U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: REPOSITORY DESIGN REQUIREMENTS

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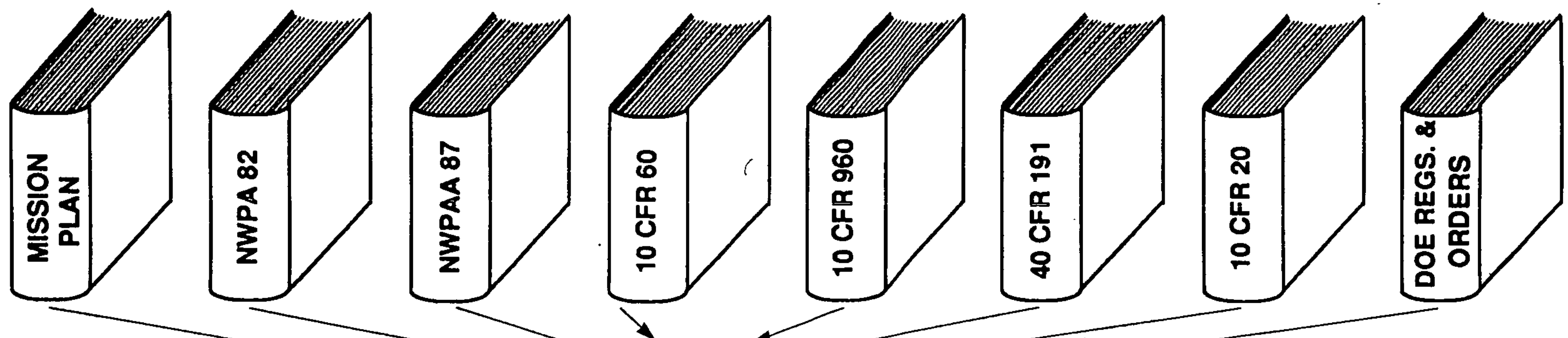
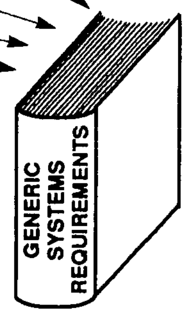
REQUIREMENTS DOCUMENTS

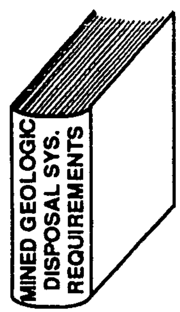


PROGRAM LEVEL



REQUIREMENTS
- TRANSPORTATION
- MRS
- MGDS

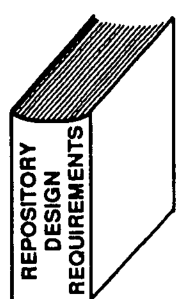
PROJECT LEVEL



SYSTEM FUNCTIONS
SYSTEM REQUIREMENTS
- PERFORMANCE CRITERIA
- CONSTRAINTS
- INTERACTIONS

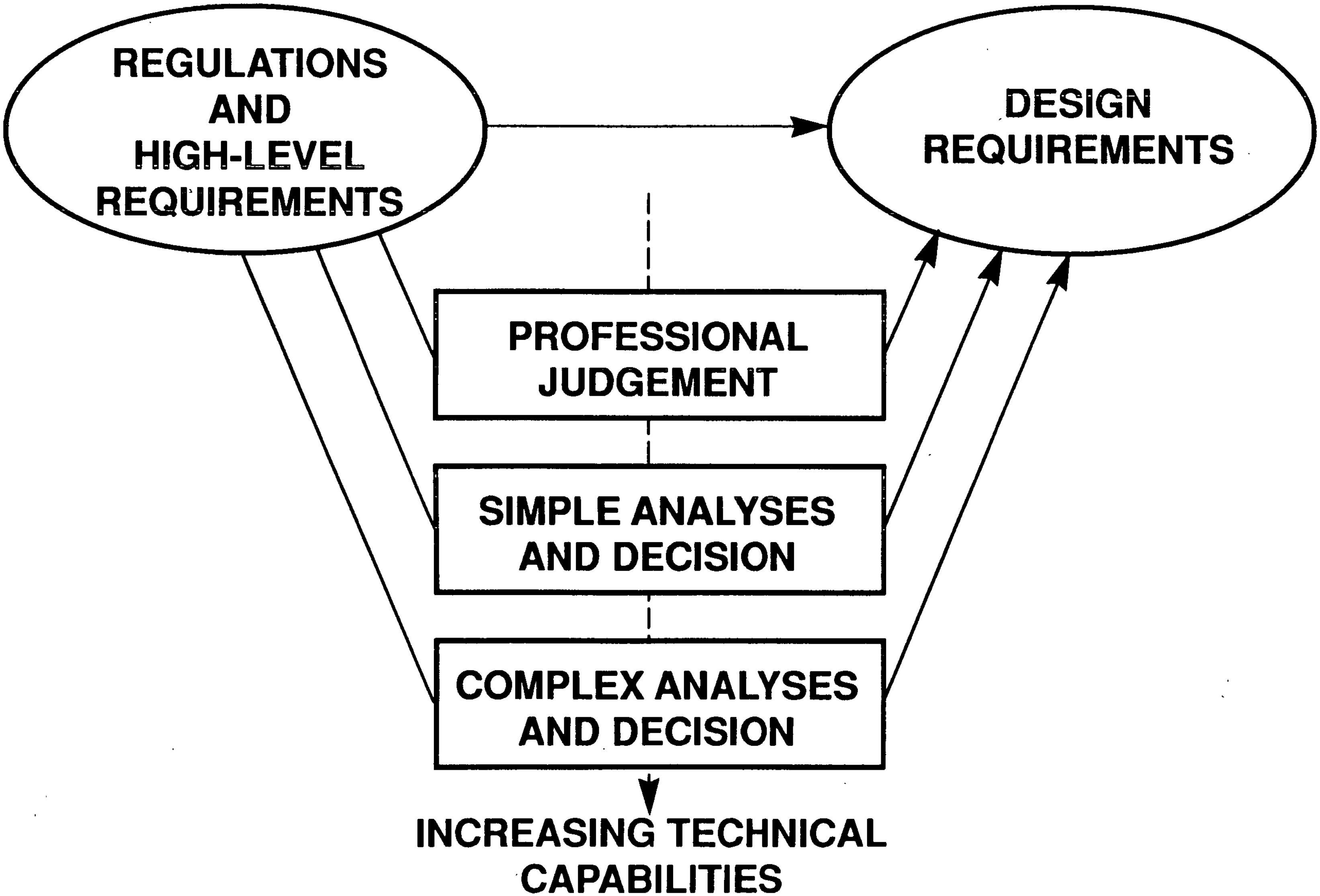
STATE REGULATIONS

DESIGNER LEVEL



SUBSYSTEM FUNCTIONS
SUBSYSTEM REQUIREMENTS
PERFORMANCE GOALS
SITE CONDITIONS
DESIGN DATA
BASELINE DESIGN
CONTROLLED ASSUMPTIONS

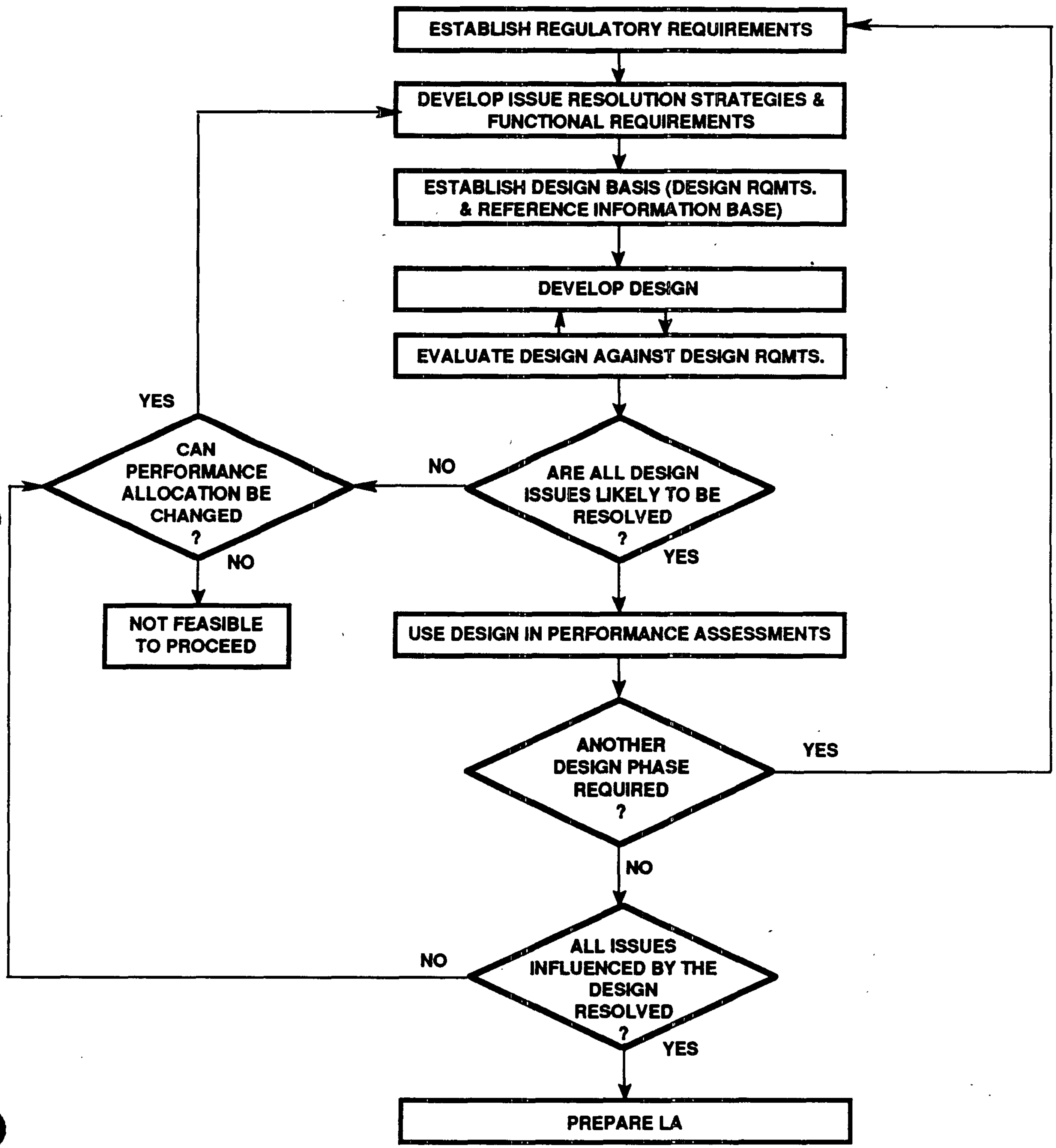
DEVELOPMENT OF DESIGN REQUIREMENTS



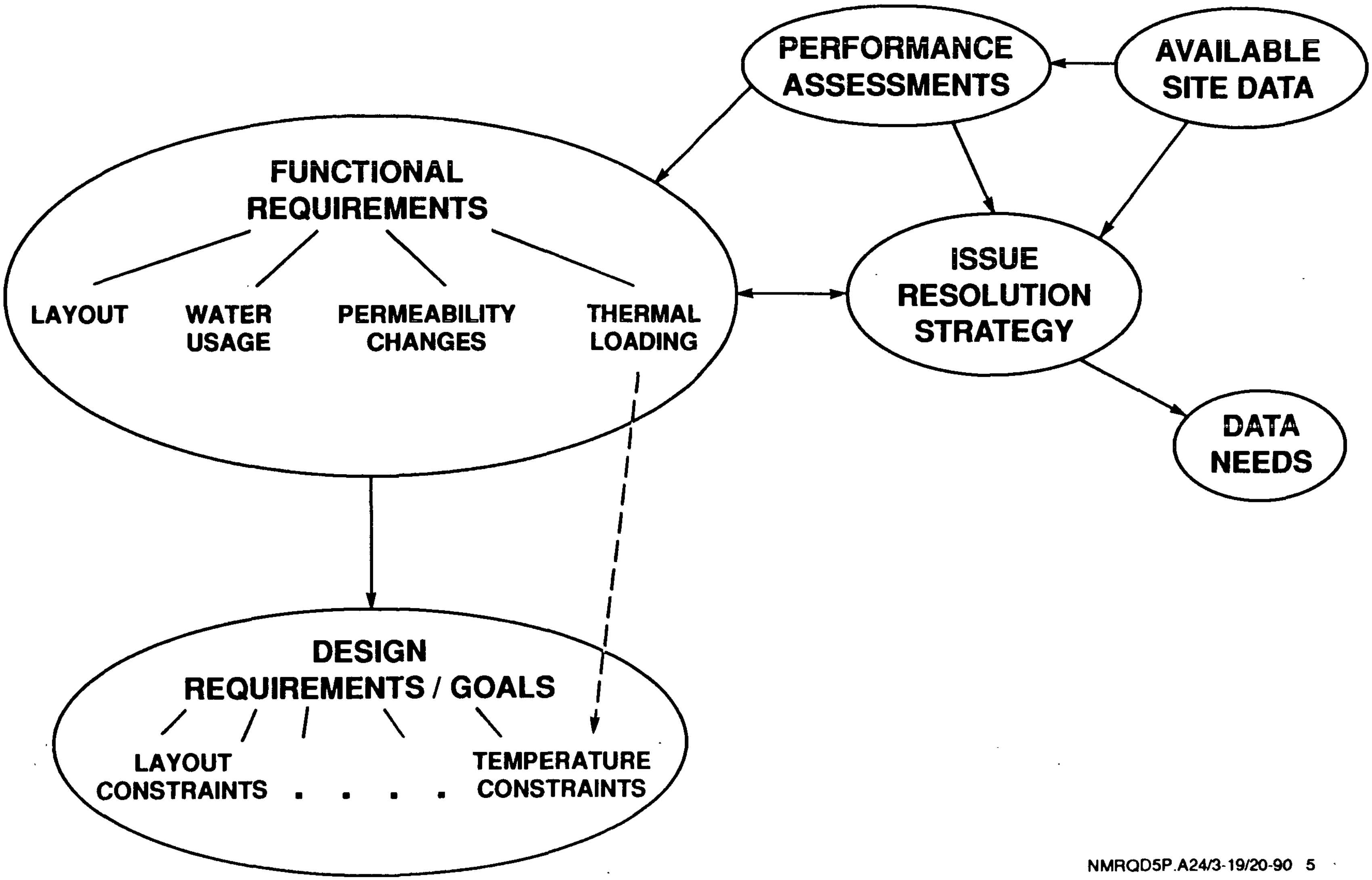
EXISTING DESIGN REQUIREMENTS

- PROFESSIONAL JUDGEMENT USING AVAILABLE DATA AND ASSUMPTIONS
- SIMPLE ANALYSES
- PERFORMANCE ALLOCATION PROCESS
- CONSTRAINTS ON TEMPERATURES AND LAYOUT

