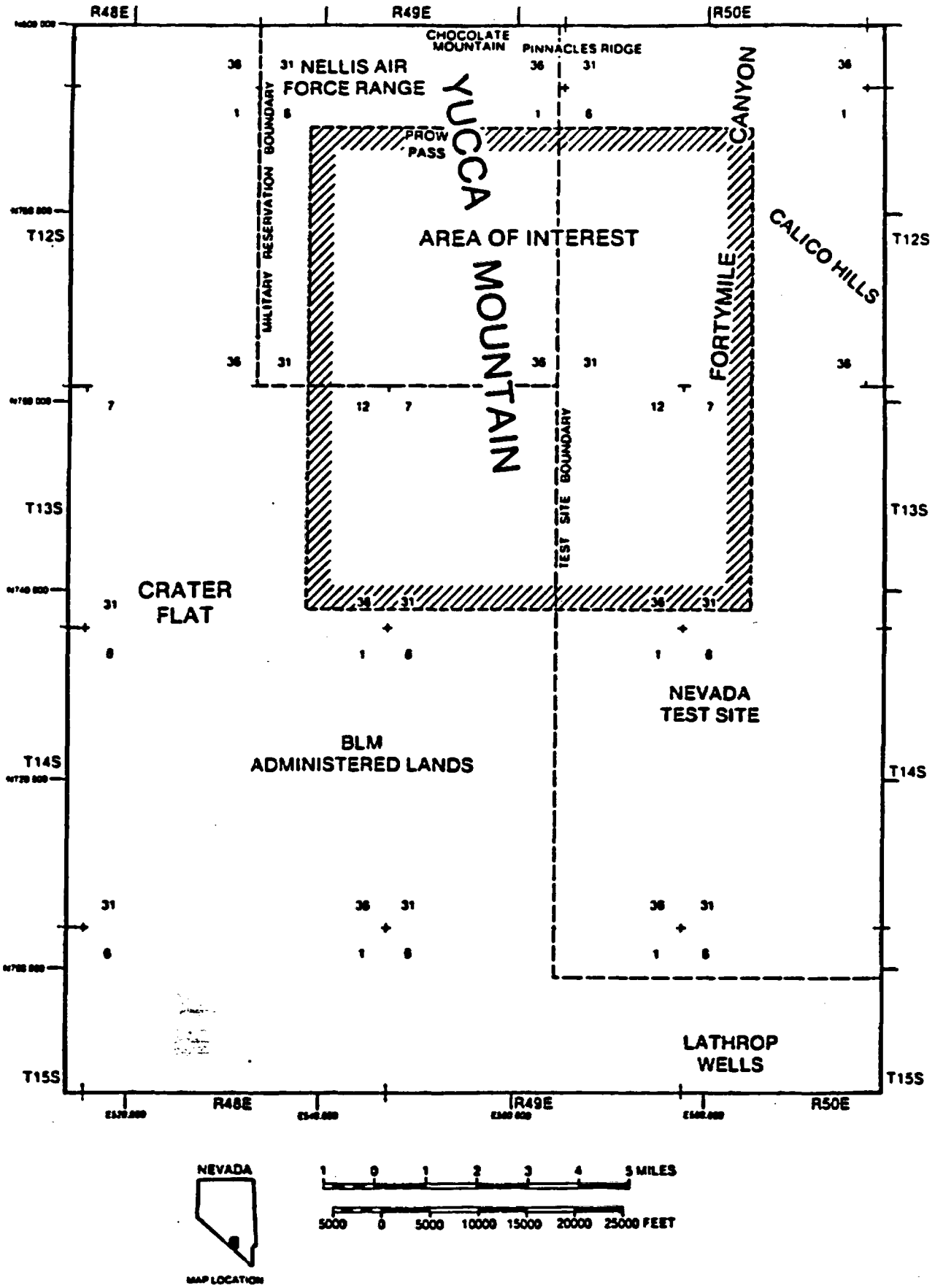

Figure 1. Index Map Showing Location of the Proposed Yucca Mountain Repository Site in Southern Nevada. From NNWSI Product No. CAL0163.

All the boundary definitions contained in this report are proposed locations, subject to revision and change. The purpose of establishing reference definitions is to provide a common basis on which a critical evaluation of the implications of those boundaries may be made. A further reason requiring an explicit statement of the location of the boundaries discussed in this report is the need for the U. S. Department of Energy (DOE) to communicate to interested parties the specific location of the various parts of a repository at Yucca Mountain.

Proposed definitions may become formalized as reference definitions for the entire Nevada Nuclear Waste Storage Investigations (NNWSI) Project and incorporated into the NNWSI Reference Information Base. The process for establishing and modifying NNWSI Project reference information is outlined in the NNWSI Systems Engineering Management Plan (DOE, in preparation).

The location of the proposed boundaries is based on current engineering design, particularly as embodied in the Conceptual Design Report (SNL, in press). Increased understanding of the natural system at Yucca Mountain and modification of existing design concepts almost certainly will result in evolving definitions. As part of that evolutionary process, comments by all readers of this report are solicited. Please address comments and suggestions to the authors or to the Administrator, Reference Information Base; Division 6316; Sandia National Laboratories; Albuquerque, New Mexico 87185.

UNDERGROUND FACILITIES

Regulatory and Policy Bases for Definition

The underground facilities are defined in 10 CFR 960.2 as

> the underground structure and the rock required for support, including mined openings and backfill materials, but excluding shafts, boreholes and their seals.

The definition in 10 CFR 60.2 is identical, but with the omission of the words and the rock required for support.

This definition is used in turn to specify the boundaries of the engineered barrier system, which consists of "the waste packages and the underground facility" (10 CFR 60.2). There are specific design and performance criteria to be met by the components of the engineered barrier system. Thus, the boundaries of the underground facilities must be specified in order to define the engineered barrier system. Only then can compliance with such criteria be assessed.

Design criteria for the underground facilities are addressed in 10 CFR 60.133, and overall performance objectives for the repository are addressed in 10 CFR 60.112 and 60.113.

Location of the Reference Boundary

Figures 2 and 3 show the location and the outer boundary of the underground facilities at Yucca Mountain. In addition to the openings themselves, the "underground structure" referred to in

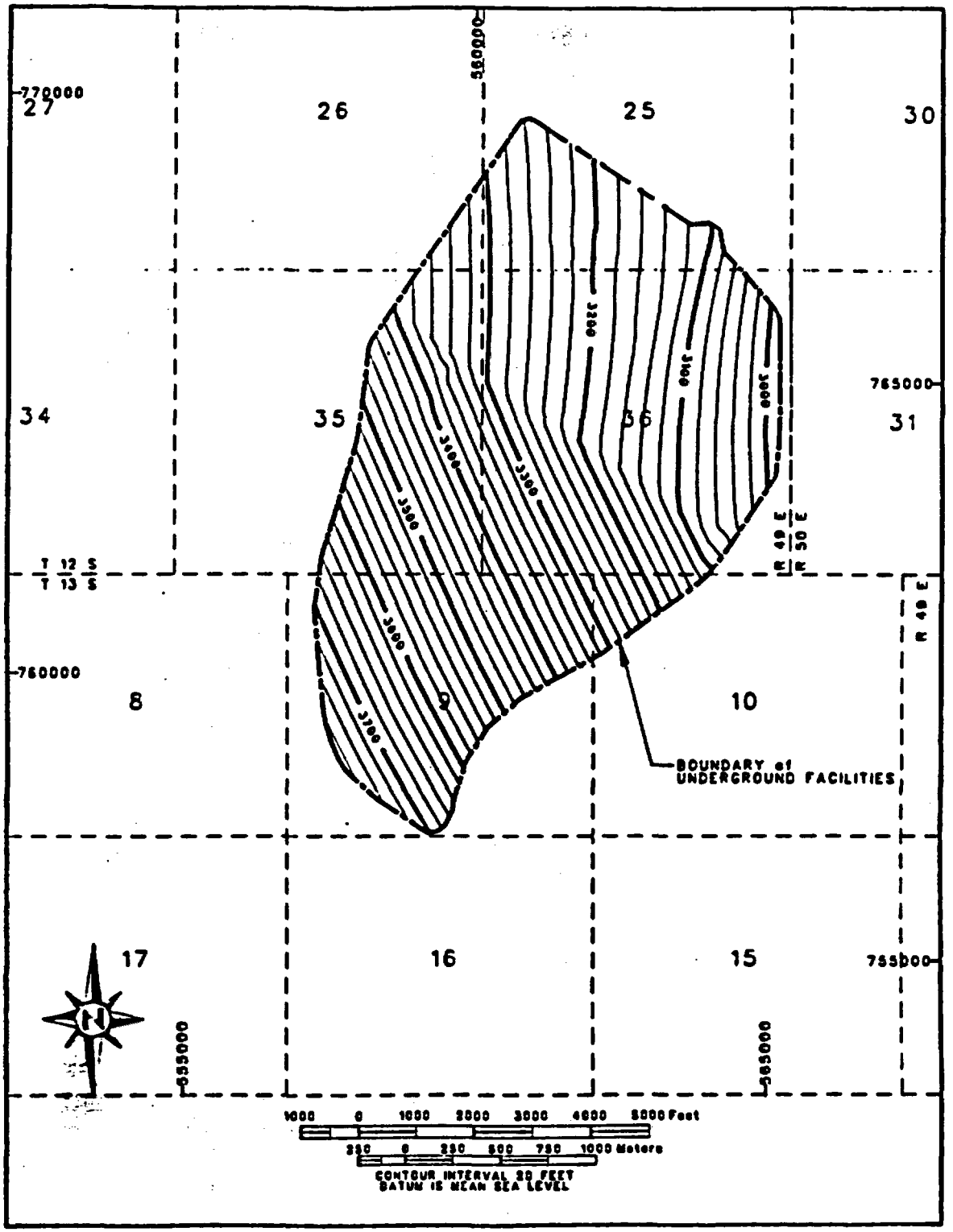

Figure 2. Reference Location of the Underground Facilities, based upon the Location of the Repository Perimeter Drift and the Elevation of the Floor of the Repository. See Text for Discussion. Coordinates are Nevada State Plane Coordinate System in Feet. From NNWSI Product No. CAL0173.