DESIGN AND PERFORMANCE ASSESSMENT LOGIC DIAGRAM



PERFORMANCE ALLOCATION FOR DESIGN GOALS



SITE CHARACTERISTICS

MAJOR SITE FEATURES IMPORTANT TO DESIGN

TOPOGRAPHY

FAULTS

STRATIGRAPHY

ROCK PROPERTIES

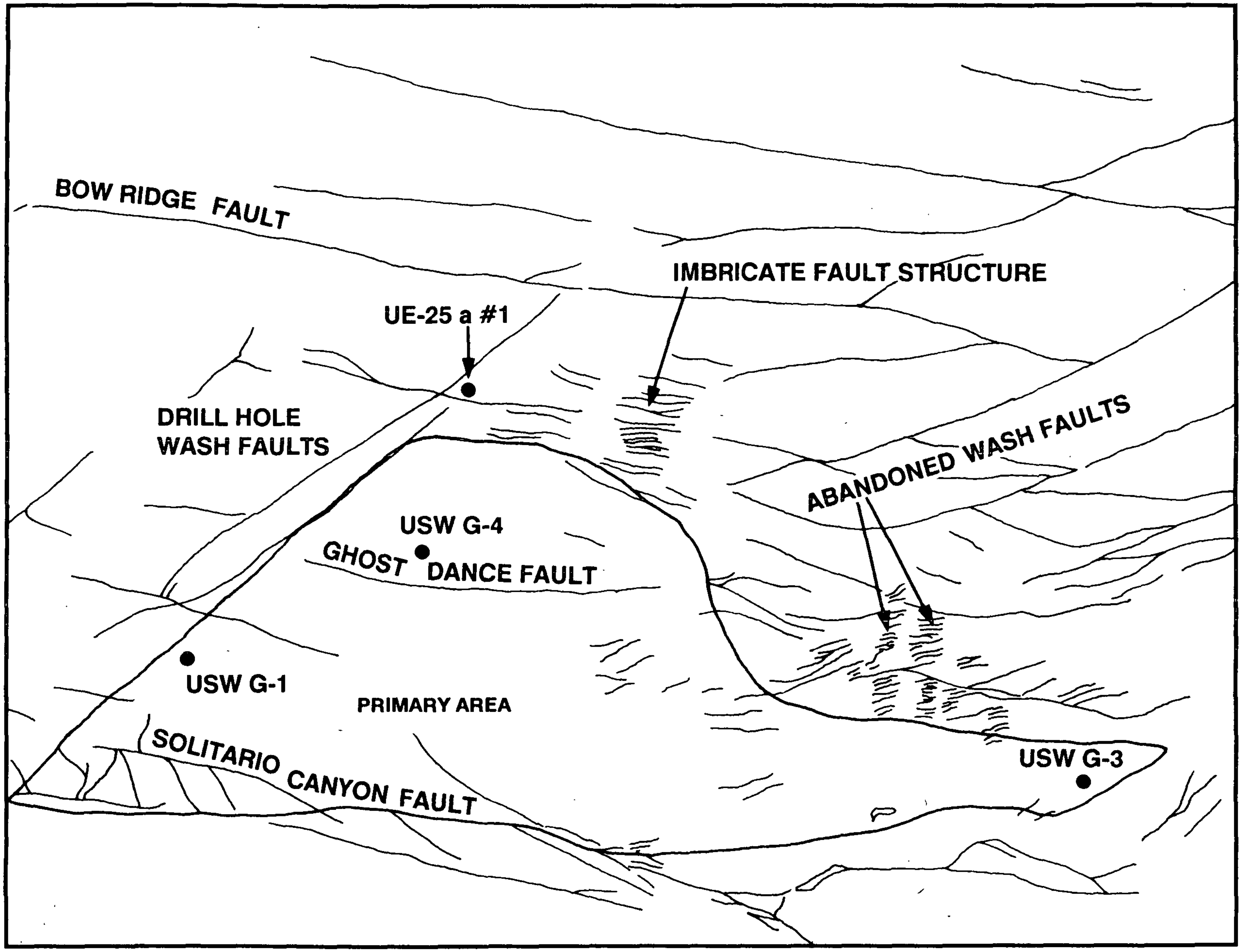
REFERENCE INFORMATION BASE (RIB)

CHANGES WITH TEMPERATURE

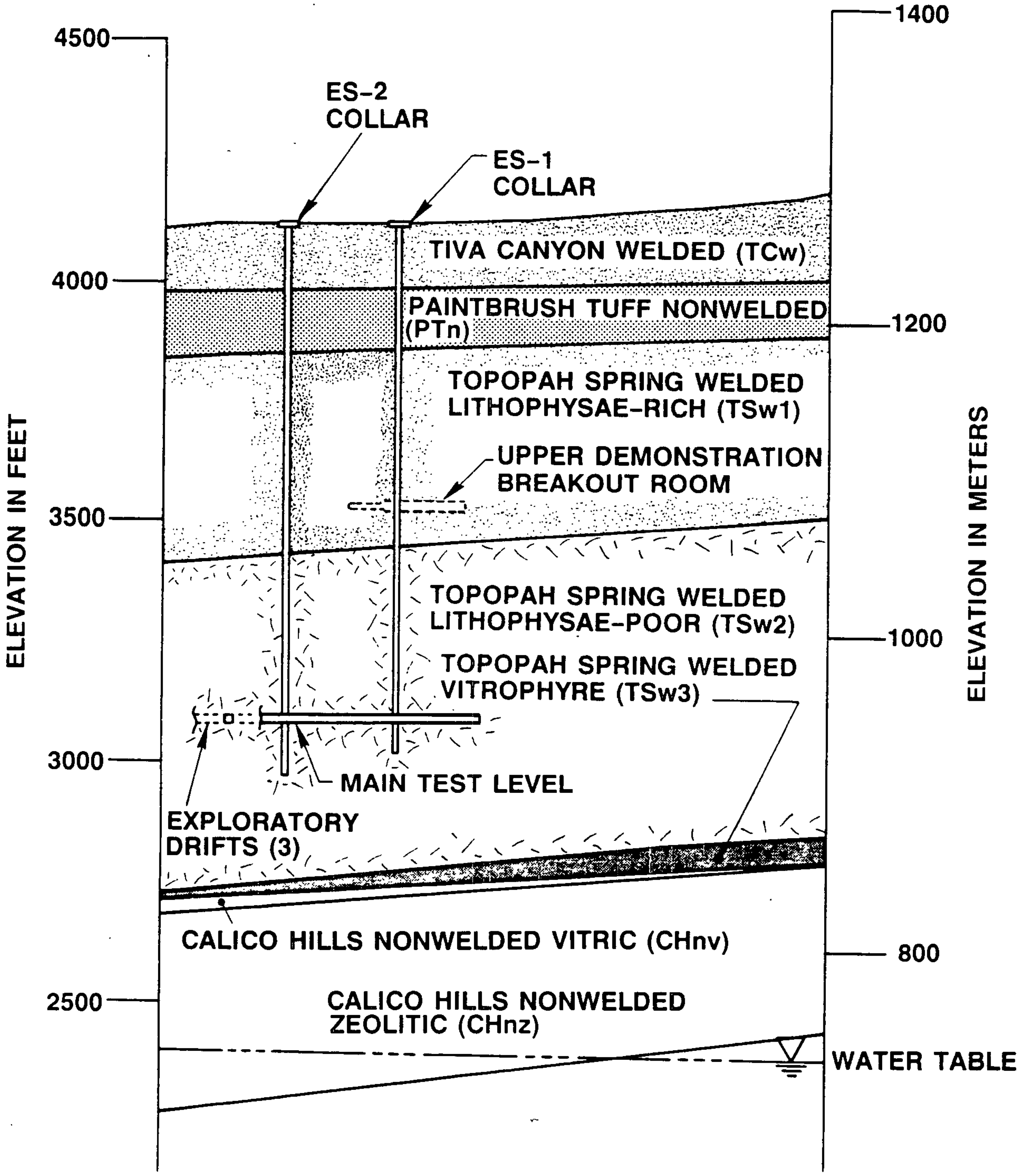
EXAMPLES OF IMPACT ON DESIGN

PHOTOGRAPHS OF YUCCA MOUNTAIN

YUCCA MOUNTAIN AREA FEATURE/STRUCTURE MAP



STRATIGRAPHY NEAR ESF



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EXAMPLES OF PROPERTIES FROM THE REFERENCE INFORMATION BASE

- THERMAL-MECHANICAL STRATIGRAPHY

- THERMAL PROPERTIES OF ROCK UNITS
  - HEAT CAPACITY
  - THERMAL CONDUCTIVITY
  - COEFFICIENT OF THERMAL EXPANSION

- MECHANICAL PROPERTIES OF INTACT ROCK
  - YOUNG'S MODULUS
  - POISSON'S RATIO
  - COMPRESSIVE STRENGTH CHARACTERISTICS

- MECHANICAL PROPERTIES OF JOINTS
  - NORMAL STIFFNESS/STRENGTH
  - SHEAR STIFFNESS/STRENGTH
  - SPATIAL-GEOMETRIC DESCRIPTIONS
  - ROUGHNESS COEFFICIENT

Keywords: matrix thermal conductivity, rock mass thermal conductivity

Description and Methodology

Thermal conductivity measurements have been made on samples from several drillholes and thermal/mechanical stratigraphic units at Yucca Mountain. Thermal conductivity experiments were performed using the transient-line-source technique. An electric current was applied to an axial heater within a thick-walled cylindrical sample and then the temperature/time response was monitored. Measurements of this type were made at different temperatures for each sample. An empirical model was used to analyze thermal conductivity data. Complete descriptions of the analysis and parameters are provided in two reports by Nimick (in preparation, a and b).

Matrix (zero porosity) thermal conductivities (K_o) were calculated from the measured values using the following equation:

$$K_o = [2(K)^2 - KK_w (3\Phi - 1)]/[K (2 - 3\Phi) + K_w], \qquad (1)$$

where K is the measured thermal conductivity, K_w is the thermal conductivity of water at the temperature of measurement, and Φ is the total porosity expressed as a volume fraction.

Values of rock mass thermal conductivity (K_{rm}) are based on a random mixture of two phases, solid and fluid, and are estimated using the following equation:

$$K_{rm} = (1/4) \{[3(1 - \Phi) - 1] K_o + (3\Phi - 1) K_f \pm [\{[3(1 - \Phi) - 1] K_o + (3\Phi - 1) K_f\}^2 + 8K_o K_f]^{1/2}\}, \qquad (2)$$

where K_f is the thermal conductivity of the fluid phase. If the sample is saturated, K_f is equal to K_w. If saturation is incomplete, the fluid phase is treated as a random mixture of air and water, and the thermal conductivity of the fluid phase is defined by the following equation:

$$K_f = (1/4) \{[3(1 - s) - 1] K_a + (3s - 1) K_w \pm [\{[3(1 - s) -1] K_a + (3s - 1) K_w\}^2 + 8K_a K_w]^{1/2}\}. \qquad (3)$$

In Equation (3), s is the saturation expressed as a volume fraction and K_a is the thermal conductivity of air at the temperature of interest. For the calculations presented here, the in situ saturation values of Montazer and Wilson (1984) were used.

Table 1 presents matrix thermal conductivities, K_o, calculated for thermal/mechanical units above and including CHn2. Estimated rock mass thermal conductivities, K_{rm}, are given in Table 2. The conductivity values in Table 2 have been estimated assuming that initial in situ saturation values do not change during heating until a nominal boiling temperature of 95°C is reached and that all pore water leaves the rock when the temperature is greater than 95°C. For other saturation histories, rock mass thermal conductivity can be estimated using Equations (2) and (3), the matrix thermal conductivities from Table 1, and appropriate porosity data.

The rock mass thermal conductivities as calculated by Equation 2 are for nonlithophysal, unfractured material. Nimick (in preparation, a and b) demonstrated that the fracture porosity has a negligible effect on the thermal conductivity of a homogeneous fractured rock mass (assuming that conductivity does not occur across a single air-filled fracture). However, lithophysal cavities do contribute to the rock mass thermal conductivities of thermal/mechanical units TSw1 and TSw2 (and by inference, TCw). In these cases, Equation 2 was used with the following conditions: (1) K_o is defined as the thermal conductivity of the relevant nonlithophysal rock mass, (2) K_f is defined as equal to K_a, and (3) Φ is defined as equal to the lithophysal cavity abundance for the relevant unit. The data for cavity abundances are taken from Nimick and Schwartz (1987).

Quality Assurance Information

All thermal conductivity and porosity data included in the analysis are supported by documentation in the Data Records Management System at Sandia National Laboratories. Data for thermal/mechanical units above and including CHn2 have been analyzed. The analysis was conducted under WBS Element 1.2.4.2.1.3S as part of Task B.2 as a Quality Assurance Level III activity. Results of the analysis are summarized in the reports by Nimick (in preparation, a and b). The data subjected to analysis are presented in Nimick (in preparation, c); all of these data were collected, analyzed and interpreted under procedures for which satisfaction of the requirements of 10CFR60, Subpart G has not been demonstrated.

Sources

Montazer, P., and W. E. Wilson, 1984. "Conceptual Hydrologic Model of Flow in the Unsaturated Zone, Yucca Mountain, Nevada," USGS-WRIR-84-4345, U. S. Geological Survey, Lakewood, CO.

Nimick F. B., and B. M. Schwartz, 1987. "Bulk, Thermal, and Mechanical Properties of the Topopah Spring Member of the Paintbrush Tuff, Yucca Mountain, Nevada," SAND85-0762, Sandia National Laboratories, Albuquerque, NM.

Nimick, F. B., (in preparation, a). "The Thermal Conductivity of Seven Thermal/Mechanical Units at Yucca Mountain, Nevada," SAND88-1387, Sandia National Laboratories, Albuquerque, NM.

Nimick, F. B., (in preparation, b). "The Thermal Conductivity of the Topopah Spring Member at Yucca Mountain, Nevada," SAND86-0090, Sandia National Laboratories, Albuquerque, NM.

Nimick, F. B., (in preparation, c). "Thermal-Conductivity Data for Tuffs From the Unsaturated Zone at Yucca Mountain, Nevada," SAND88-0624, Sandia National Laboratories, Albuquerque, NM.

TABLE 1. ESTIMATED MATRIX THERMAL CONDUCTIVITIES (K_o)

Thermal/ Mechanical Unit	Matrix Thermal Conductivity (W/m•K) Mean Value	Standard Deviation	n[a]
TCw[b]	1.910	0.086	0
PTn	2.330	0.298	2
TSw1	1.910	0.086	4
TSw2	2.231	0.047	11
TSw3	1.348	0.115	3
CHn1v	1.657	0.087	4
CHn2v[c]	≥1.657	–	0
CHn1z[d]	1.821	0.044	7
CHn2z	2.135	0.160	1

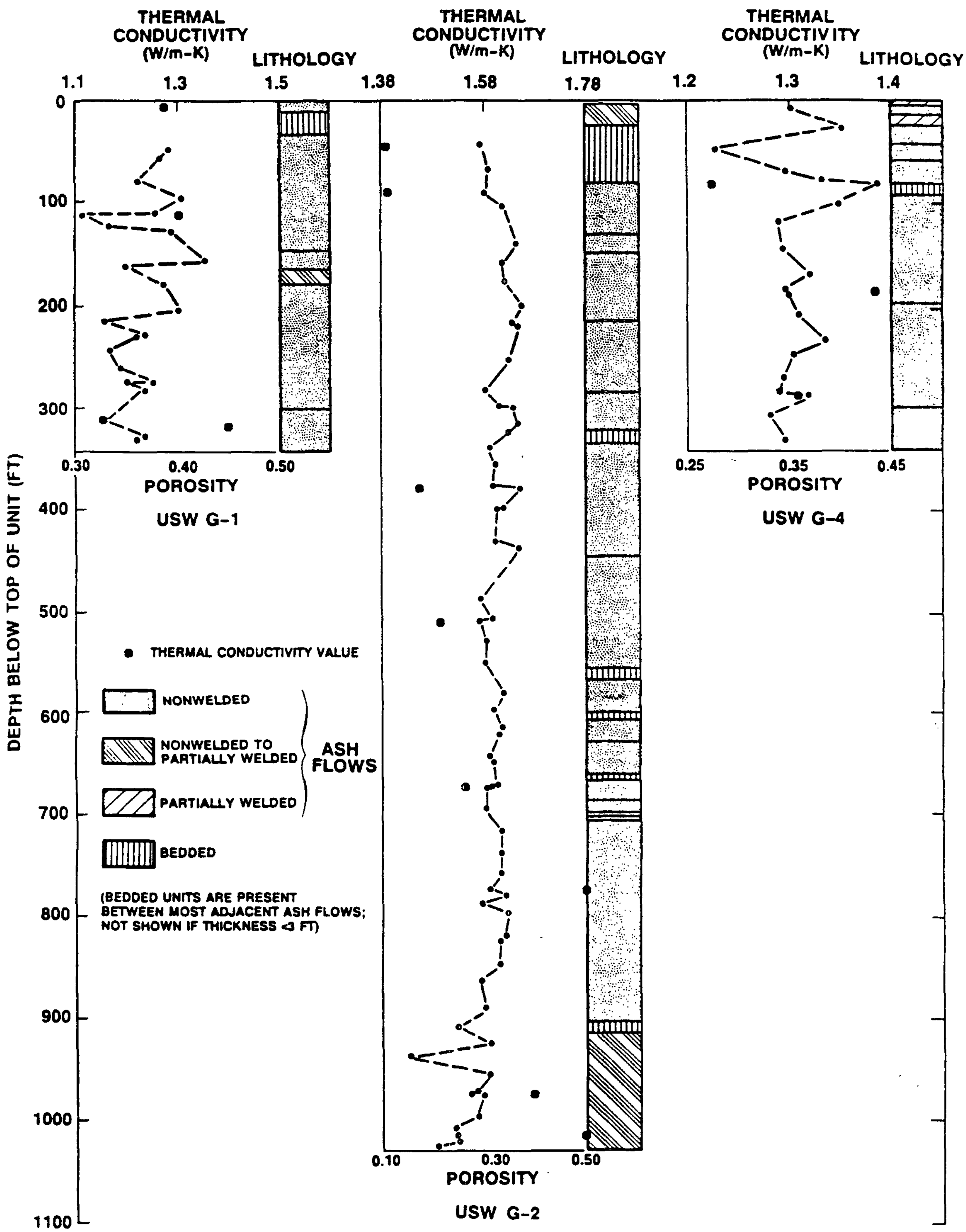
[a] n = number of samples.
[b] The value for unit TCw is assumed to be the same as the value for unit TSw1.
[c] The value for unit CHn1v is assumed to be a lower bound value for unit CHn2v.
[d] The data given here are for the repository area and are based on samples from drillholes USW G-1 and USW G-4. Values for USW G-2 are higher [see Nimick (in preparation, a) for discussion].

TABLE 2. ESTIMATED ROCK MASS THERMAL CONDUCTIVITIES (K_{rm})

Thermal/ Mechanical Unit	Rock Mass Thermal Conductivity (W/m•K) In Situ Saturation Mean Value	In Situ Saturation Standard Deviation	Dry Mean Value	Dry Standard Deviation
TCw[a]				
Lithophysae poor	1.506	–	1.423	–
Lithophysae rich	1.390	–	1.313	–
PTn[b]	<1.611	–	<1.450	–
TSw1				
Lithophysae poor	1.506	0.155	1.423	0.141
Lithophysae rich	1.390	0.100	1.313	0.088
TSw2	1.910	0.083	1.839	0.064
TSw3	1.304	0.136	1.285	0.113
CHn1v	1.195	0.124	0.845	0.200
CHn2v[b]	>1.195	–	>0.845	–
CHn1z[c]	1.270	0.236	≤0.543[d]	0.042
CHn2z	1.559	0.144	≤0.543[d]	0.042

[a] These values are assumed to be the same as the values for unit TSw1.
[b] The values given are bounding values; these values should be used for the unit until additional data are obtained.
[c] Data for samples from USW G-1 and USW G-4 used for unit CHn1z; data from USW G-2 resulted in lower values.
[d] Values for K_s, and therefore calculated values for K_{rm}, could only be bounded for high temperatures.

THERMAL CONDUCTIVITY AND POROSITY OF UNIT CHn1z



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TEMPERATURE EFFECTS AND THERMAL AND MECHANICAL PROPERTIES

CHANGE	APPROX. TEMP. (°C)	EFFECT ON DESIGN PARAMETERS
BOILING AND REMOVAL OF PORE WATER	>95	• DECREASE IN THERMAL CONDUCTIVITY (0-6% IN WELDED; 35-50% IN NONWELDED) • LARGE INCREASE (FACTOR OF 2 TO 14) IN VOLUMETRIC HEAT CAPACITY DURING BOILING; DECREASE IN VOLUMETRIC HEAT CAPACITY (RELATIVE TO SATURATION) WHEN PORES DRY (0-15% IN WELDED, 42-44% IN NONWELDED) • SLIGHT INCREASE IN STRENGTH OF INTACT ROCK
DEHYDRATION OF HYDROUS MINERALS (MAINLY ZEOLITES) AND GLASS	95-230	• PROBABLE DECREASE IN THERMAL CONDUCTIVITY OF ZEOLITIZED UNITS (PROBABLE CHANGE <10%) • CONTRACTION OF ZEOLITIZED UNITS AND WELDED VITRIC MATERIAL • SLIGHT DECREASE IN YOUNG'S MODULUS OF ZEOLITIZED UNITS • SLIGHT INCREASE IN YOUNG'S MODULUS, STRENGTH OF WELDED VITRIC MATERIAL

TEMPERATURE EFFECTS AND THERMAL AND MECHANICAL PROPERTIES

(CONTINUED)

CHANGE	APPROX. TEMP. (°C)	EFFECT ON DESIGN PARAMETERS
SILICA PHASE TRANSFORMATIONS (WELDED, DEVITRIFIED ONLY)	150-250	• LARGE INCREASE IN COEFFICIENT OF THERMAL EXPANSION • SMALL INCREASE IN VOLUMETRIC HEAT CAPACITY • SMALL DECREASE IN YOUNG'S MODULUS, STRENGTH (AFTER THERMAL EXPANSION OCCURS)
GENERAL HEAT CAPACITY CHANGE	>25	• HEAT CAPACITY OF SOLID COMPONENTS INCREASES SLOWLY WITH TEMPERATURE AT ALL TEMPERATURES ABOVE AMBIENT (HEAT CAPACITY AT 250°C ~34% HIGHER THAN VALUE AT 25°C)

PHOTOGRAPH OF G-TUNNEL HEATED-BLOCK EXPERIMENT

FIELD TESTS

G-TUNNEL HEATER EXPERIMENTS

- **WELDED TUFF**
  - EMPLACEMENT HOLE TEMPERATURES UP TO 300° C
  - NO SPALLING
- **NONWELDED TUFF**
  - EMPLACEMENT HOLE TEMPERATURES UP TO 180° C
  - NO SPALLING
- **TEMPERATURES PREDICTED**

USABLE AREA FOR NUCLEAR WASTE DISPOSAL IN YUCCA MOUNTAIN

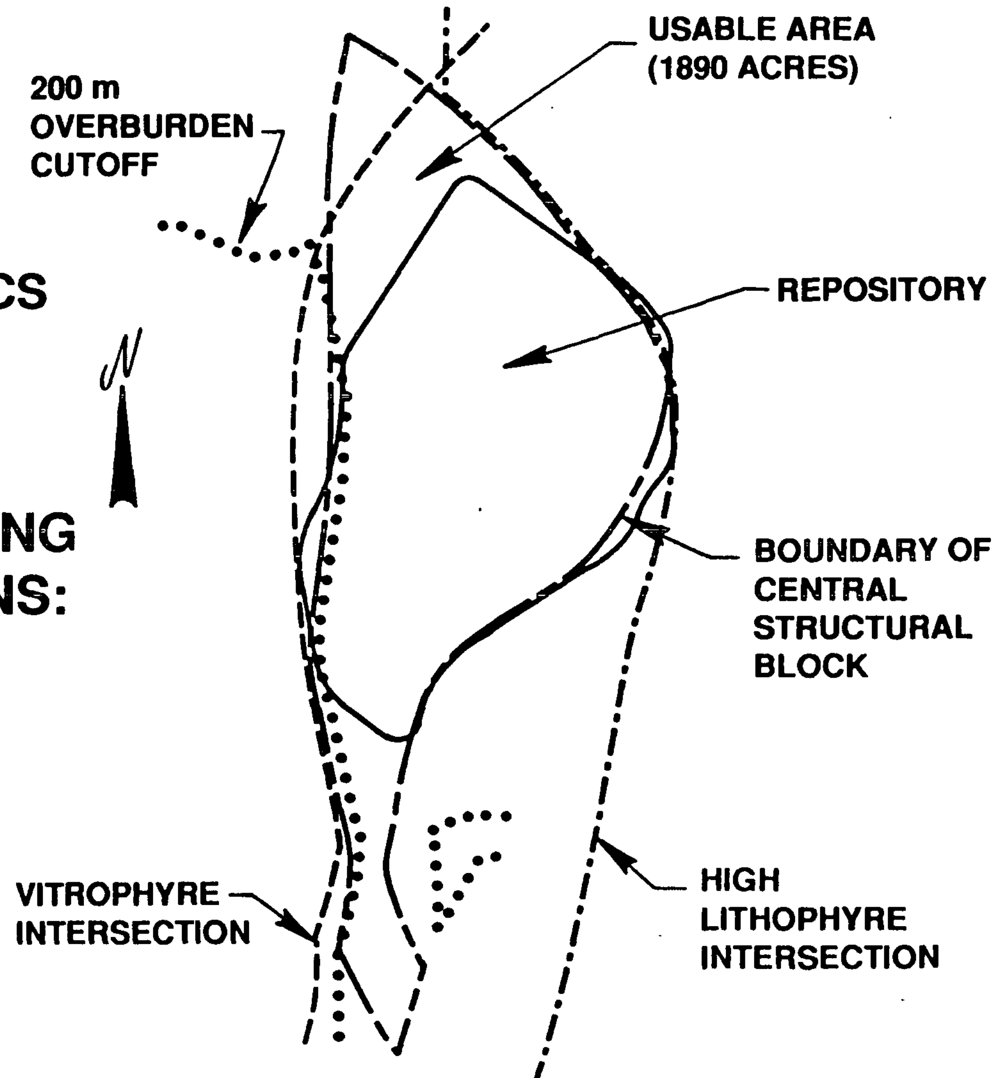
CONSTRAINTS:

- SITING GUIDELINES:
  - 200 m OVERBURDEN
  - ROCK CHARACTERISTICS
    * LITHOPHYSAE
    * VITROPHYRE

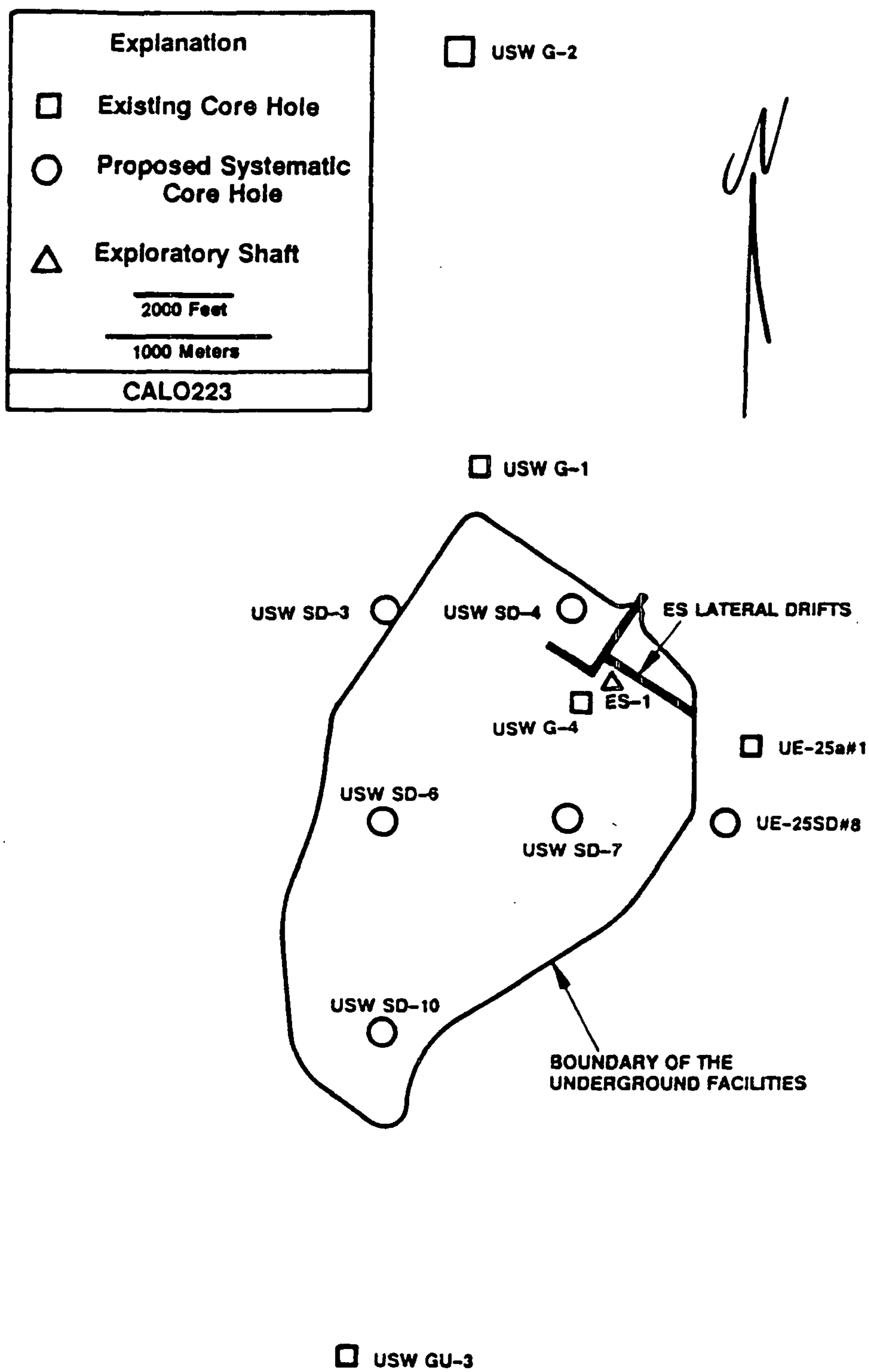
- MINING/WASTE HANDLING EQUIPMENT LIMITATIONS:
  - 10% MAXIMUM GRADE

MODEL:

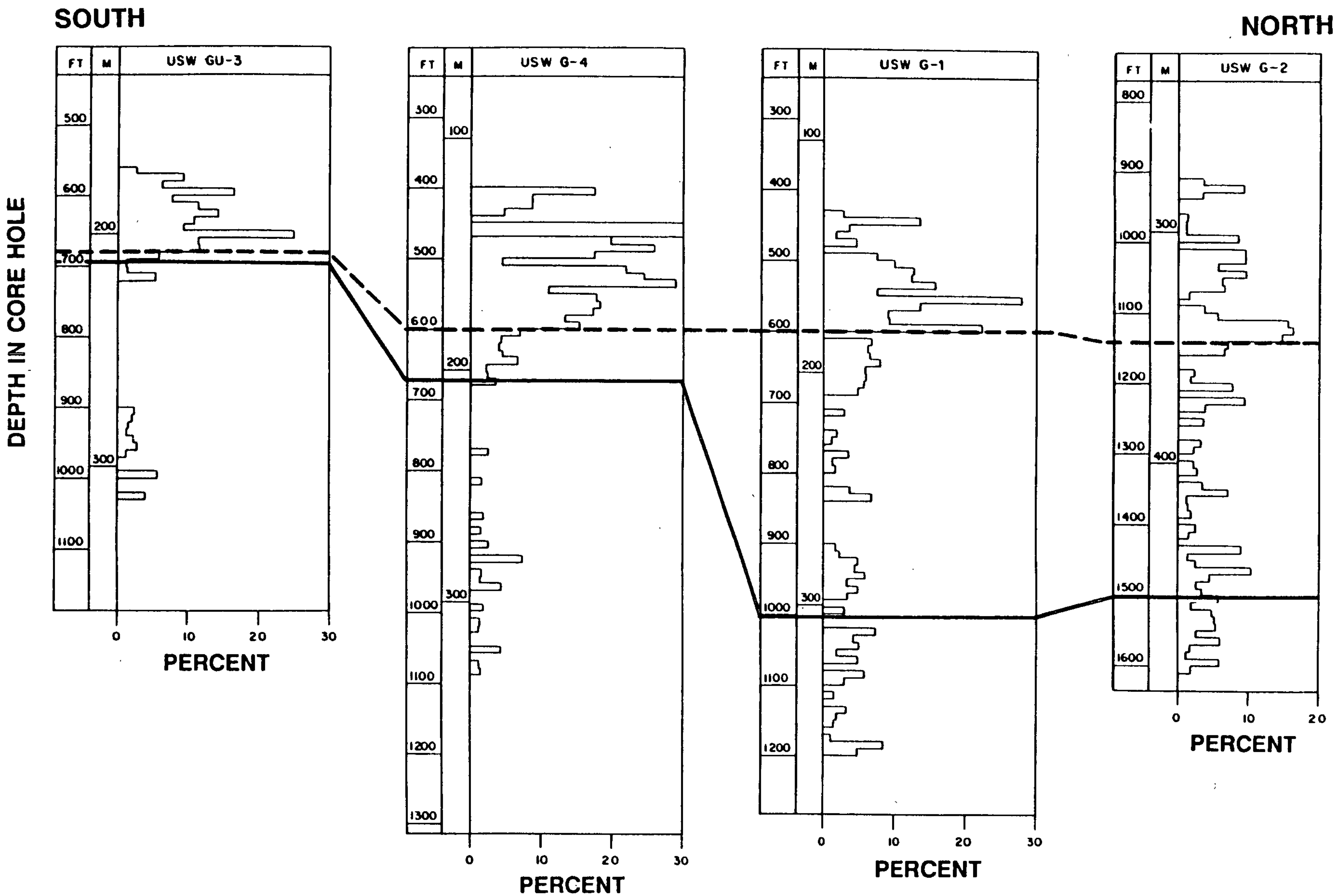
- 3-D GRAPHICS REPRESENTATION OF YUCCA MOUNTAIN



LOCATION OF EXISTING AND PLANNED COREHOLES



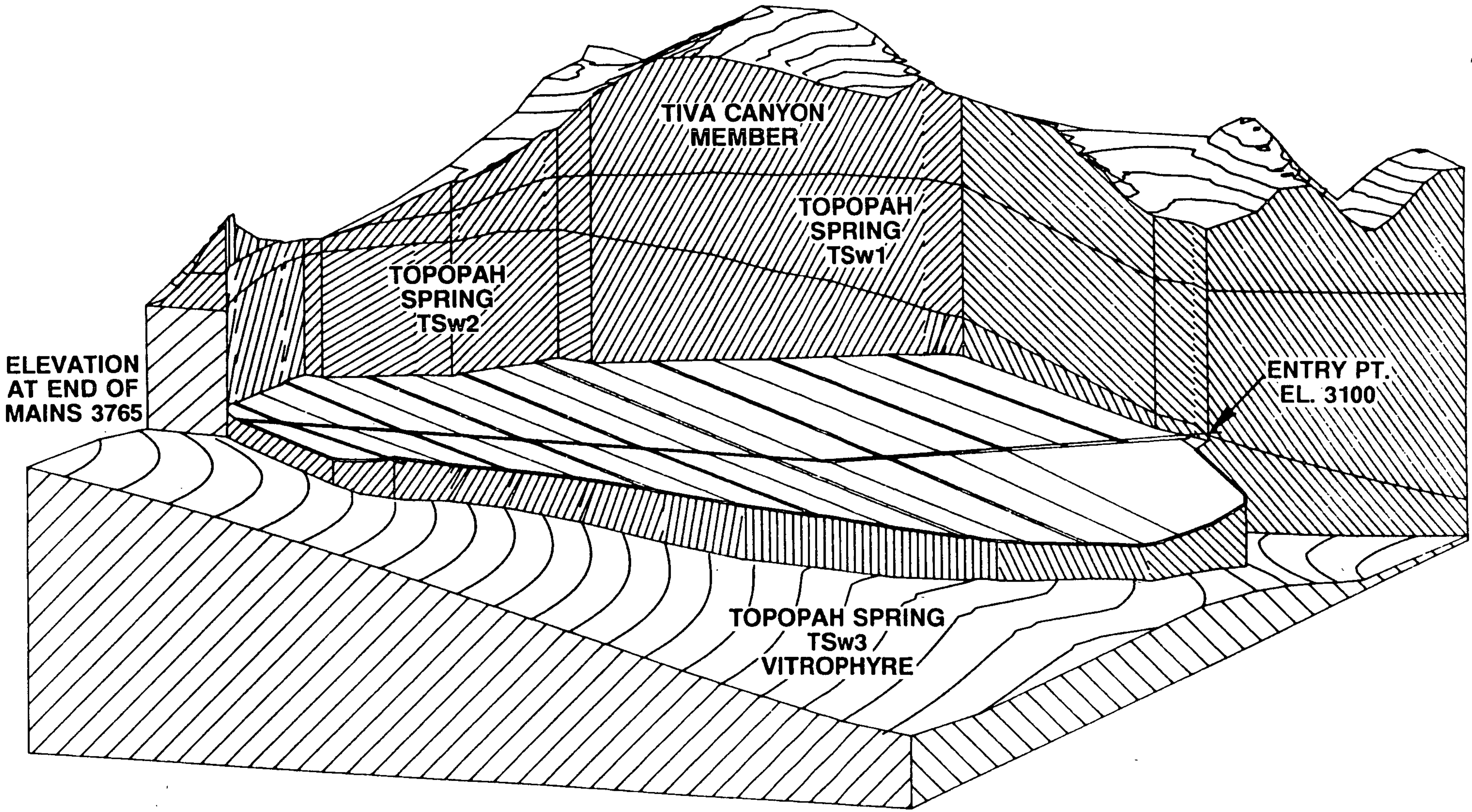
CHANGE IN TSw1 - TSw2 CONTACT BASED ON LITHOPHYSAE VOIDS