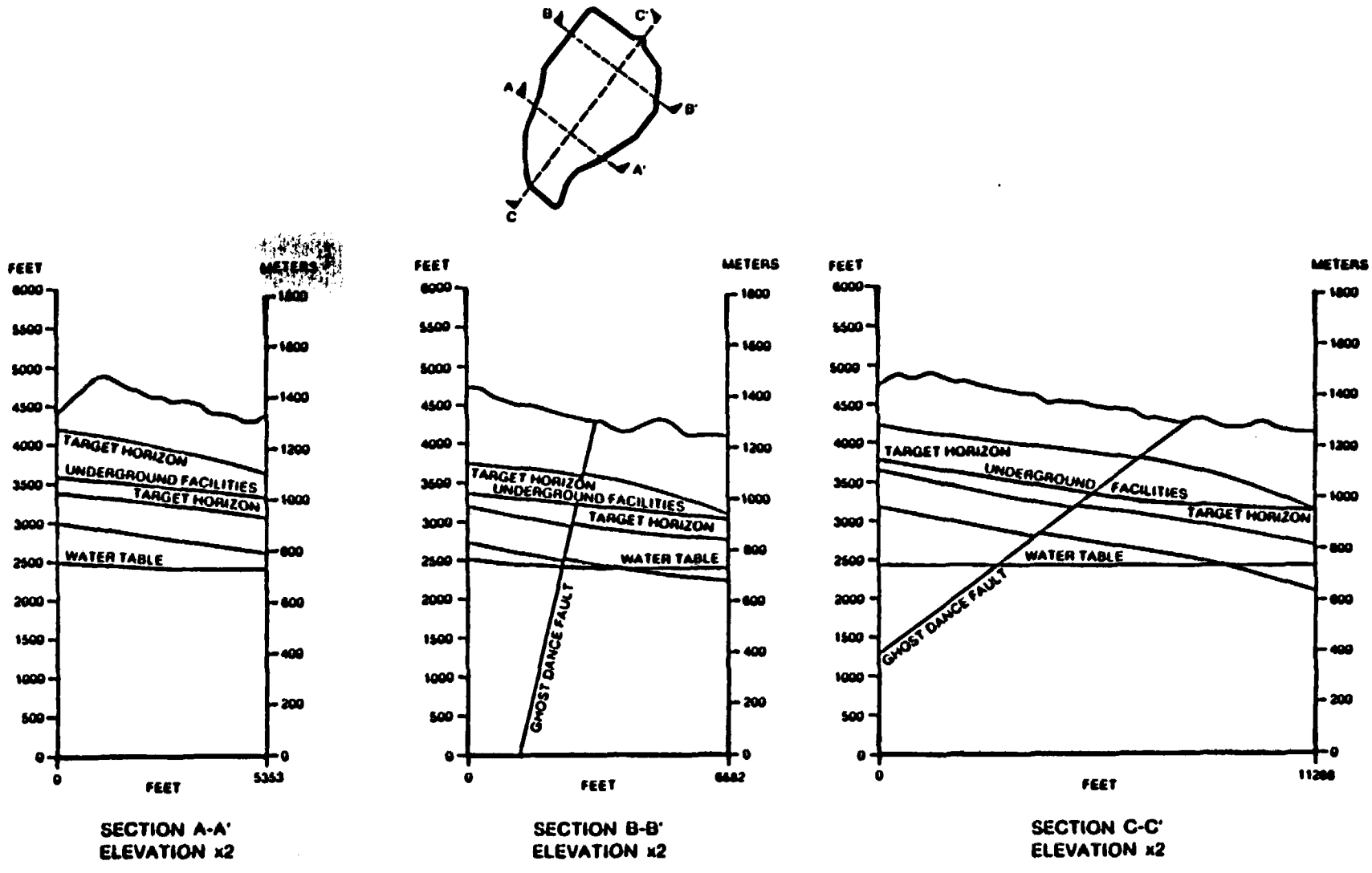

Figure 3. Selected Cross Sections Showing the Reference Location of the Underground Facilities. NNWSI Product No. CAL0158.

the definition (10 CFR 960.2) includes the rock necessary to support those openings in a stable condition throughout the construction and retrievability periods (see 10 CFR 60.133(e) and (c)). The proposed boundary of the underground facility is located 5 meters beyond the actual limits of excavated openings (Braithwaite, in preparation) in order to include the additional volume of rock required to support safely all excavations and waste emplacement holes (Figure 4).

Figures 2 and 3 show the vertical location (elevation) of the underground facilities in plan view and selected cross sections. The elevation of the floor of the access drifts of the underground facilities varies from 2,941 to 3,765 feet (Figure 2), and the depth below surface ranges from 652 to 1,461 feet. For vertical emplacement of the waste packages in the floor of the drifts (the reference case), the thickness of the underground facilities will be approximately 80 feet (24 meters) (Figure 4a; drift: 22 feet; emplacement borehole: 25 feet; rock required for support: 16.5 feet (5 m) on both top and bottom). For the alternative of horizontal emplacement of the waste, the thickness of the underground facilities reduces to about 46 feet (14 meters) (Figure 4b).

Rationale for Boundary Location

The boundary of the underground facilities as shown in Figure 2 is based on the location of the perimeter drift obtained from an engineering drawing by Parsons Brinkerhoff Quade & Douglas (SNL,

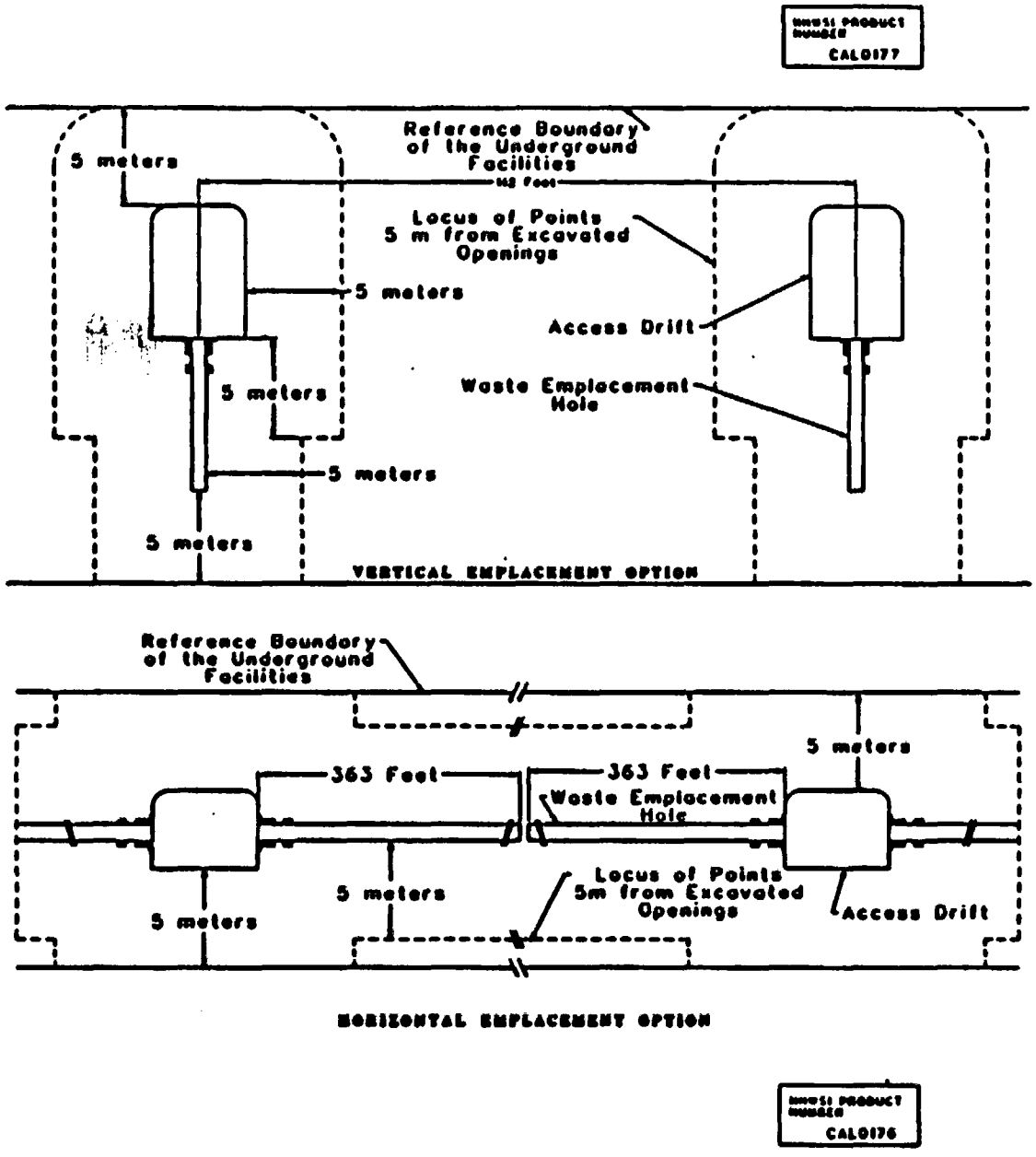

Figure 4. Conceptual Relationship of the Boundary of the Underground Facilities to the Excavated Openings for (A) Vertical Emplacement (the Reference Case) and (B) Horizontal Emplacement. See Discussion of Rationale for Boundary Location. NNWSI Product Nos. CAL0176 (Horizontal) and CAL0177.

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in press). This drift location represents the result of preliminary engineering design within a primary exploration area (Figure 5) at the Yucca Mountain location (Mansure and Ortiz, 1984).

The engineering design was based on initial requirements of about 1,500 acres (Mansure, 1985) of repository area based on the statuatory design capacity of 70,000 metric tons of heavy metal (NWPA, 1982) and on design considerations such as maximum thermal loading of 57 kW per acre, required to keep the underground facilities at a temperature of less than 100 degrees Celsius during the period of repository operation (Johnstone and others 1984). Ventilation requirements, drift size(s) required for vertical or horizontal emplacement, ease of operation and maintenance, and retrievability were other design considerations. The engineering design of the underground facilities has undergone numerous changes and revisions since the initial requirements were formulated. The current status of engineering plans is summarized in the Conceptual Design Report (SNL, in press) and in the Reference Information Base (RIB, 1987).