TSw1 - TSw2 CONTACT USED FOR THE CONCEPTUAL DESIGN

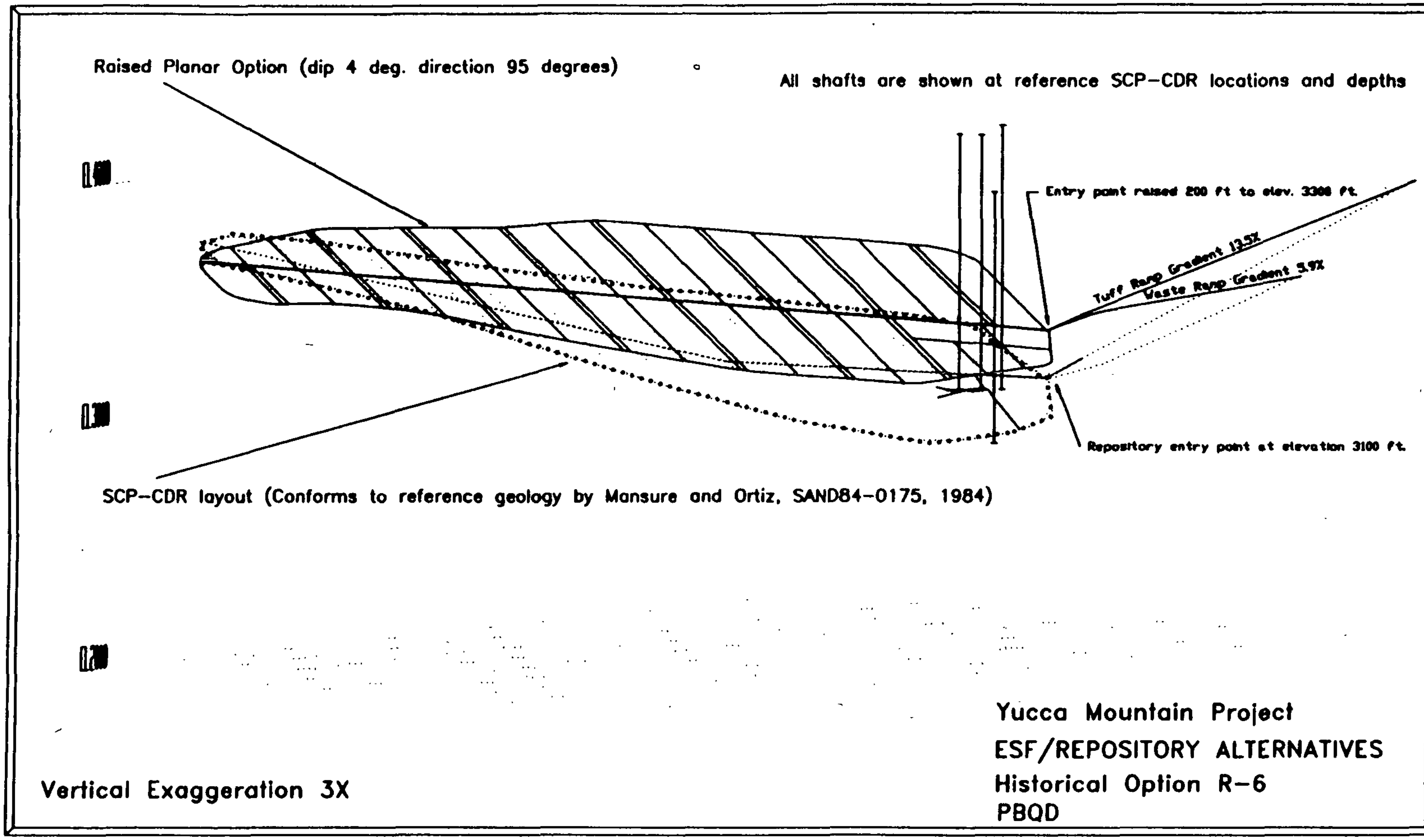
REVISED TSw1 - TSw2 CONTACT

REPOSITORY CONCEPTUAL DESIGN



SCALE 2:1

ESF/REPOSITORY ALTERNATIVE

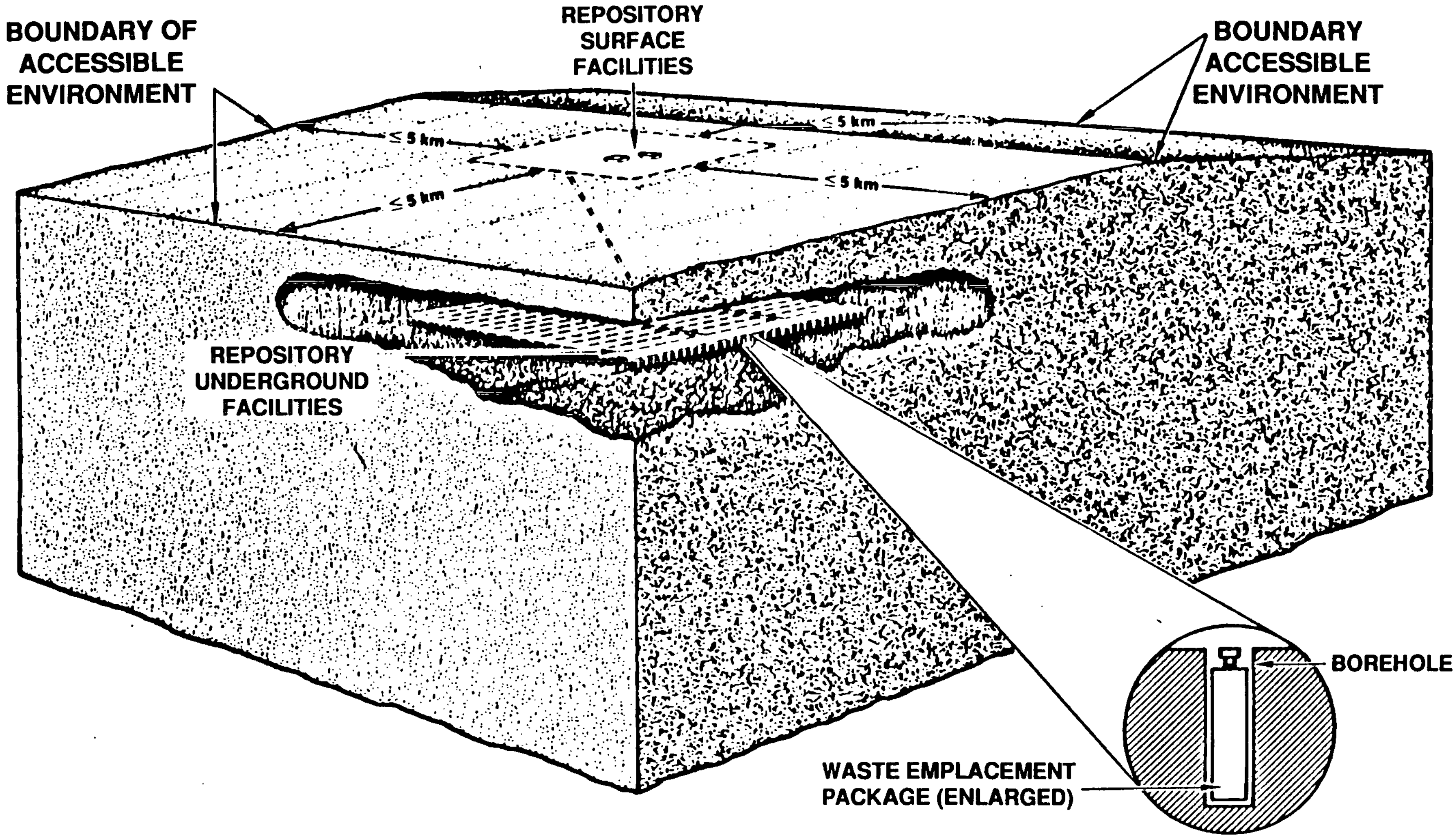


HIERARCHY OF FUNCTIONS AND COMPONENTS

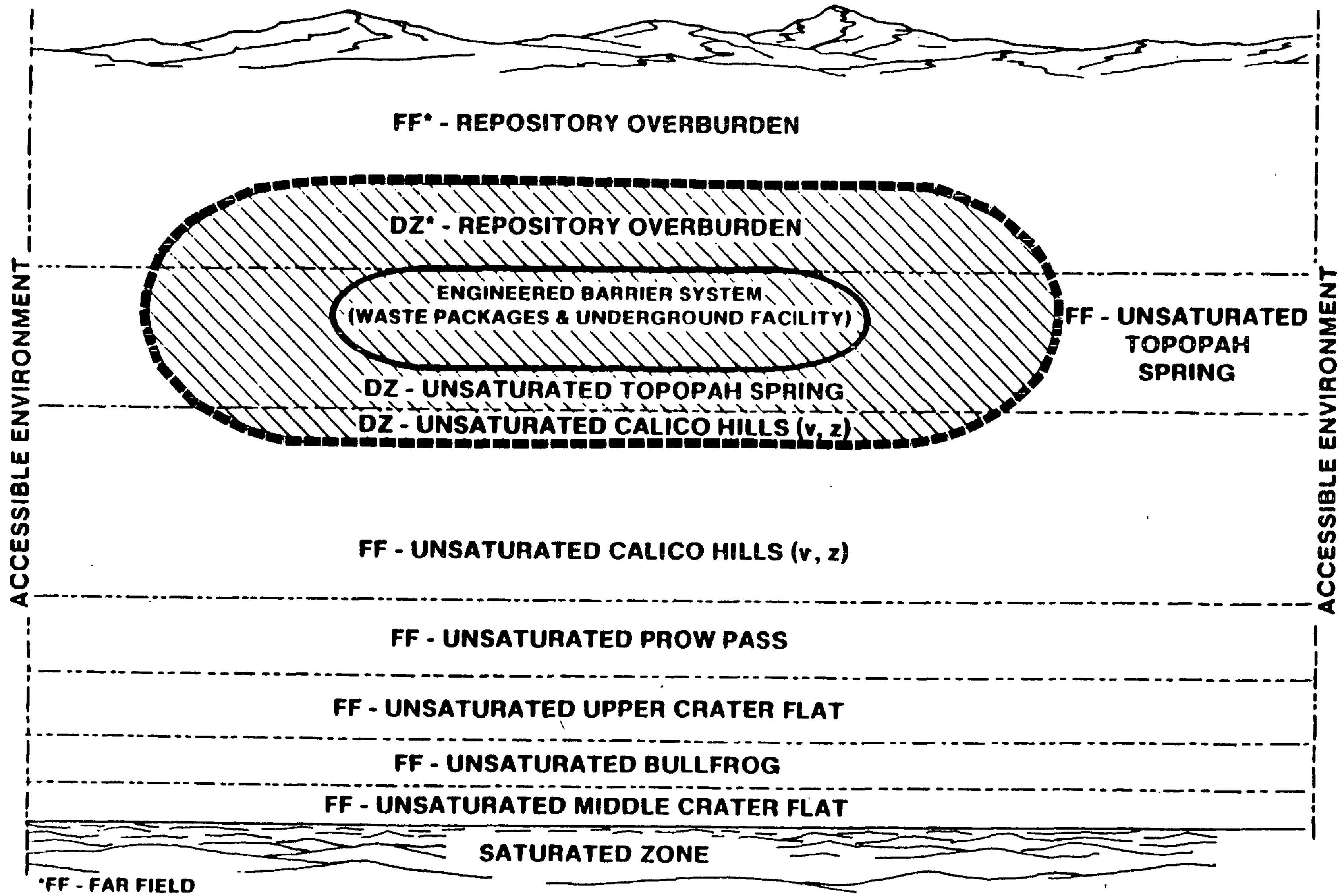
YUCCA MOUNTAIN MINED GEOLOGIC DISPOSAL SYSTEM

- **1.0 PRECLOSURE WASTE DISPOSAL**
  - **1.1 SITE**
    - 1.1.1 SURFACE
    - 1.1.2 SUBSURFACE
  - **1.2 REPOSITORY**
    - **1.2.1 MINING**
      - 1.2.1.1 ACCESS CONSTRUCTION
      - 1.2.1.2 DRIFT CONSTRUCTION
      - 1.2.1.3 BOREHOLE CONSTRUCTION
      - 1.2.1.4 ROCK HANDLING
      - 1.2.1.5 WATER REMOVAL
      - 1.2.1.6 MINING VENTILATION
    - **1.2.2 WASTE HANDLING**
      - 1.2.2.1 RECEIVING
      - 1.2.2.2 PREPARATION
      - 1.2.2.3 STORAGE
      - 1.2.2.4 EMPLACEMENT
      - 1.2.2.5 RETRIEVAL
      - 1.2.2.6 SHIPPING
      - 1.2.2.7 WASTE-HANDLING VENTILATION
      - 1.2.2.8 CONTAMINATION CONTROL
    - **1.2.3 PERFORMANCE CONFIRMATION**
      - 1.2.3.1 WASTE EVALUATION
      - 1.2.3.2 GEOLOGIC EVALUATION
      - 1.2.3.3 NATURAL AND ENGINEERED BARRIERS EVALUATION
      - 1.2.3.4 DESIGN MODIFICATION
    - **1.2.4 DECOMMISSIONING**
      - 1.2.4.1 UNDERGROUND CLOSURE
      - 1.2.4.2 SURFACE-FACILITY DECOMMISSIONING
      - 1.2.4.3 INSTITUTIONAL-BARRIER IMPLEMENTATION
    - **1.2.5 SUPPORT**
      - 1.2.5.1 INFORMATION
      - 1.2.5.2 ADMINISTRATION
      - 1.2.5.3 PERSONNEL SERVICES
      - 1.2.5.4 SECURITY & SAFEGUARDS
      - 1.2.5.5 SUPPLIES
      - 1.2.5.6 MAINTENANCE
      - 1.2.5.7 UTILITIES
      - 1.2.5.8 TRANSPORTATION
      - 1.2.5.9 MONITORING
        - 1.2.5.9.1 RADIOLOGICAL MONITORING
        - 1.2.5.9.2 NONRADIOLOGICAL MONITORING
      - 1.2.5.10 EMERGENCY PREPAREDNESS
  - **1.3 WASTE EMPLACEMENT PACKAGE**
- **2.0 POSTCLOSURE WASTE DISPOSAL**
  - **2.1 NATURAL BARRIERS**
    - **2.1.1 DISTURBED ZONE**
      - 2.1.1.1 REPOSITORY OVERBURDEN
      - 2.1.1.2 UNSATURATED TOPOPAH SPRING
      - 2.1.1.3 UNSATURATED CALICO HILLS-V
      - 2.1.1.4 UNSATURATED CALICO HILLS-Z
    - **2.1.2 FAR FIELD**
      - 2.1.2.1 REPOSITORY OVERBURDEN
        - 2.1.2.1.1 UNDIFFERENTIATED
        - 2.1.2.1.2 TIVA CANYON
        - 2.1.2.1.3 PAINT BRUSH
        - 2.1.2.1.4 TOPOPAH SPRING
      - 2.1.2.2 UNSATURATED TOPOPAH SPRING
      - 2.1.2.3 UNSATURATED CALICO HILLS-V
      - 2.1.2.4 UNSATURATED CALICO HILLS-Z
      - 2.1.2.5 UNSATURATED PROW PASS
      - 2.1.2.6 UNSATURATED UPPER CRATER FLAT
      - 2.1.2.7 UNSATURATED BULLFROG
      - 2.1.2.8 UNSATURATED MIDDLE CRATER FLAT
      - 2.1.2.9 SATURATED ZONE
  - **2.2 ENGINEERED BARRIERS**
    - **2.2.1 WASTE PACKAGE**
      - 2.2.1.1 CONTAINER
      - 2.2.1.2 WASTE FORM
    - **2.2.2 REPOSITORY ENGINEERED BARRIERS**
      - 2.2.2.1 HOST ROCK
      - 2.2.2.2 UNDERGROUND OPENINGS
      - 2.2.2.3 REPOSITORY SEALS
    - **2.2.3 SHAFT AND BOREHOLE SEALS**
  - **2.3 INSTITUTIONAL BARRIERS**

PARTS OF THE YUCCA MOUNTAIN MINED GEOLOGIC DISPOSAL SYSTEM



PARTS OF THE MGDS THAT WILL ISOLATE RADIOACTIVE WASTE



*FF - FAR FIELD
DZ - DISTURBED ZONE

NOT TO SCALE

PHYSICAL BOUNDARIES AND INTERFACES

- ENGINEERED BARRIER SYSTEM
- DISTURBED ZONE
- ACCESSIBLE ENVIRONMENT

- WASTE PACKAGE - REPOSITORY INTERFACE
- SURFACE - UNDERGROUND INTERFACE
- ESF - REPOSITORY INTERFACE
- EXTERNAL INTERFACES
- REPOSITORY - SITE INTERFACE

ENGINEERED BARRIER SYSTEM

INCLUDES:

- WASTE PACKAGE (INCLUDING ASSOCIATED COMPONENTS)
- UNDERGROUND OPENINGS
- BACKFILL MATERIALS

EXCLUDES:

- SHAFTS
- BOREHOLES
- SEALS
- HOST ROCK (NRC POSITION)

DISTURBED ZONE

NRC DRAFT POSITION:

DISTURBED ZONE IS DEFINED "BY THE ZONE OF SIGNIFICANT CHANGES IN INTRINSIC PERMEABILITY AND EFFECTIVE POROSITY CAUSED BY CONSTRUCTION OF THE FACILITY OR BY THERMAL EFFECTS OF THE EMPLACED WASTE" (1986)

"SIGNIFICANT" IS "ABOUT A FACTOR OF TWO CHANGE IN EFFECTIVE POROSITY, WHICH WOULD GENERALLY CORRESPOND TO ABOUT AN ORDER OF MAGNITUDE CHANGE IN INTRINSIC PERMEABILITY" (1985)

MINIMUM GUIDELINES INTERPRETED AS 50 METERS

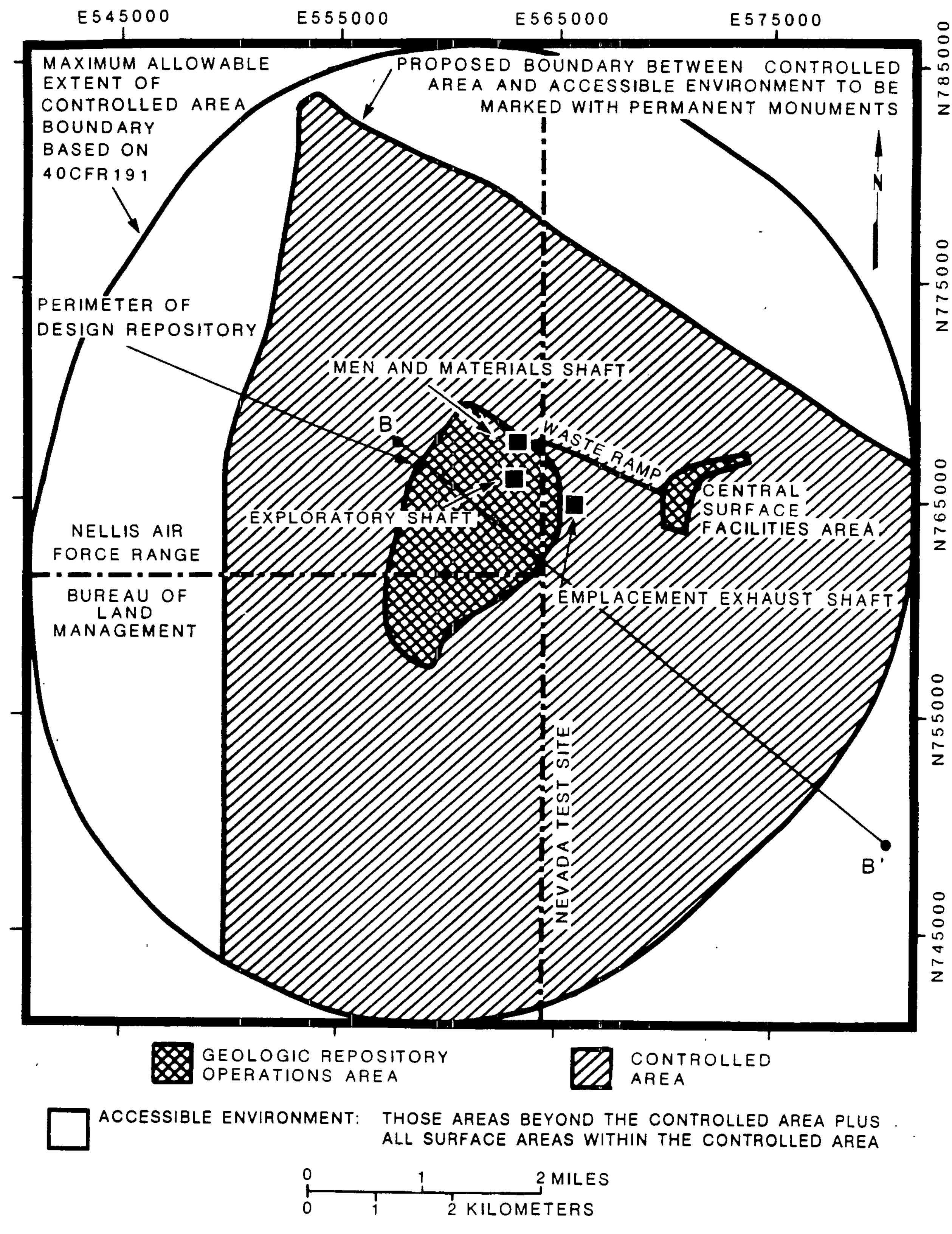
DISTURBED ZONE

(CONTINUED)

DOE APPROACH:

- IDENTIFY LIKELY PATHS OF GROUND-WATER TRAVEL AND MODES OF FLOW
- OBTAIN PREDICTIONS OF CHANGES IN MATRIX POROSITY AND PERMEABILITY(ASSUMES MATRIX FLOW)
- EVALUATE THE EXTENT AND DURATION OF CHANGES
- COMPARE GROUND-WATER TRAVEL TIME WITH AND WITHOUT A REPOSITORY TO EVALUATE IF PROPERTY CHANGES ARE SIGNIFICANT
- EVALUATE AND CONSIDER OTHER REPOSITORY-INDUCED CHANGES AS NECESSARY

ACCESSIBLE ENVIRONMENT



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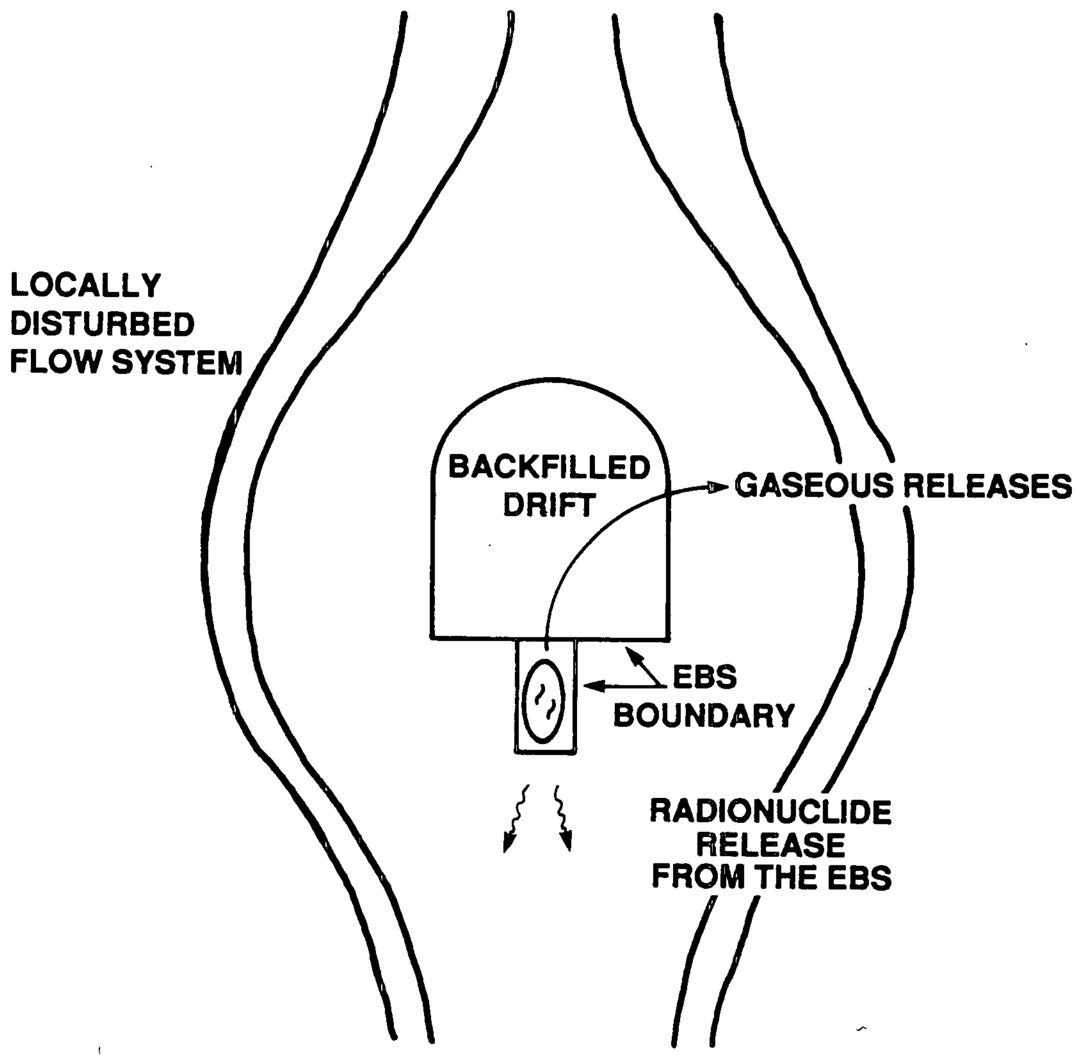
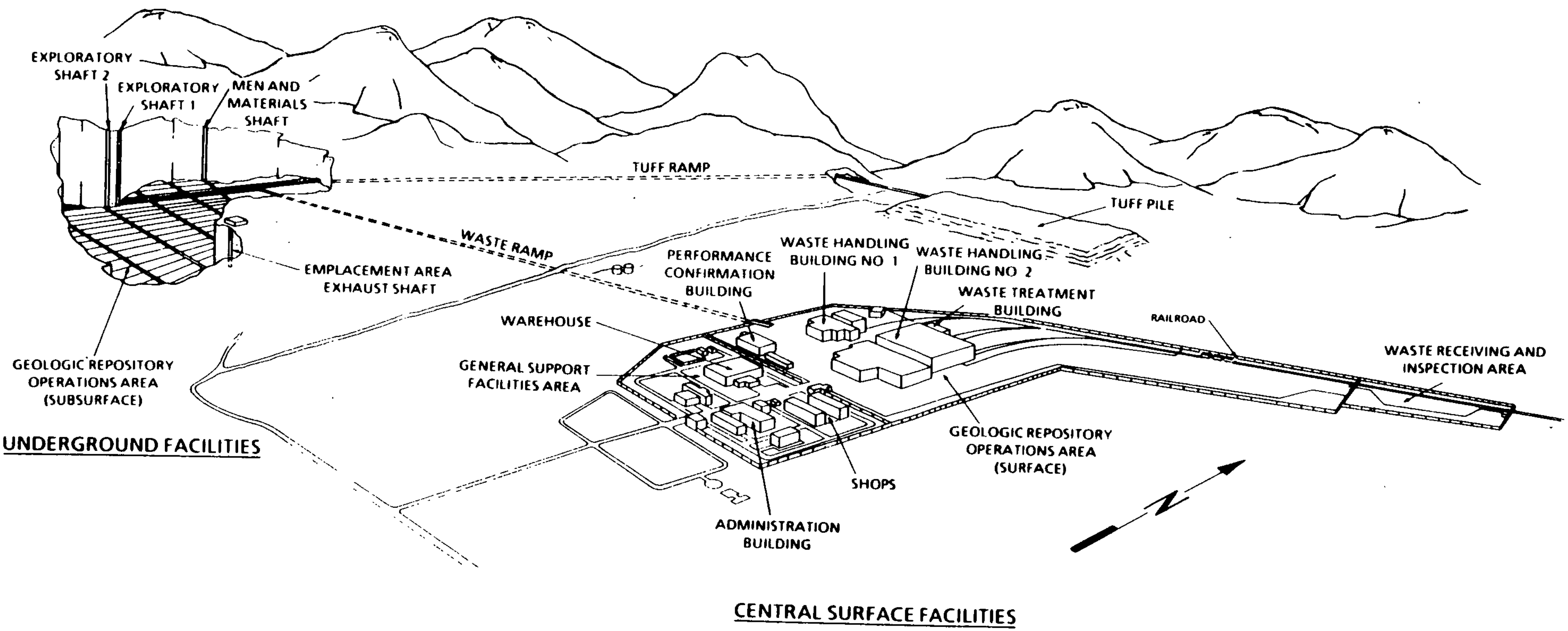
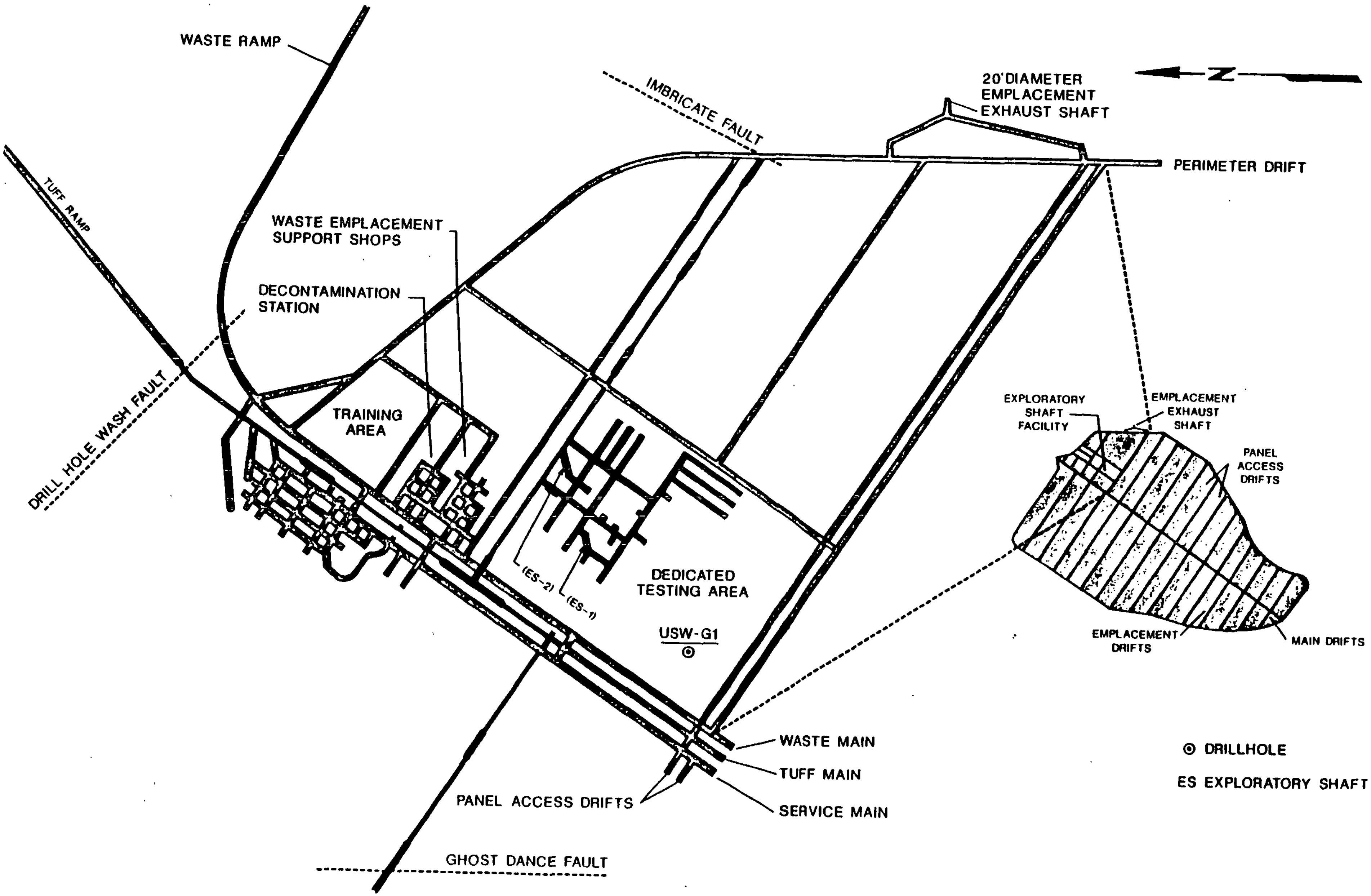
WASTE PACKAGE - REPOSITORY INTERFACE



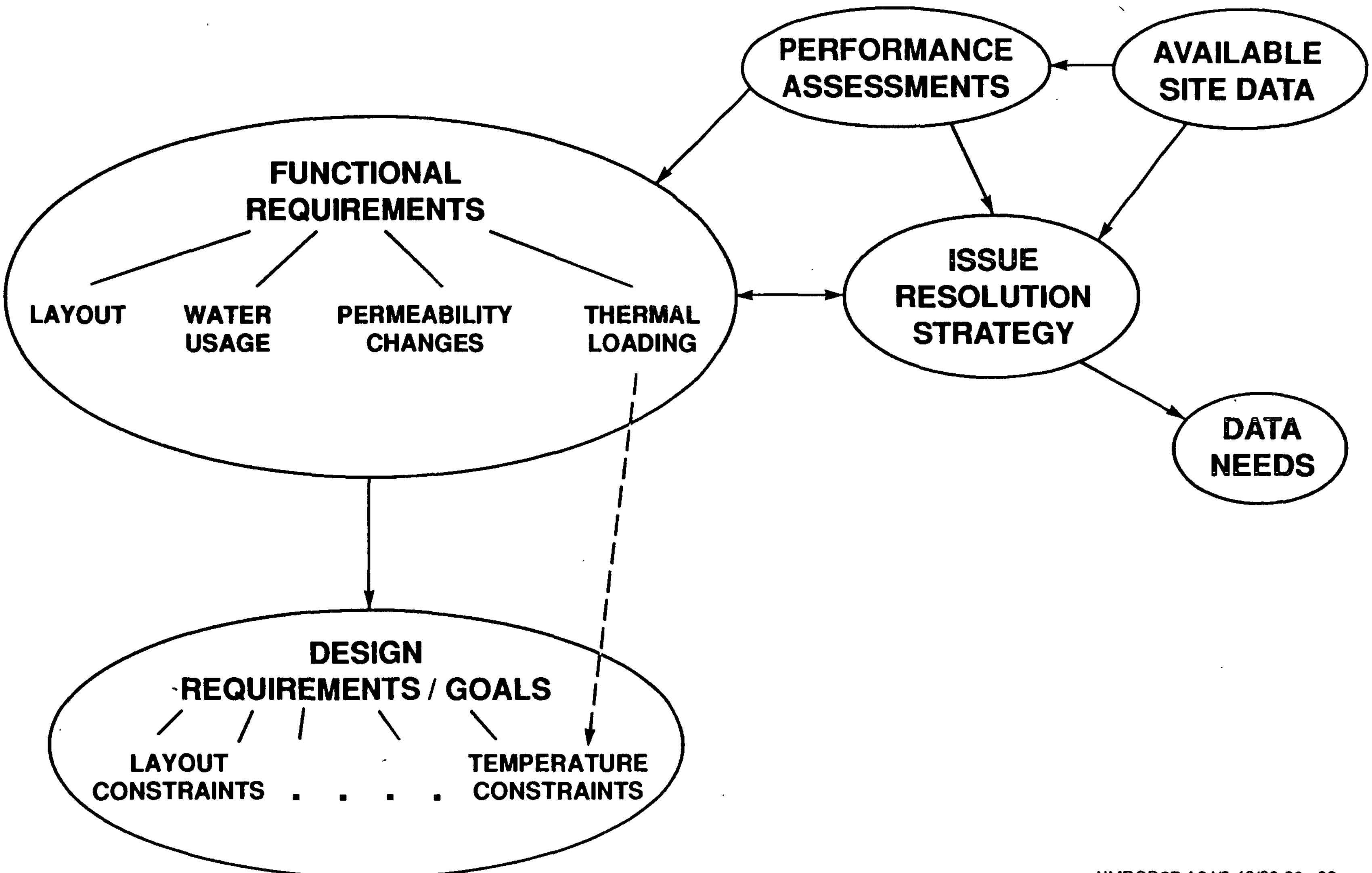
PRELIMINARY DRAWING OF REPOSITORY COMPLEX