The critical concept for this report is that the perimeter drift defines the outer limit of mined openings at waste emplacement depths. Numerous mined openings will be constructed within the area defined by the location of the perimeter drift, with the number and general configuration of such openings determined by the mode of waste emplacement (vertical or horizontal). The underground facilities are here taken as a volume of rock required

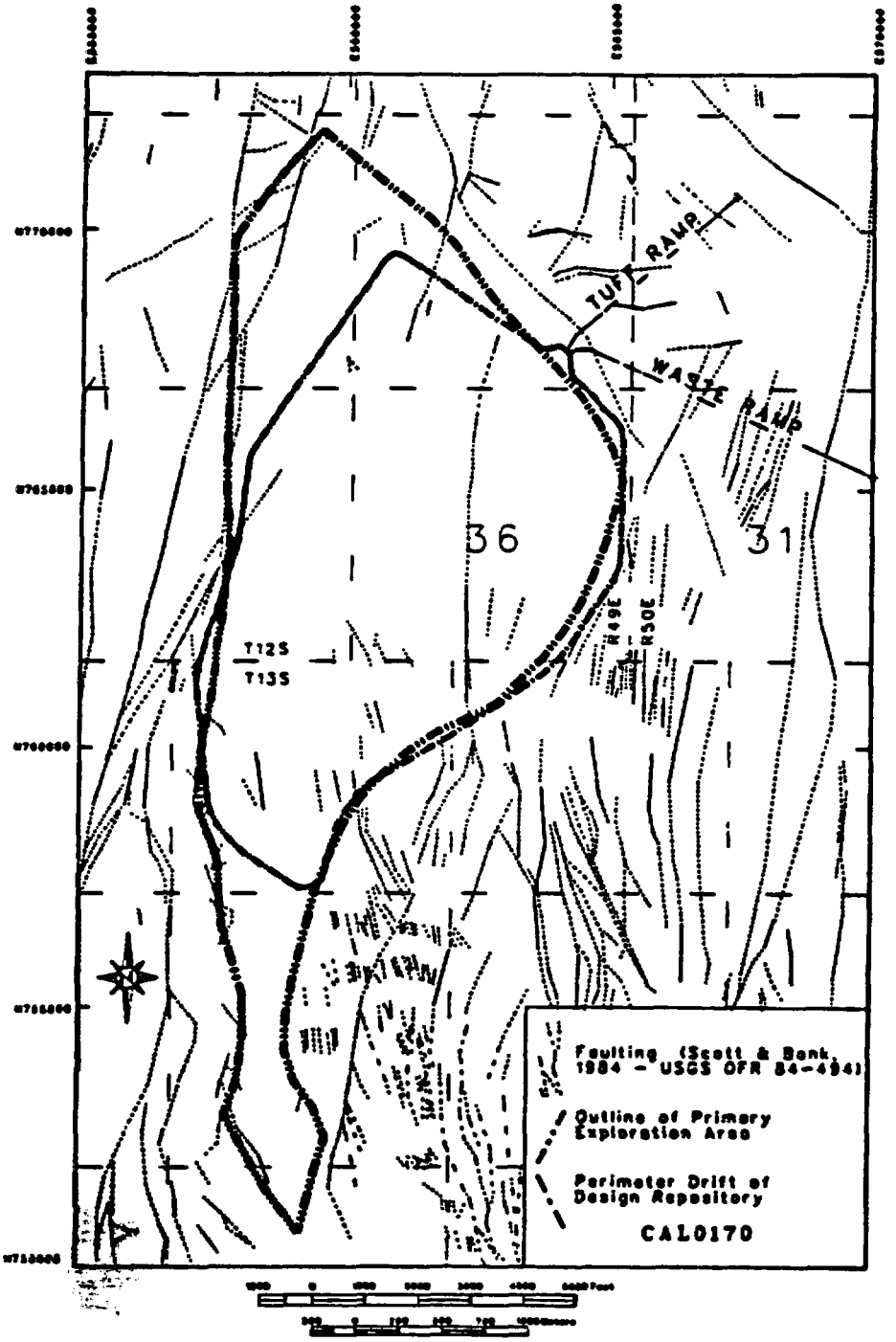

Figure 5. Location of the Underground Facilities in Relationship to the Primary Exploration Area Identified by Mansure and Ortiz (1984) Among Others. Map also Shows Location of Interpreted Faults that Influenced Choice of the Primary Exploration Area. NNWSI Product No. CAL0170.

to support safely all design excavations and waste emplacement holes. Accordingly, some portion of the rock between the various drifts and emplacement holes is part of the underground facilities.

Braithwaite (in preparation) has addressed the problem of the minimum volume of rock required for long-term stability of the excavated openings. Applying standard methods for evaluating pillar stability in mines given the design "room" dimensions, Braithwaite (in preparation, p. 19-22) determined that the minimum pillar width for engineering stability in both horizontal and vertical emplacement options was similar, averaging approximately 5 meters. Following this logic, Braithwaite (in preparation, abstract) proposed that the boundary of the engineered barrier system (defined in 10 CFR 60.2 as the underground facility plus the waste packages) be defined as the "locus of points five (5) meters into the host rock" (see Figure 4).

Application of Braithwaite's definition to the drift and emplacement borehole configurations currently envisaged for the Yucca Mountain site leads to an outline of the underground facilities that is highly complex in detail (see dashed lines, Figure 4). Until such time as the direction of likely radionuclide travel, release rates from the waste packages, and the general physical environment within the repository horizon has been determined in greater detail, we propose that the upper and lower reference boundaries of the underground facilities be represented by smooth

planar surfaces located 5 meters above and below the maximum limits of the excavated openings (Figure 4). Use of these planar surfaces will enclose a volume that includes a significant amount of rock located more than 5 meters beyond the underground openings (especially for the vertical emplacement option; see Figure 4a). However, at this stage of project development, it appears appropriate to simplify the geometry of the underground facilities in order to facilitate meaningful comparisons of design and performance assessment calculations. As the project progresses and both regulatory intentions and design concepts mature, the reference boundary of the underground facility may need to be revised.

DISTURBED ZONE

Regulatory and Policy Bases for Definition

The disturbed zone is defined in 10 CFR 60.2 as

> that portion of the controlled area the physical or chemical properties of which have changed as a result of underground facility construction or as a result of heat generated by the emplaced radioactive waste such that the resultant change of properties may have a significant effect on the performance of the geologic repository.

The definition found in 10 CFR Part 960 excludes shafts (and by extension, access ramps that serve an identical purpose) from the disturbed zone.

An early Nuclear Regulatory Commission draft generic technical position paper (Gordon and others, 1985, section 3.0) goes on to define

> The meaning of "significant" in this context is considered to be about a factor of two change in effective porosity, which would correspond to about an order of magnitude change in intrinsic permeability. . . .

Although this expansion of the term "significant" is not found in the revised draft generic technical position paper (NRC, 1986), it does provide some guidance as to what changes the Nuclear Regulatory Commission might consider significant.

The principal reference to the disturbed zone includes that found in 10 CFR 60.113(a)(2), which states that

> The geologic repository shall be located so that pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years. . . .

This requirement is repeated in 10 CFR 960.4-2-1(d), wherein a site is disqualified

> if the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment is expected to be less than 1,000 years along any pathway of likely and significant radionuclide travel.

The term also appears in the sections on Siting Criteria (10 CFR 60.122(b)(7)), where a

> Pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment that substantially exceeds 1,000 years

is cited as a favorable condition. A time "substantially in excess of 1,000 years" is stated more specifically in 10 CFR 960.4-2-1(b) as "more than 10,000 years."

In order to calculate such travel times, it is necessary to define the spatial starting point from which calculations of ground water travel times to the accessible environment are to be made in order to demonstrate compliance with 10 CFR 60.113. The term "disturbed zone" is not used in any other context in any regulations pertaining to a repository.

Location of the Reference Boundary

The proposed disturbed zone extends 10 meters vertically downward from the location of the waste packages (Langkopf, in preparation) within the area covered by the underground facilities. The location is shown in Figure 6 as contours representing the elevation of the base of the disturbed zone for the reference case of vertical emplacement. For the alternative case of horizontal emplacement, the location of the disturbed zone would be approximately 32 feet (10 meters) higher.

Rationale for Boundary Location

The disturbed zone here is defined as extending 10 meters downward from the location of the waste packages (Langkopf, in preparation). Langkopf reviewed available laboratory and computer studies to determine if the intrinsic hydrologic properties of the host tuff at Yucca Mountain could be changed by the four processes identified by the Nuclear Regulatory Commission (NRC, 1986, section 4.0) as having the potential to affect rock within the disturbed zone:

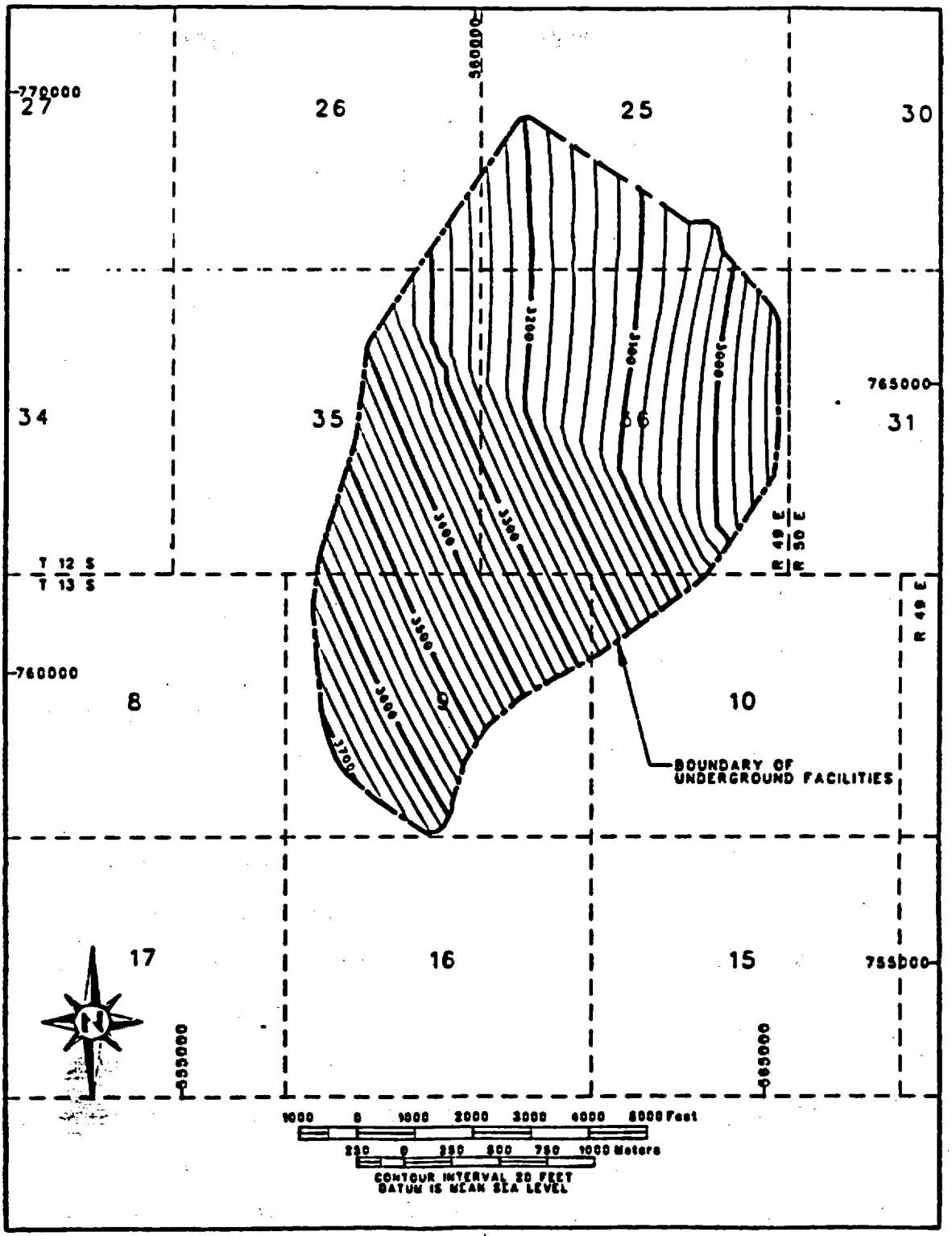

Figure 6. Reference Location of the Base of the Disturbed Zone for the Reference Case of Vertical Emplacement. NNWSI Product No. CALO174.

1) stress redistribution
2) construction and excavation
3) thermomechanical effects, and
4) thermochemical effects.

Numerical modeling of changes in fracture aperture related to stress redistribution resulting from drift excavation and heating of the rock indicated that joint movement is restricted to a zone within 2 to 3 meters of the drifts (Langkopf, in preparation). The only joint movement that "may have a significant effect on the performance of the geologic repository" (10 CFR 60.2), however, probably is essentially complete closure of a joint. This conclusion arises from the interpretation that under unsaturated conditions, ground water flow is predominantly through the matrix pores. Water is unable to flow from unsaturated matrix pores into the (relatively) much larger apertures of open fractures (Wang and Narasimhan, 1985, p. 3). Thus under these conditions, water is expected to be able to move from block to block across fractures only in those locations where fracture asperities are in contact. If the proportion of the rock mass that is hydrologically isolated by large-aperture joints does not change significantly due to the redistribution of stress resulting either from excavation of the drifts or from heat generated by the waste, then presumably the hydrologic behavior of that rock mass also will not change significantly (assuming the rock does not saturate, causing a shift to a fracture-flow environment; Wang and Narasimhan, 1985, p. 3; Lin et al., 1986, p. 32-33).

Langkopf (in preparation) summarizes other studies directed toward evaluating changes in porosity and permeability as a result of thermochemical effects (silica dissolution and reprecipitation as a function of temperature). One study concluded that changes in porosity from thermally induced silica dissolution and reprecipitation are on the order of 10^{-5} percent, certainly less than a change by the factor of two suggested as significant by Gordon (1985). Another study cited by Langkopf suggests that the 100-degree (Celsius) isotherm may represent the outer limit of silica alteration. The maximum extent of the 100-degree isotherm resulting from waste emplacement appears to be approximately 10 meters. The maximum change in permeability caused by silica reprecipitation in fractures described in the studies reviewed by Langkopf was approximately one order of magnitude, a "significant" change according to Gordon and others (1985). The particular study citing changes of this magnitude, however, indicated that such changes were restricted to within 3 to 5 meters of a borehole.

After reviewing the available information, Langkopf (in preparation) proposed a boundary of the disturbed zone located 10 meters below the waste packages. The selection of a 10-meter distance is believed to be a conservative choice because nearly all the available information suggests that significant changes in the rock properties will occur only over a much smaller distance.

The proposed definition of the disturbed zone as extending 10

meters downward below the emplaced waste packages conflicts with the minimum distance specified in the Nuclear Regulatory Commission's draft generic technical position paper (NRC, 1986, section 5.0), which states that the "minimum appropriate distance" may be considered

> 5 opening diameters for circular openings, 5 opening heights for noncircular openings, or fifty meters, whichever is largest.

Note that the reference design for the Yucca Mountain repository calls for underground openings that would be a maximum of 25 feet (7.6 meters) in diameter or 22 feet (6.7 meters) high (RIB, 1987); either dimension would lead to calculation of a disturbed zone that is less than the NRC's 50-meter minimum.

The regulations of 10 CFR 60 clearly take precedence over the suggested guidance offered by a draft generic technical position paper. Since it appears that in any event, the NNWSI Project will be required to present calculations determining in what volume of rock there is a "significant effect on the performance of the geologic repository" (10 CFR 60.2), it follows that the boundaries of the disturbed zone should be based on those calculations, rather than on some arbitrary minimum value. Indeed, the draft generic technical position paper states that a different approach may be justified if

> the hydrogeology of the site indicates that some of the recommendations in this guidance document do not need to be satisfied, or (if) alternative methodologies are appropriate. (NRC, 1986, section 5.0)

GEOLOGIC REPOSITORY OPERATIONS AREA

Regulatory and Policy Bases for Definition

The geologic repository operations area is defined in 10 CFR Part 60.2 as

> a high-level radioactive waste facility that is part of a geologic repository, including both surface and subsurface areas where waste handling activities are conducted.

The definition in 10 CFR Part 960 is virtually identical, omitting only the phrase "high-level" from the description of the facility. The phrase "where waste handling activities are conducted" is interpreted to be generally descriptive of the entire operational area of a repository, rather than specifically limiting the geologic repository operations area to those physical locations where actual waste manipulation occurs. This interpretation is supported by 10 CFR 60.75(c)(2), which contains a discussion of Nuclear Regulatory Commission office space "in the geologic repository operations area's office complex." Certainly no waste is "handled" in this office, yet it is in the geologic repository operations area. A general interpretation of the term is also implied by the definition of a geologic repository contained in 10 CRF 60.2, which describes two parts of a repository: "(1) the geologic repository operations area, and (2) the portion of the geologic setting that provides isolation of the radioactive waste."

The functions of the geologic repository operations area are spelled out in 10 CFR 60.102, and specific performance objectives for this area are given in 10 CFR 60.111. Among these objectives

are limitation of preclosure exposure to, or release of, radioactive materials, and the retrievability of wastes after emplacement. Detailed design criteria for the geologic repository operations area are specified by 10 CFR 60.131 and 60.132.

Regulations contained in 10 CFR 60.71 through 60.75 specify the various types of records, reports, tests, and inspections that must be maintained for and conducted at the geologic repository operations area.

Also, the geologic repository operations area, as specified by 10 CFR 60.121, must be

> located in and on lands that are either acquired lands under the jurisdiction and control of DOE, or lands permanently withdrawn and reserved for its use.

Thus, the location of the geologic repository operations area must be defined in order to permit assessment of compliance with specific performance objectives, design criteria, and record-keeping requirements, and to ensure withdrawal or other control of lands on which waste handling activities take place.

Location of the Reference Boundary

The locations of the various surface and subsurface portions of the geologic repository operations area are shown in Figure 7. The subsurface operations area is identical with the underground facilities shown in Figure 2, with the addition of the ramps and shafts, which are integral parts of the waste handling operations of the repository.

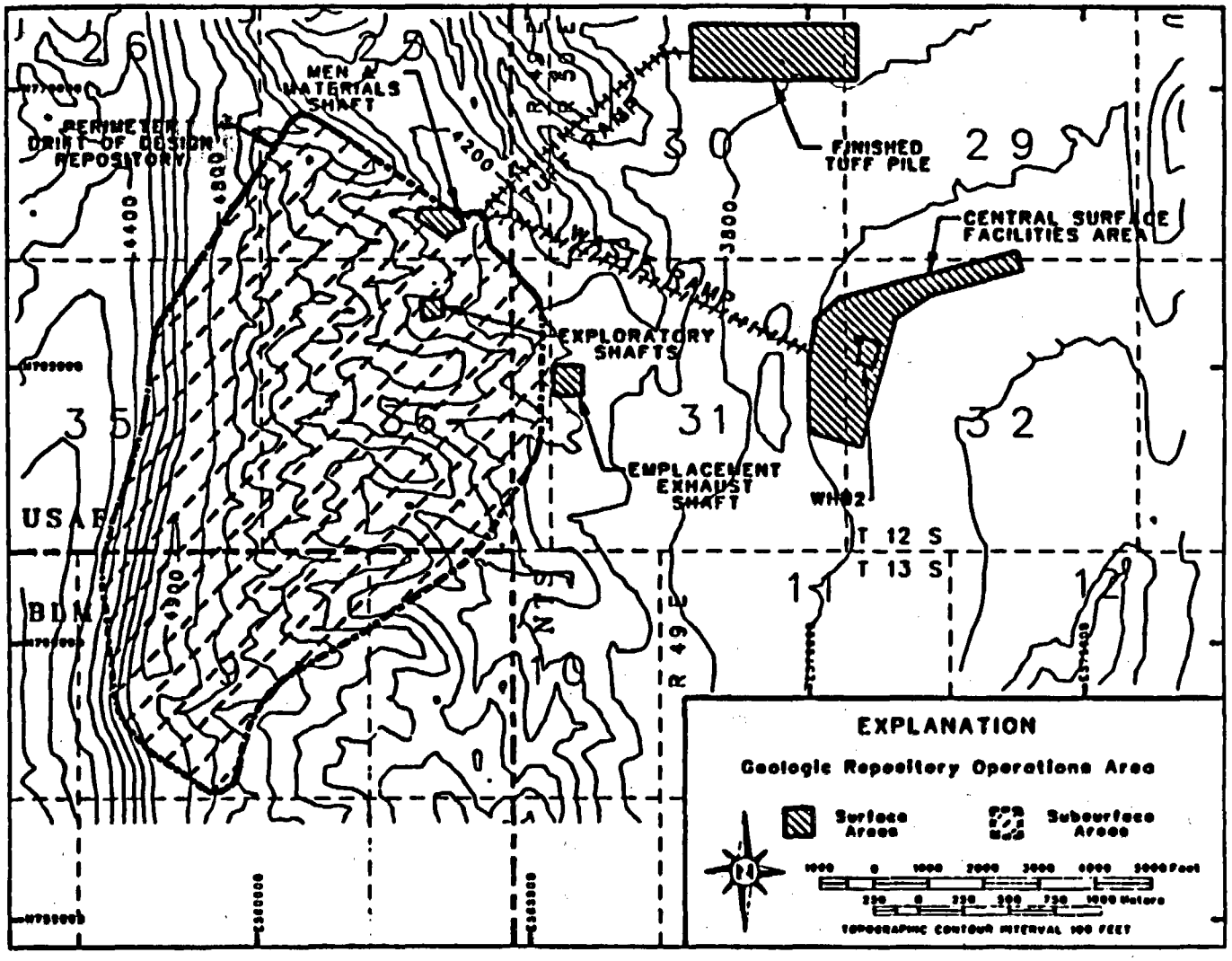

Figure 7. Reference Location of the Geologic Repository Operations Area, Showing Surface and Subsurface Facilities. Coordinates are the Nevada State Plane Coordinate System in Feet. Topographic Base Shows Surface Elevations in Feet. NNWSI Product No. CAL0162.

The surface operation areas consist of several individual plots. The central surface facilities area will contain the main facilities for receiving transported waste, repackaging waste as appropriate, and preparing waste for transfer to the underground facilities. These activities are generally restricted to the waste handling building. Other facilities in the central surface facilities area include buildings for maintaining waste handling and transport equipment and for general office and warehouse activities. Finally, the portal of the waste handling ramp is within the boundary of the central surface facilities area.