ESF-REPOSITORY INTERFACE



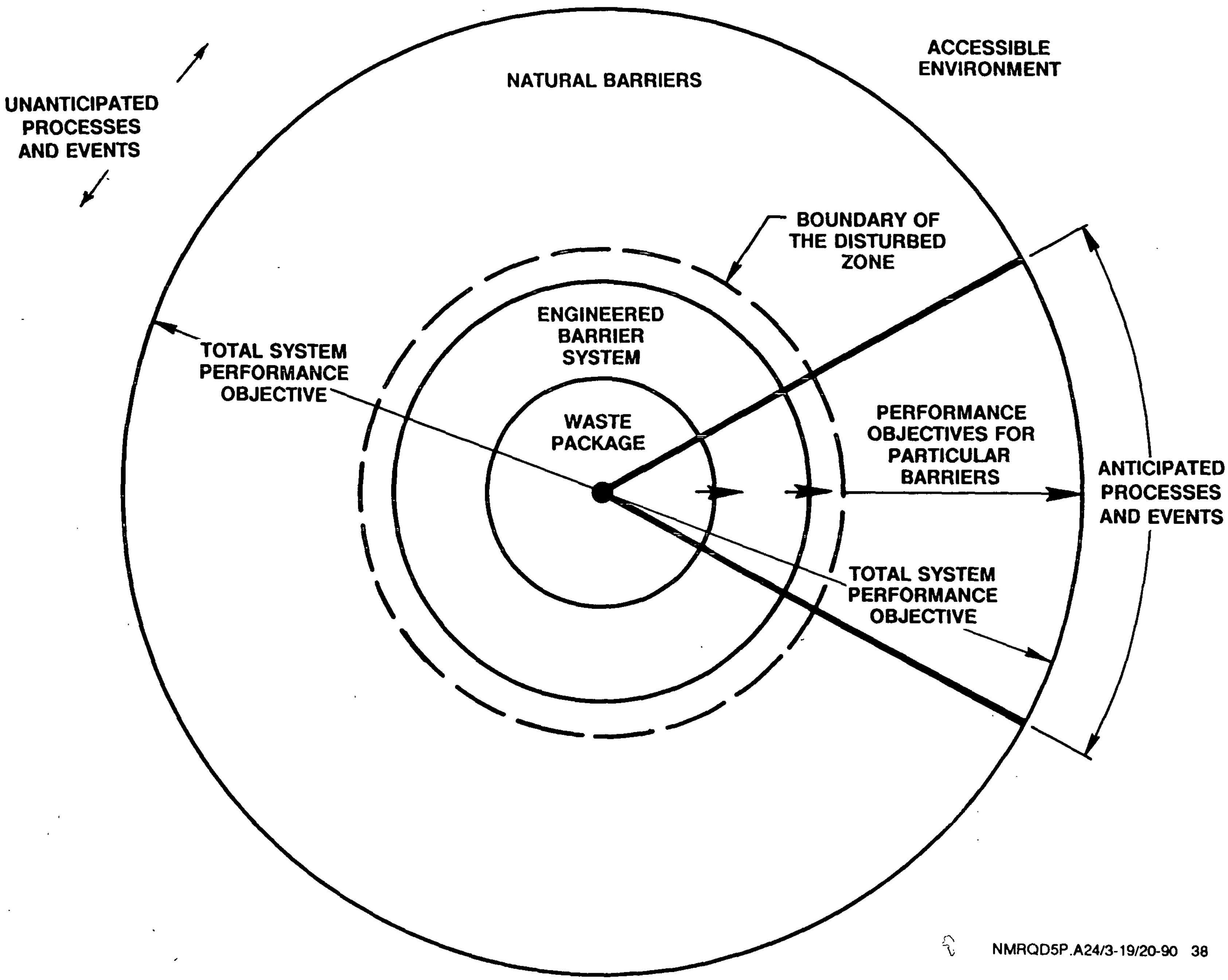
PERFORMANCE ALLOCATION FOR DESIGN GOALS



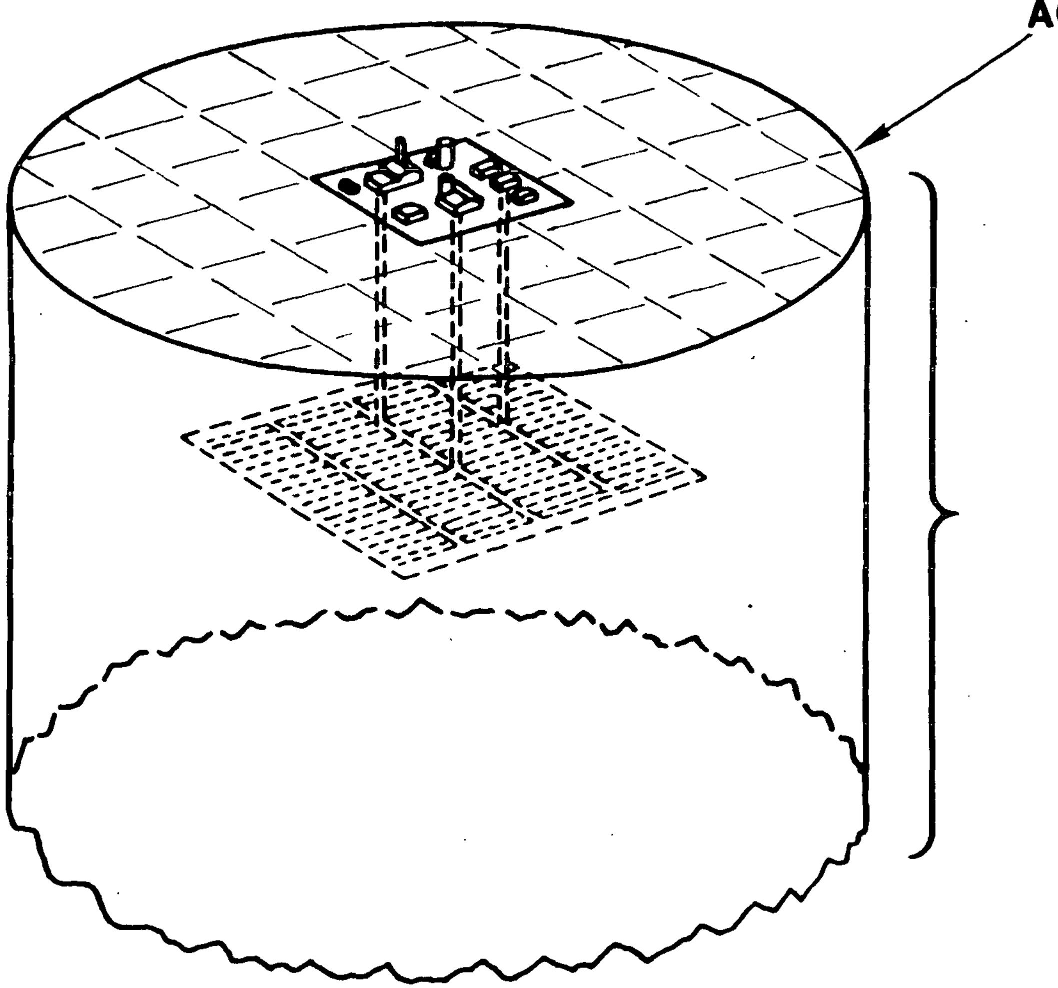
REGULATORY BASIS FOR REPOSITORY DESIGN REQUIREMENTS

- PRECLOSURE OBJECTIVES (60.111)
  - RADIATION PROTECTION - 10 CFR 20
  - RETRIEVABILITY
- FOUR POSTCLOSURE OBJECTIVES (60.112, 60.113)
- GENERAL AND ADDITIONAL DESIGN CRITERIA (60.131, 60.132, 60.133, 60.134)

PERFORMANCE OBJECTIVES



EPA STANDARD FOR RADIOACTIVE RELEASE TO THE ACCESSIBLE ENVIRONMENT



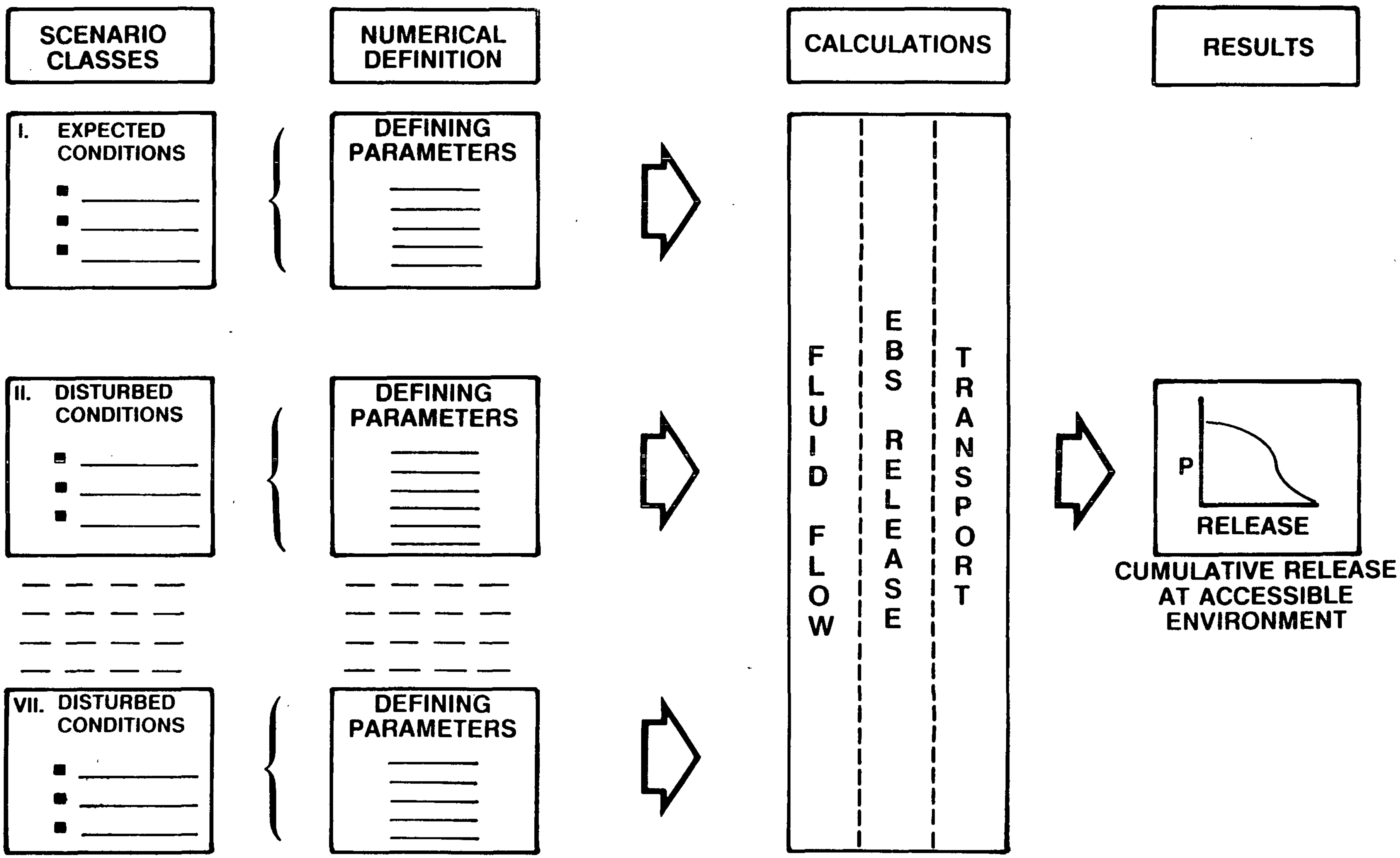
I. RADIOACTIVE RELEASE

$$\oint_{0}^{10,000} \dot{R}\, dt$$

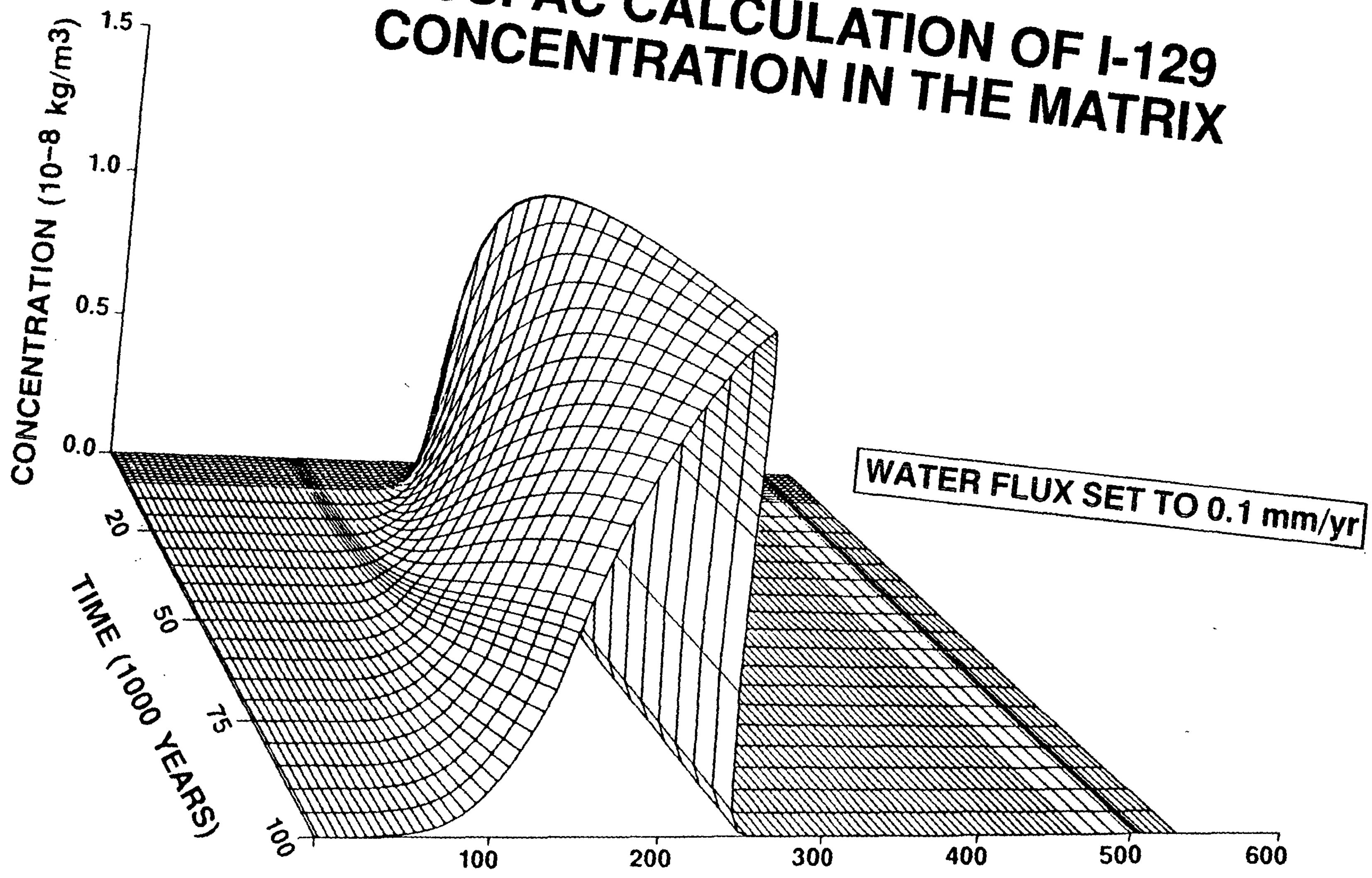
MUST BE LESS THAN THE SUM OF:

RADIONUCLIDE	CI/1000 MTHM

PROBABILISTIC ESTIMATES OF RELEASES WILL INCORPORATE MULTIPLE SCENARIO CLASSES

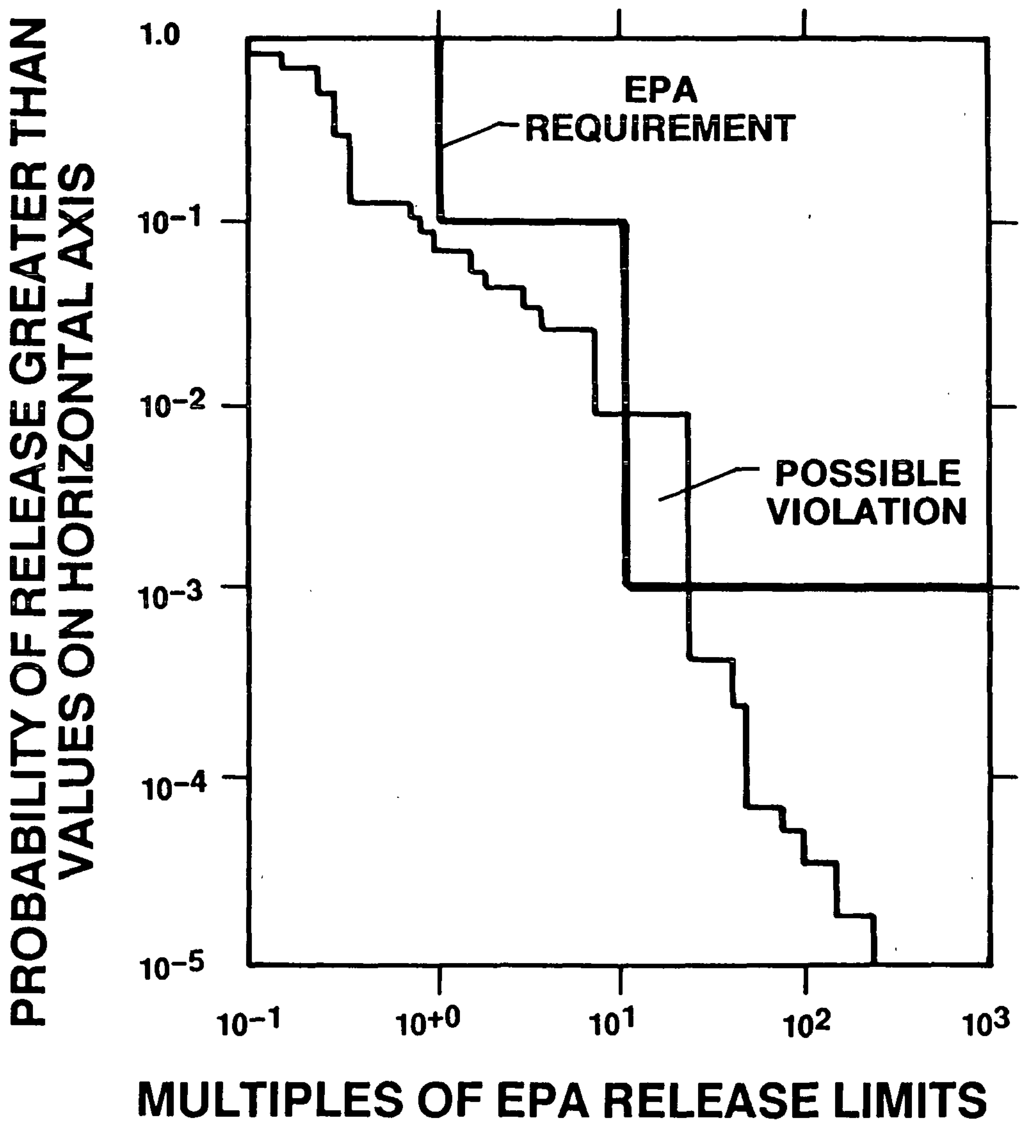


TOSPAC CALCULATION OF I-129 CONCENTRATION IN THE MATRIX

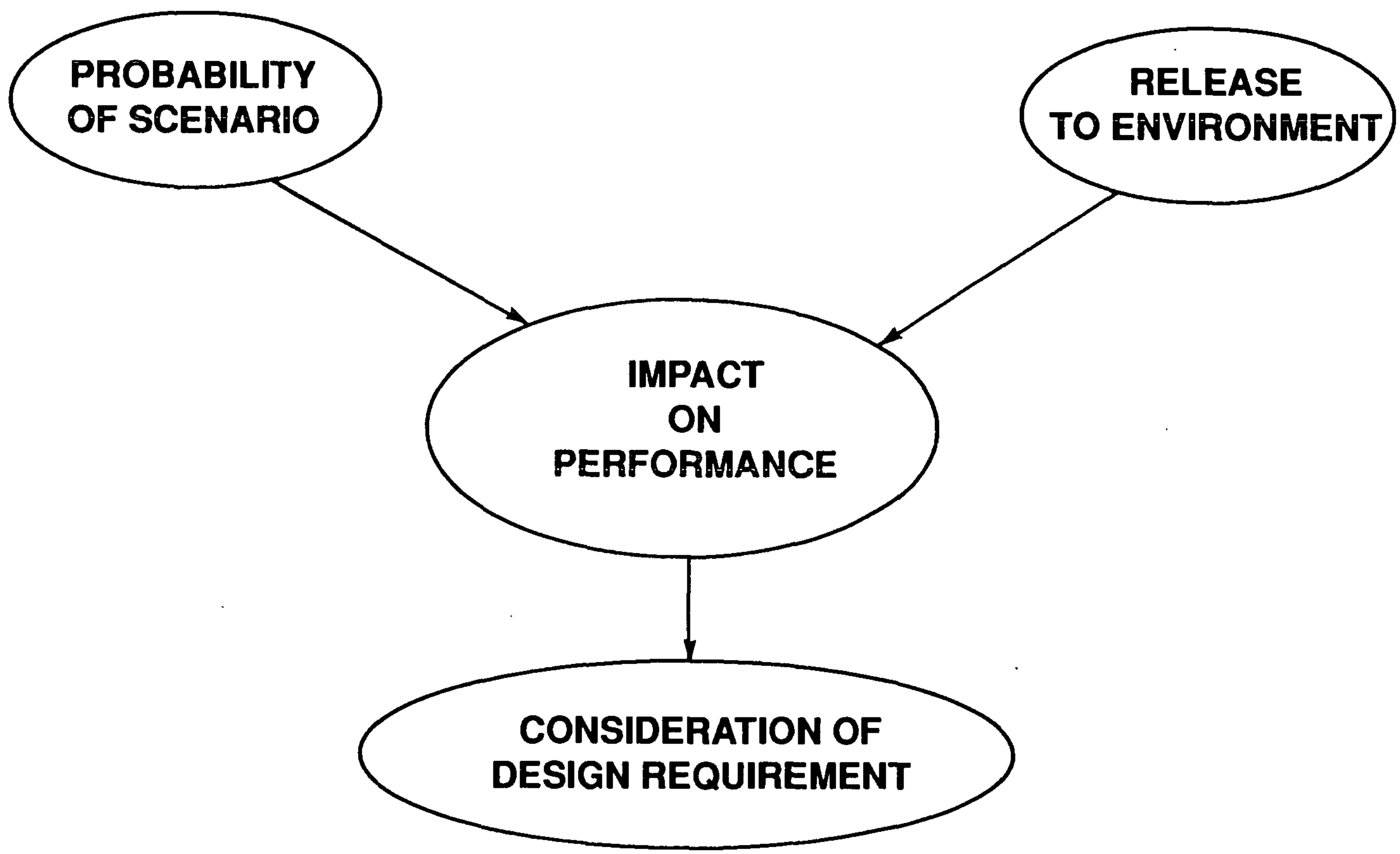


DISTANCE ABOVE WATER TABLE (m)

HYPOTHETICAL COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION



DESIGN REQUIREMENTS FROM PERFORMANCE ASSESSMENT



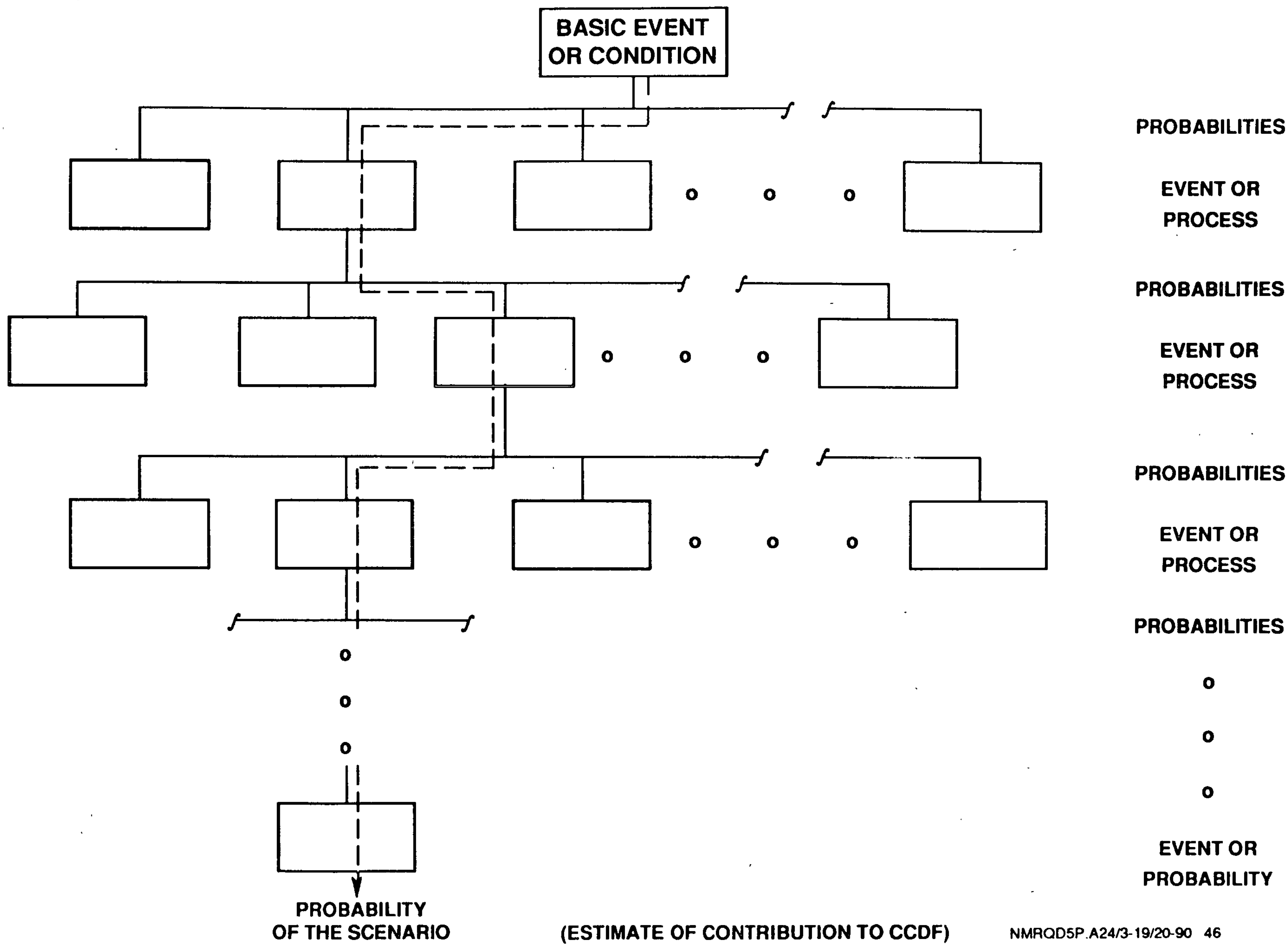
SCENARIO SELECTION

- ALL SUFFICIENTLY CREDIBLE NATURAL PROCESSES AND EVENTS
  - P> 10^{-4} IN 10,000 YEARS
  - SIGNIFICANT CONTRIBUTION TO CCDF
- HUMAN ACTIVITIES

BASIC EVENTS

- NOMINAL FLOW
- HUMAN INTRUSION
- BASALTIC VOLCANISM
- CLIMATE CHANGE
- TECTONICS
- GAS RELEASE
- OTHER HUMAN ACTIVITIES (e.g., IRRIGATION)
- CLOSURE OF REPOSITORY (SEAL FAILURE, etc.)

EVENT TREE



(ESTIMATE OF CONTRIBUTION TO CCDF)

HYPOTHETICAL SCENARIO