Smaller surface operating areas (Figure 7) encompass the various shafts that provide access to the underground facilities for men and materials (the men and materials shaft) and ventilation (the emplacement exhaust shaft and the former exploratory shafts which will be converted to air intake shafts (SNL, in press, p. 4-19)). The portal of the tuff ramp through which excavated rock is removed to the surface dump area is included within a separate surface portion of the geologic repository operations area, which also includes the tuff pile itself.

Rationale for Boundary Location

The geologic repository operations area includes essentially all areas within which the activities of the repository are conducted. As such, the boundaries of the geologic repository operations area are determined by design and operational considerations. The

boundary of the underground portions of the geologic repository operations area are determined by the same design requirements used for the definition of the underground facilities. The location of the surface portions of the geologic repository operations area are determined by design requirements that dictate area needs for locating the waste receiving and processing buildings and ancillary support facilities (offices, shops, warehouses), and for disposing of the material excavated to create the underground openings. The site selection process for the waste handling buildings and other surface facilities is documented by Neal (1985).

The inclusion of the former exploratory shaft(s) within the geologic repository operations area deserves a brief comment. Although the geologic repository operations area will be the subject of licensing proceedings by the Nuclear Regulatory Commission, no such licensing is involved in construction of a test facility such as the exploratory shaft facility (discussion in 10 CFR 60.15). During the site characterization phase of the NNWSI Project, the exploratory shaft will be a test facility designed for the acquisition of data from the "in situ testing at depth" required by 10 CFR 60.15(c). Assuming that the Yucca Mountain site is selected by the Department of Energy for construction and licensing of an actual geologic repository, the former exploratory shaft test facility would become part of that repository as called for by 10 CFR 60.15(d)(3):

> ... exploratory ... shafts in the geologic repository operations area shall be located where

> shafts are planned for underground facility construction and operations .... 10 CRF 60.15(d)(3)

The conceptual design for a repository at Yucca Mountain (SNL, in press, p. 4-19) calls for use of the exploratory shafts as air intake shafts during construction and operation of an actual repository. However, until a repository is developed, the geologic repository operations area will not exist. Therefore, the exploratory shaft will not be part of a geologic repository operations area during the site characterization phase of the project. A reading of sections of 10 CFR 60 relevant to performance and design requirements indicates that no major difficulties would be encountered in incorporating the exploratory shafts into the geologic repository operations area.

RESTRICTED AREA

Regulatory and Policy Bases for Definition

The restricted area refers to preclosure activities (10 CFR 960.1) and is defined in 10 CFR Part 60.2 as

> any area access to which is controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials.

Regulations and precedent regarding radiation hazards in general (10 CFR 20) require that personnel within a restricted area be monitored for their exposure to radiation (10 CFR 20.202). These regulations also place limits upon the maximum exposure to radiation allowed within a restricted area in general and also within designated "radiation areas" or "high radiation areas" that may occur within that restricted area.

Releases of radiation beyond the restricted area are limited by 10 CFR 60.111 to the amounts specified by 10 CFR 20 and by the Environmental Protection Agency (EPA) in 40 CFR 191.03. Thus, the use of a definition of the preclosure restricted area is to identify an appropriate region from which members of the public are excluded to protect them from radiation exposure.

The definition of restricted area is important in one other regard. "Items important to safety" are defined by 10 CFR 60.2 as those parts of repository system that are "essential to the prevention or mitigation of an accident" that might result in a 0.5 rem radiation dose "at or beyond the nearest boundary of the *unrestricted area*" (emphasis added). The "unrestricted area" of 10 CFR 60.2 is everything outside the restricted area. Thus, definition of the restricted area is also necessary to determine the list of items important to safety (frequently referred to as the Q-list).

Location of the Reference Boundary

The boundary of the restricted area, for purposes of the NNWSI Project at this time, is taken to be identical to the boundary of the controlled area, which is defined below. The location of the restricted area is shown in Figure 8.

Rationale for Boundary Location

The creation of a restricted area is intended to restrict access

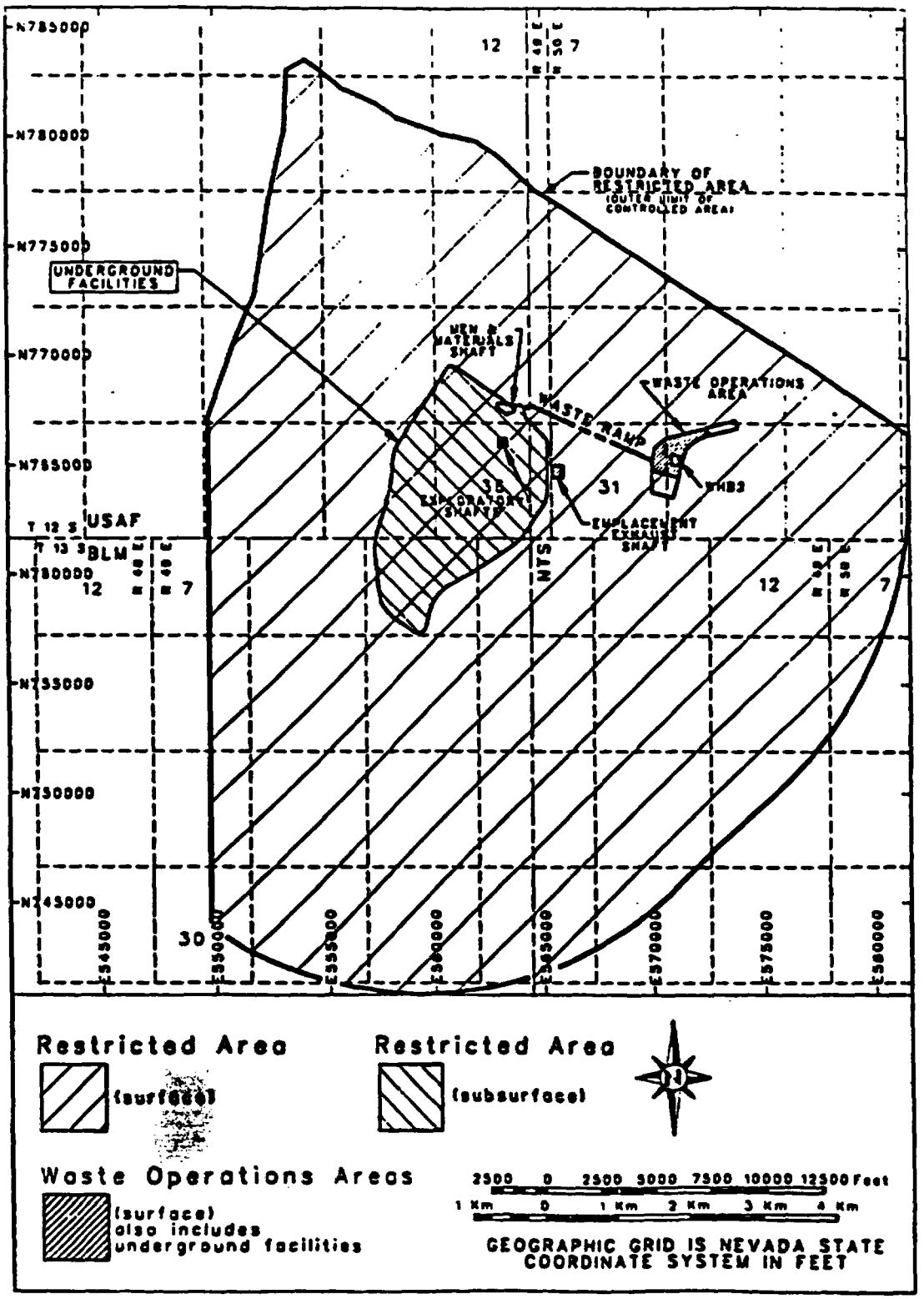

Figure 8. Reference Location of the Restricted Area for Preclosure Repository Operations Shown in Reference to the Major Components of the Geologic Repository Operations Area. See text for discussion. NNWSI Product CAL0228.

by the public to regions where there is a potential that radiation doses from the repository might exceed the regulatory requirements of 10 CFR 20 and 40 CFR 191.03. Potential exposure of individuals within the restricted area is considered to be occupation exposure (see 10 CFR 20.101). Potential occupational exposure in excess of specified limits (10 CFR 20.101(a)) requires dosimetry monitoring (10 CFR 20.202) and record keeping (10 CFR 20.101(b)(3).

The use of the term restricted area with its requirements for protection from exposure to radiation should not be construed to imply a radiation area or high radiation area such as are discussed in 10 CRF 20.203. The restricted area inevitably will contain both areas of elevated radiation, which will require specific cautionary warnings and additional access control, and areas of virtually no radiation other than background. Physical security of the radioactive waste also will require additional access controls. Consideration of these supplementary limitations on access and of the monitoring and record-keeping requirements specific to these special areas are beyond the scope of this discussion of the restricted area.

The choice of the boundary of the restricted area is complicated by the two-fold use of this boundary in the regulations. The use of the boundary in the context of expected occupational exposure argues for a restricted area limited in extent to the immediate vicinity of handling and processing the waste or contaminated material (the "waste operations area" described by the conceptual

design report; SNL, in press). The other use of the boundary, in regard to accident-condition releases and determination of items important to safety, argues for a restricted area that includes virtually the entire repository site. Both the "site boundary," here chosen to be equivalent to the controlled area, and the boundary of the much more areally restricted waste operations area are shown in figure 8 for comparison.

The larger boundary, equivalent in extent to the controlled area, is hereby proposed as the reference boundary of the restricted area. Use of the smaller "waste operations area" would meet all 10 CFR 20 requirements for worker radiation safety. However, this choice would unnecessarily constrain the compliance boundary for accident-condition exposure guidance for definition of systems important to safety imposed by 10 CFR 60.131(b). In addition, this choice may impact compliance with the radiological control requirements for normal conditions as specified in 10 CFR 60.111 and 60.131(1). Thus, the reference boundary has been defined to maximize the ability of DOE to demonstrate radiation protection for members of the public (who are outside the restricted area) under both normal operating and accident conditions. The choice of the restricted area boundary may be modified in the future as the engineering design of the repository proceeds. The boundary may also require modification if radiation monitoring requirements for the larger area prove impractical, or if an evolving regulatory environment so indicates.

CONTROLLED AREA

Regulatory and Policy Bases for Definition

The controlled area is defined in 40 CFR Part 191.12(g) as:

> (1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system; and (2) the subsurface underlying such a surface location.

This definition in 40 CFR Part 191 is slightly more restrictive and postdates the definitions found in either 10 CFR 60.2 or 10 CFR 960.1, which make reference to a 10-kilometer distance from the location of the waste.

The limits of the controlled area, which is to be permanently marked and documented as specified by 10 CFR 60.51, 60.102, and 40 CFR 191.14, also define the beginning of the accessible environment as discussed below. As such, the limits of the controlled area become the benchmark location at which releases of radioactivity following permanent closure of the repository must meet the regulatory limits established by the EPA in 40 CFR 191.13.

Ownership and control of lands that comprise the controlled area must be secured by DOE. Specifically, 10 CFR 60.121 states that

> Both the geologic repository operations area and the controlled area shall be located on lands that are either acquired lands under the jurisdiction and control of DOE, or lands permanently withdrawn and reserved for its use.

The regulations in 10 CFR 60.121 specify additional requirements with regard to encumbrances to the title and with regard to water rights.

The purposes of this boundary are multiple. First, it identifies the location from which the integrated releases of radionuclides for a period of 10,000 years after closure must be calculated in order to assess compliance with 40 CFR 191.13. Second, it establishes the locations where permanent monuments must be erected in order to alert future generations to the presence of the buried waste. Third, it establishes a minimum region that must be protected from the conduct of incompatible activities for long time periods.

Location of the Reference Boundary

The location of the reference boundary for the controlled area is shown in Figure 9. The maximum possible size of the controlled area, shown in Figure 9, is based upon a 5-kilometer distance (40 CFR 191.12) from the outer boundary of the original position of the waste. This "original position" is taken to correspond to the area enclosed by the perimeter drift of the underground facilities. Because the total area enclosed by the maximum distance allowed (5 km) exceeds the 100 square kilometer limit imposed by the same regulation (40 CFR 191.12), the distance to the outer boundary of the controlled area has been reduced to the northeast and west where distance to the accessible environment appears less critical to waste isolation (see discussion

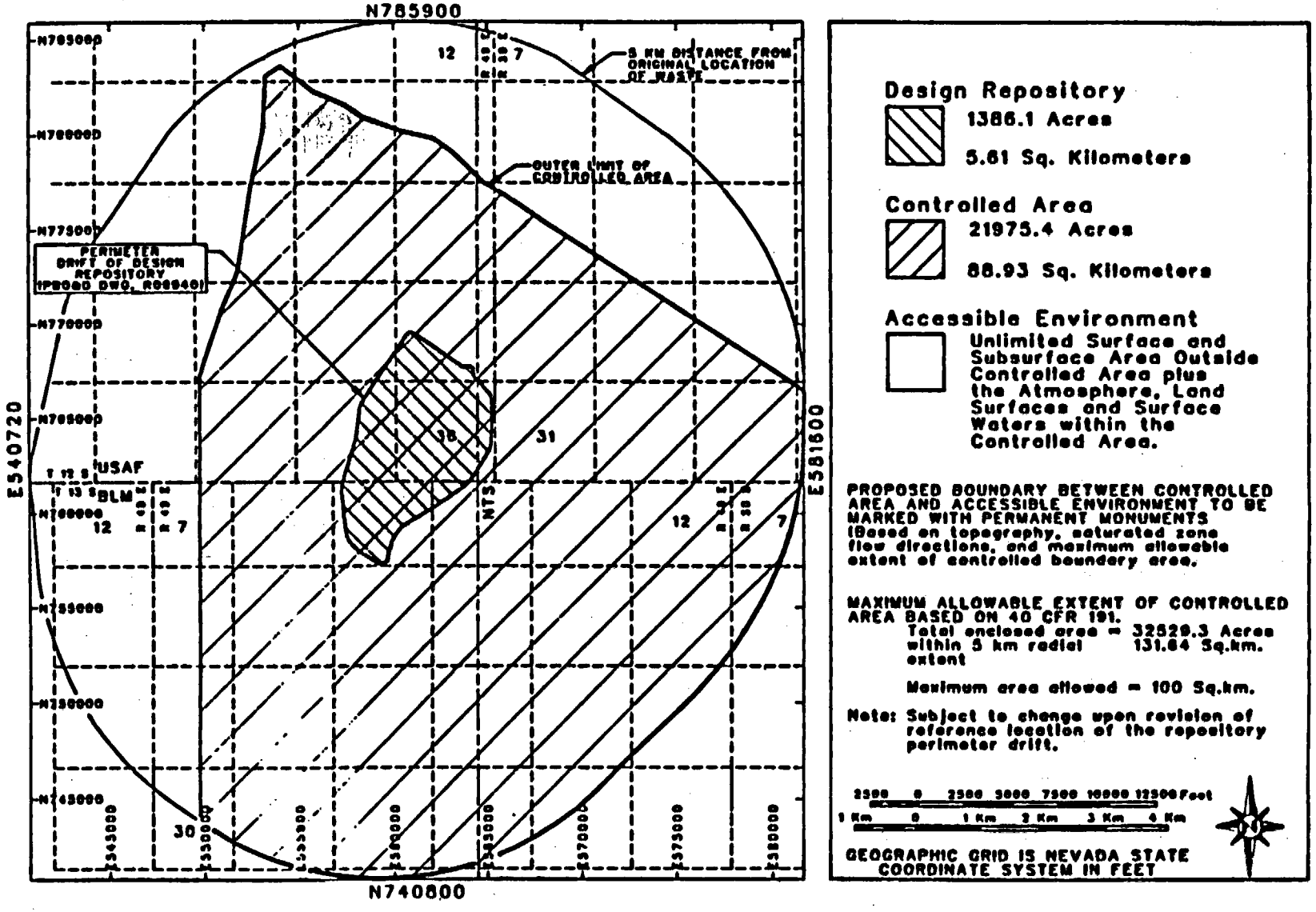

Figure 9. Reference Location of the Controlled Area Shown in Relation to the Underground Facilities. NNWSI Product No. CAL0165.

immediately following).

Rationale for Boundary Location

The location of the controlled area has been chosen to provide maximum possible isolation of the waste in the event of subsurface releases from the waste packages and to ensure maximum permanence of the "passive institutional controls" referred to by 40 CFR 191.12.

The arcuate southeastern boundary of the controlled area, which corresponds to the maximum permitted distance of 5 kilometers, was determined by the configuration of the regional ground water gradient in the saturated zone. As shown in Figure 10, the water table is interpreted to slope toward the southeast. The gradient becomes quite low to the east and south of the underground facilites, and exact delineation of flow paths is difficult. However, ground water flow that might carry released radioactivity toward the accessible environment most likely will be in a southerly to easterly direction.

The northwestern and northeastern boundaries of the controlled area are chosen to follow topographic highs (Figure 11) wherever possible. The assumption is made that markers and monuments anchored in relatively flat bedrock areas such as broad ridge crests are likely to be more permanent than monuments affixed in alluvial materials, which typically occur in topographically low areas. Loose rock debris on steep slopes and the potential for

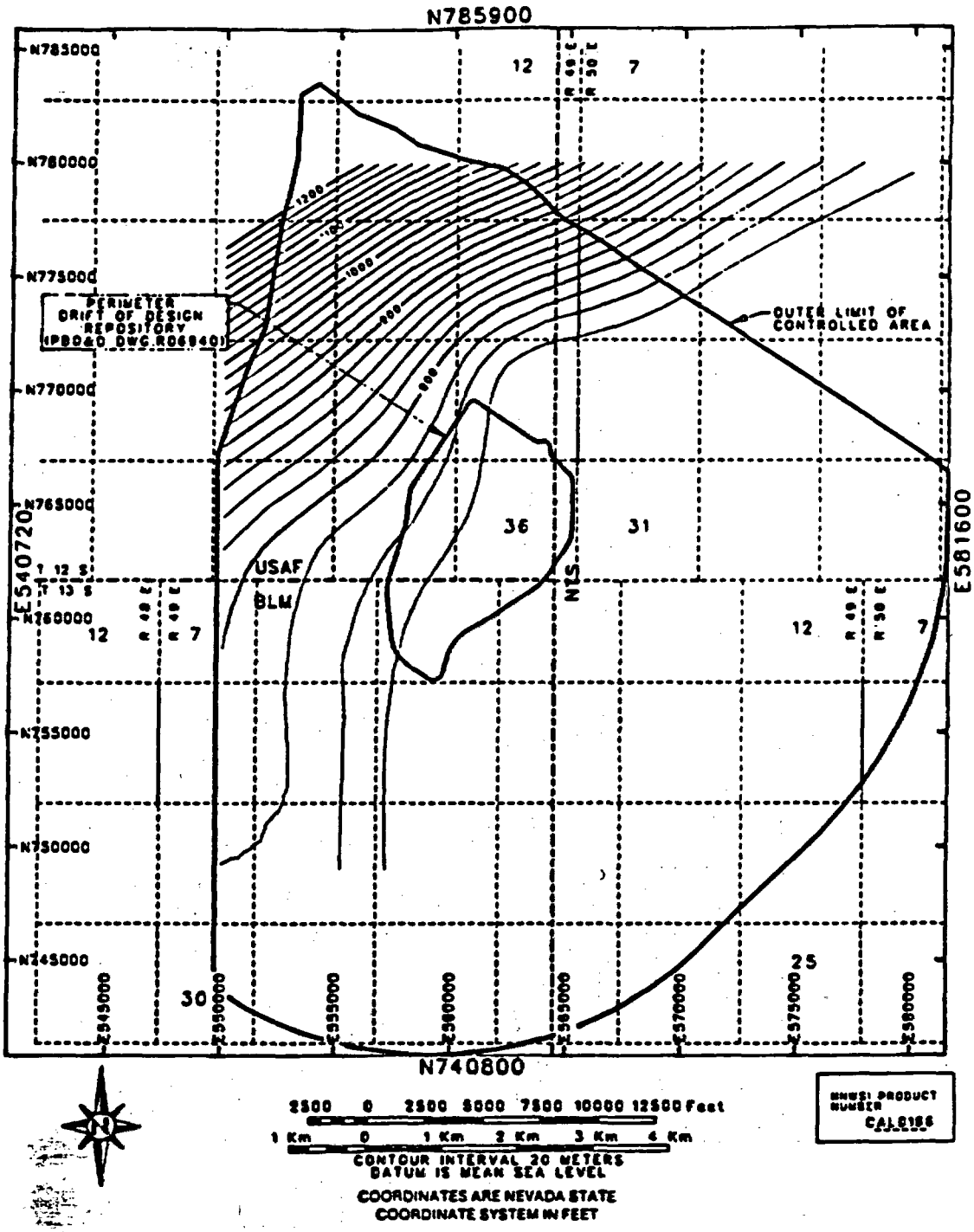

Figure 10. Location of the Controlled Area with Respect to the Regional Ground Water Table. Ground Water Flow that Might Transport any Radioactive Material Released from the Repository is Expected to be Generally toward the Southeast (see Text for Discussion). From NNWSI Product No. CAL0166.

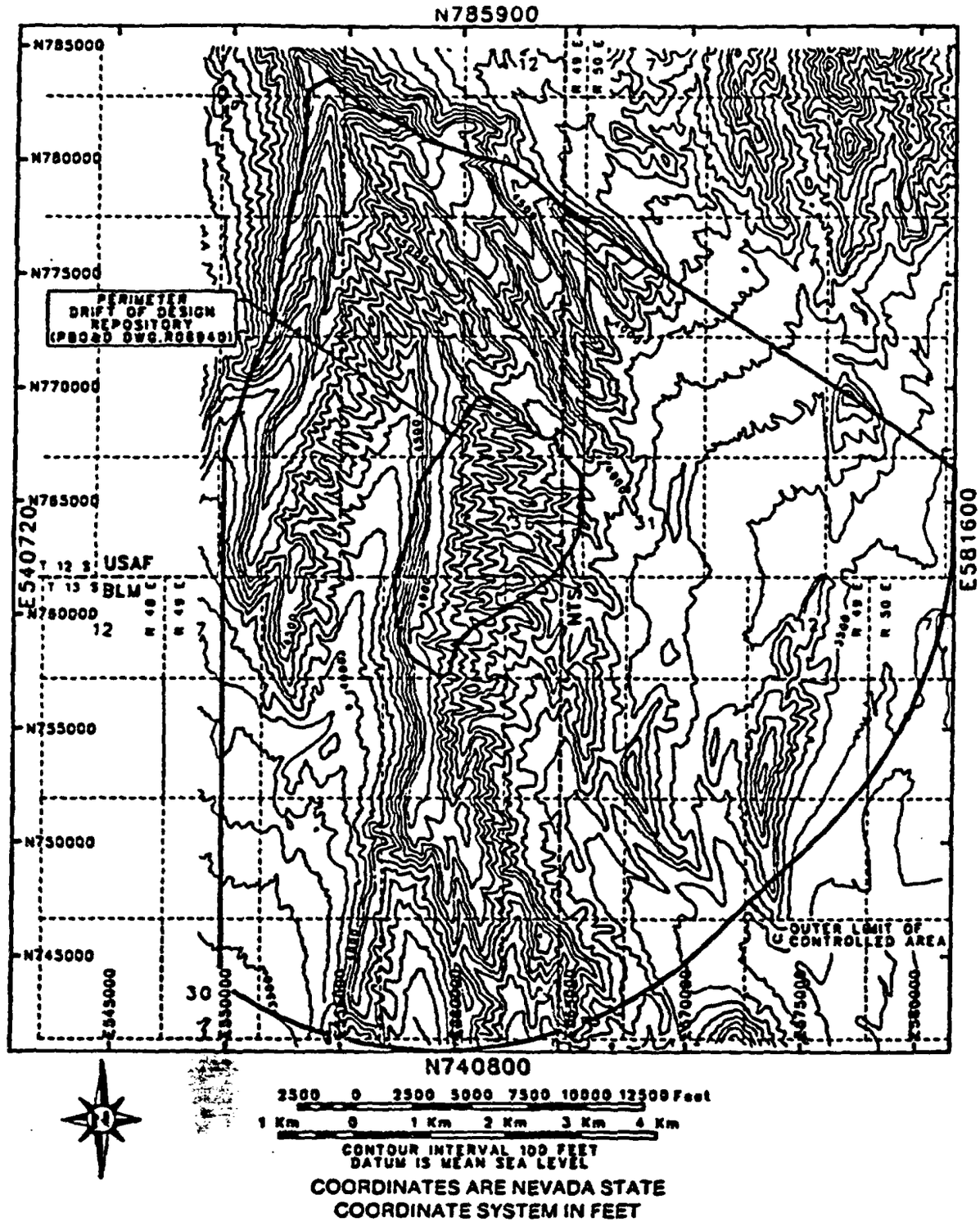

Figure 11. Location of the Controlled Area with Respect to Present-Day Topography (see Text for Discussion). From NNWSI Product No. CAL0167.

landslides from steep bedrock areas argue against locating monuments and markers in these areas if possible. Additionally, markers on high ground should be more readily visible at a distance than markers in valley areas, thus accentuating the intended purpose of calling attention to the boundaries of the site.

ACCESSIBLE ENVIRONMENT

Regulatory and Policy Bases for Definition

The accessible environment is defined in 40 CFR Part 191.12 as

(1) the atmosphere,
(2) land surfaces,
(3) surface waters,
(4) oceans, and
(5) all of the lithosphere that is beyond the controlled area.

This definition is virtually identical to the definitions found in 10 CFR 60.2 and in 10 CFR 960.2. The American Geological Institute (1972, p. 413) defines the lithosphere simply as the "solid portion of the Earth, as compared with the atmosphere and hydrosphere."

The criteria for siting a geologic repository found in 10 CFR Part 960 make extensive references to the "accessible environment." For example, the overall system guideline of 10 CFR 960.4-1 and the numberous technical guidelines of 10 CFR 960.4-2 list siting criteria in terms of a number of "qualifying" and "disqualifying" conditions, supplemented by "favorable" and "potentially adverse" conditions. Selected illustrative passages from the regulations

include

> Qualifying Condition. The geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure . . . . (10 CFR 960.4-1 (a));
>
> Qualifying Condition. The geohydrologic setting . . . shall permit compliance with (1) the requirements specified in 960.4-1 for radionuclide releases to the accessible environment (10 CFR 960.4-2-1 (a));
>
> Qualifying Condition. The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation (and) . . . shall permit compliance with (1) the requirements specified in 960.4-1 for radionuclide releases to the accessible environment (10 CFR 960.4-2-2 (a));
>
> Disqualifying Condition. A site shall be disqualified if the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment is expected to be less than 1,000 years . . . . (10 CFR 960.4-2-1 (d));
>
> Favorable Condition. A geologic setting where the nature and rates of the erosional processes that have been operating during the Quaternary Period are predicted to have less than one chance in 10,000 over the next 10,000 years of leading to releases of radionuclides to the accessible environment (10 CFR 960.4-2-5 (b)(2);
>
> Potentially Adverse Condition. The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment along ground-water flow paths from the host rock to the accessible environment (10 CFR 960.4-2-1 (c)(2)).

The final selection criteria for developing a particular geologic repository make reference to the accessible environment:

> Site comparisons performed to support the recommendation of sites for the development of repositories in 960.3-2-4 shall evaluate predicted releases of radionuclides to the accessible environment. (10 CFR 960.3-1-5)

The performance of the geologic repository following permanent closure is the subject of rigorous criteria established by 10 CFR Part 60. Subpart 60.112 deals with the overall performance objectives:

> The geologic setting shall be selected and the engineered barrier system and the shafts, boreholes and their seals shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to such generally applicable environmental standards for radioactivity as may have been established . . . .

Subpart 60.113(a)(2) deals with the rate of ground water flow to the accessible environment:

> The geologic repository shall be located so that pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years . . . .

Cumulative releases of radioisotopes are further addressed in 40 CFR 191.13:

> Disposal systems for spent nuclear fuel or high-level or transuranic wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall: (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and (2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A).

Maximum radiation doses to individuals in the accessible environment are specified in 40 CFR 191.15:

> Disposal systems for spent nuclear fuel or high-level or transuranic wastes shall be designed to provide a reasonable expectation that for 1,000 years after disposal, undisturbed performance of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public in the accessible environment to exceed 25 millirems to the whole body or 75 millirems to any critical organ.

Thus, definition of the boundary of the accessible environment is required to identify the location at which compliance with numerous regulatory requirements and siting criteria must be assessed.

Location of the Reference Boundary

The accessible environment as defined by regulation (40 CFR 191.12) includes all regions at or above the ground surface and subsurface regions outside the projection to depth of the outer limit of the controlled area. Accordingly, the accessible environment has only an inner limit, which in the subsurface is coincident with the maximum extent of the controlled area (Figure 9). The topographic surface is always part of the accessible environment, even within the controlled area.

Rationale for Boundary Location

The accessible environment, unlike most of the other reference boundaries at Yucca Mountain, has only an inner boundary, and has unlimited extent beyond that boundary. The inner limit of the accessible environment is identical with the outer boundary of the controlled area, discussed at length above. To reiterate salient features of this singular boundary, the the land surface, surface

waters and oceans belong to the accessible environment by definition (10 CFR 60.2). Otherwise, the limits of the accessible environment were chosen to reflect the maximum permitted distance (5 km) in the direction of assumed ground water flow (south and east) and the location of topographic highs (north and west) on which to locate monuments identifying the location of the controlled area for future generations

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APPENDIX

Information from the Reference Information Base Used in this Report

The following information from the NNWSI Reference Information Base is used in this report:

Dimensions of Drifts for Vertical and Horizontal Emplacement Options	Ch 2, Sec 2, Sbsec 1, Item 7 and Subsec 2, Item 7 (RIB, 1987)

Candidate Information for the Reference Information Base

The following figures are candidate information for the Reference Information Base:

Figure 2. Underground Facilities
Figure 3. Underground Facilities
Figure 6. Disturbed Zone
Figure 7. Geologic Repository Operations Area
Figure 8. Restricted Area
Figure 9. Controlled Area/Accessible Environment

Candidate Information for the Site & Engineering Properties Data Base

This report contains no candidate information for the Site and Engineering Properties Data Base.

DISTRIBUTION LIST

B. C. Rusche (RW-1), Director
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Bldg.
Washington, D.C. 20585

Ralph Stein (RW-23)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Bldg.
Washington, D.C. 20585

J. J. Fiore (RW-221)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Bldg.
Washington, D.C. 20585

M. W. Frei (RW-231)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Bldg.
Washington, D.C. 20585

Carl P. Gertz, Project Manager (6)
Waste Management Project Office
U.S. Department of Energy
Nevada Operations Office
P.O. Box 98518
Las Vegas, NV 89193-8518

Chief, Repository Projects Branch
Division of Waste Management
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

NTS Section Leader
Repository Project Branch
Division of Waste Management
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

B. G. Gale (RW-223)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Bldg.
Washington, D.C. 20585

R. W. Gale (RW-40)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Bldg.
Washington, D.C. 20585

J. O. Neff, Manager
Salt Repository Project Office
U.S. Department of Energy
110 North 25 Mile Avenue
Hereford, TX 79045

V. J. Cassella (RW-222)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Bldg.
Washington, D.C. 20585

S. A. Mann, Manager
Crystalline Rock Project Office
U.S. Department of Energy
9800 South Cass Avenue
Argonne, IL 60439

L. D. Ramspott (3)
Technical Project Officer for NNWSI
Lawrence Livermore National
Laboratory
P.O. Box 808
Mail Stop L-204
Livermore, CA 94550

J. A. Cross, Manager
Las Vegas Branch
Fenix & Scisson, Inc.
P.O. Box 93265
Mail Stop 514
Las Vegas, NV 89193-3265

Document Control Center
Division of Waste Management
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

V. M. Glanzman
U.S. Geological Survey
P.O. Box 25046
913 Federal Center
Denver, CO 80225

P. T. Prestholt
NRC Site Representative
1050 East Flamingo Road
Suite 319
Las Vegas, NV 89109

M. E. Spaeth
Technical Project Officer for NNWSI
Science Applications International Corp.
101 Convention Center Dr.
Suite 407
Las Vegas, NV 89109

SAIC-T&MSS Library (2)
Science Applications International Corp.
101 Convention Center Dr.
Suite 407
Las Vegas, NV 89109

W. S. Twenhofel, Consultant
Science Applications International Corp.
820 Estes Street
Lakewood, CO 89215

A. E. Gurrola, General Manager
Energy Support Division
Holmes & Narver, Inc.
P.O. Box 93838
Mail Stop 580
Las Vegas, NV 89193-3838

D. T. Oakley (4)
Technical Project Officer for NNWSI
Los Alamos National Laboratory
P.O. Box 1663
N-5, Mail Stop J521
Los Alamos, NM 87545

L. R. Hayes (6)
Technical Project Officer for NNWSi
U.S. Geological Survey
P.O. Box 25046
421 Federal Center
Denver, CO 80225

C. H. Johnson
Technical Program Manager
Nuclear Waste Project Office
State of Nevada
Evergreen Center, Suite 252
1802 North Carson Street
Carson City, NV 89701

ONWI Library
Battelle Columbus Laboratory
Office of Nuclear Waste Isolation
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Columbus, OH 43201

W. M. Hewitt, Program Manager
Roy F. Weston, Inc.
955 L'Enfant Plaza, Southwest
Suite 800
Washington, D.C. 20024

T. Hay, Executive Assistant
Office of the Governor
State of Nevada
Capitol Complex
Carson City, NV 89710

John Fordham
Desert Research Institute
Water Resources Center
P.O. Box 60220
Reno, NV 89506

Department of Comprehensive Planning
Clark County
225 Bridger Avenue, 7th Floor
Las Vegas, NV 89155

Lincoln County Commission
Lincoln County
P.O. Box 90
Pioche, NV 89043

Community Planning & Development
City of North Las Vegas
P.O. Box 4086
North Las Vegas, NV 89030

City Manager
City of Henderson
Henderson, NV 89015

T. G. Barbour
Science Applications International Corp.
1626 Cole Blvd., Suite 270
Golden, CO 80401

E. P. Binnall
Field Systems Group Leader
Building 50B/4235
Lawrence Berkeley Laboratory
Berkeley, CA 94720

T. H. Isaacs (RW-20)
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
Forrestal Bldg.
Washington, D.C. 20585

D. H. Alexander (RW-232)
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
Forrestal Bldg.
Washington, D.C. 20585

B. J. King, Librarian (2)
Basalt Waste Isolation Project Library
Rockwell Hanford Operations
P.O. Box 800
Richland, WA 99352

D. L. Fraser, General Manager
Reynolds Electrical & Engineering Co.
P.O. Box 98521
Mail Stop 555
Las Vegas, NV 89193-8521

J. P. Pedalino
Technical Project Officer for NNWSI
Holmes & Narver, Inc.
101 Convention Center Dr.
Suite 860
Las Vegas, NV 89109

S. H. Kale (RW-20)
Office of Civilian Radioactive Waste Management
U.S. Department of Energy
Forrestal Bldg.
Washington, D.C. 20585

J. H. Anttonen
Deputy Assistant Manager for Commercial Nuclear Waste
Basalt Waste Isolation Project Office
U.S. Department of Energy
P.O. Box 550
Richland, WA 99352

P. K. Fitzsimmons, Director
Health Physics & Environmental Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

Prof. S. W. Dickson
Department of Geological Sciences
Mackay School of Mines
University of Nevada
Reno, NV 89557

V. M. Glanzman
U.S. Geological Survey
P.O. Box 25046
913 Federal Center
Denver, CO 80225

R. R. Loux, Jr., (3)
Executive Director
Nuclear Waste Project Office
State of Nevada
Evergreen Center, Suite 252
1802 North Carson Street
Carson City, NV 89701

Dr. Martin Mifflin
Desert Research Institute
Water Resources Center
2505 Chandler Avenue
Suite 1
Las Vegas, NV 89120

Planning Department
Nye County
P.O. Box 153
Tonopah, NV 89049

Economic Development Department
City of Las Vegas
400 East Stewart Avenue
Las Vegas, NV 89101

Director of Community Planning
City of Boulder City
P.O. Box 367
Boulder City, NV 89005

Commission of the European
Communities
200 Rue de la Loi
B-1049 Brussels
BELGIUM

Technical Information Center
Roy F. Weston, Inc.
955 L'Enfant Plaza, Southwest
Suite 800
Washington, D.C. 20024

Gerald Parker (RW-241)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Bldg.
Washington, D.C. 20585

J. P. Knight (RW-24)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Bldg.
Washington, D.C. 20585.

Allen Jelacic (RW-233)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Bldg.
Washington, D.C. 20585

J. R. Rollo
Deputy Assistant Director for
Engineering Geology
U.S. Geological Survey
106 National Center
12201 Sunrise Valley Dr.
Reston, VA 22092

Vincent Gong
Technical Project Officer for NNWSI
Reynolds Electrical & Engineering Co.
P.O. Box 98521
Mail Stop 615
Las Vegas, NV 89193-8521

Eric Anderson
Mountain West Research-Southwest
Inc.
Phoenix Gateway Center
432 North 44 Street
Suite 400
Phoenix, AZ 85008-6572

Judy Foremaster (5)
City of Caliente
P.O. Box 158
Caliente, NV 89008

C. Bresee (RW-22)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Bldg.
Washington, D.C. 20585

J. L. Fogg (12)
Technical Information office
Nevada Operations Office
U. S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

R. L. Bullock
Technical Project Officer for NNWSI
Fenix & Scisson, Inc.
P.O. Box 93265
Mail Stop 514
Las Vegas, NV 89193-3265

C. L. West, Director
Office of External Affairs
U.S. Department of Energy
Nevada Operations Office
P.O. Box 98518
Las Vegas, NV 89193-8518

Elaine Ezra
NNWSI GIS Project Manager
EG&G Energy Measurements, Inc.
P.O. Box 1912
Mail Stop H-02
Las Vegas, NV 89125

A. T. Tamura
Science and Technology Division
Office of Scientific and Technical
Information
U.S. Department of Energy
P.O. Box 62
Oak Ridge, TN 37831

L. Jardine
Project Manager
Bechtel National Inc.
P.O. Box 3965
San Francisco, CA 94119

R. Harig
Parsons Brinckerhoff Quade &
Douglas
1625 Van Ness Ave.
San Francisco, CA 94109-3679

Dr. Roger Kasperson
CENTED
Clark University
950 Main Street
Worcester, MA 01610

Robert E. Cummings
Engineers International, Inc.
P.O. Box 43817
Tucson, AZ 85733-3817

Dr. Jaak Daemen
Department of Mining and
Geotechnical Engineering
University of Arizona
Tucson, AZ 85721

C. E. Kay (RW-1)
Acting Director
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, D.C. 20585

S. J. Brocoum (RW-233)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, D.C. 20585

J. D. Saltzman (RW-40)
Office of Civilian Radioactive
Waste Management
U. S. Department of Energy
Forrestal Building
Washington, D.C. 20585

6300 R. W. Lynch
6310 T. O. Hunter
6310 NNWSICF
6310 43/12132/RPT/Q3
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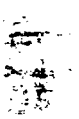

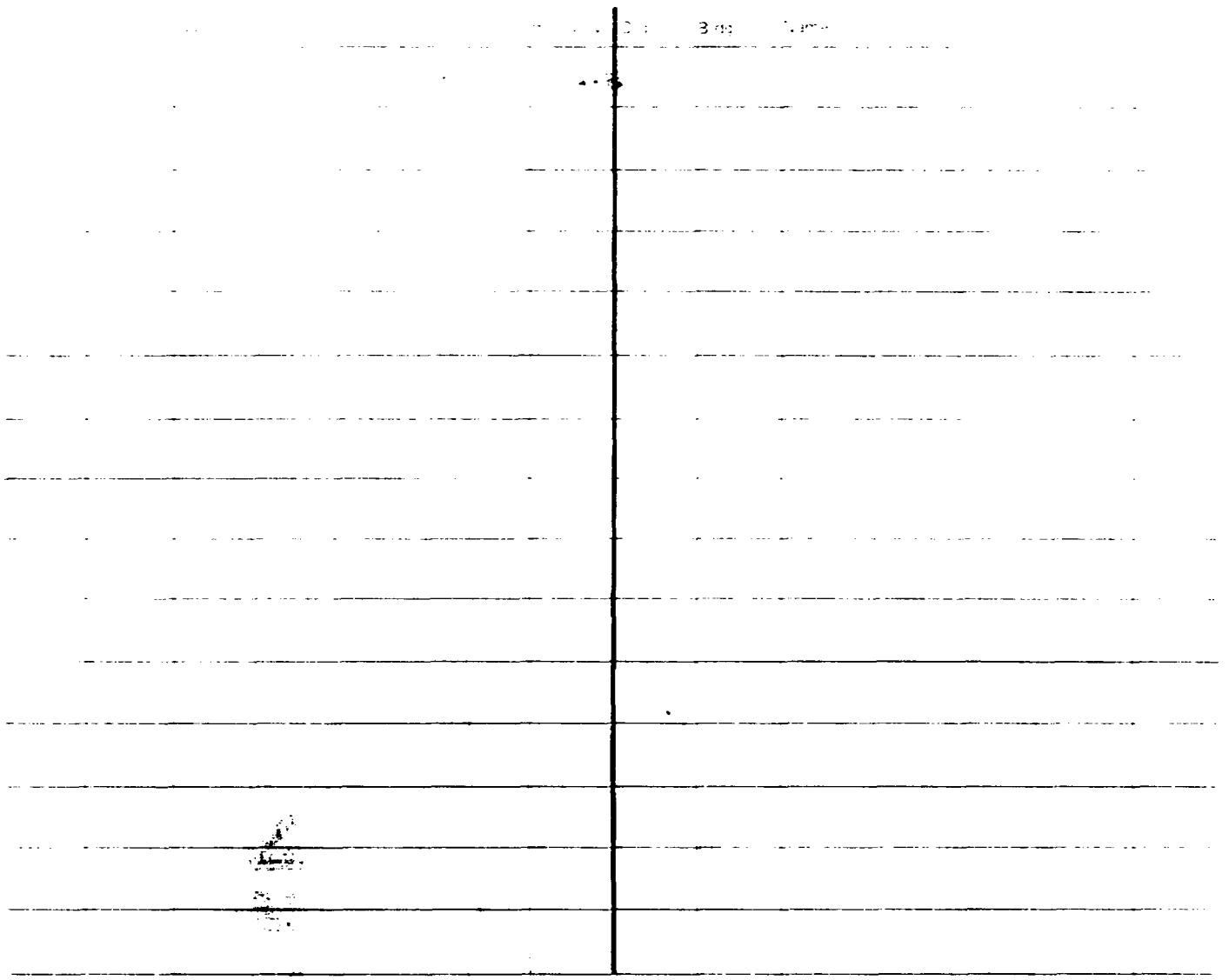

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