February 13, 1998

Dr. Leon Reiter, Staff Officer
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard, Suite 1300
Arlington, Virginia 22201

SUBJECT: REQUEST FOR INFORMATION ON THE U.S. DEPARTMENT OF ENERGY'S UNDERGROUND GEOLOGIC MAPPING PROGRAM: HANDOUTS FROM APPENDIX 7 MEETING, OCTOBER 1997

Dear Dr. Reiter:

Attached are the handouts you requested, as discussed in the memorandum from N. K. Stablein to S. J. Brocoum dated January 23, 1998, on the above subject. The handouts provided by the U.S. Department of Energy at the Appendix 7 meeting are preliminary materials, largely developed to facilitate discussions at the meeting. The agenda attached is a checklist of the handouts. The handouts attached have circled numbers that correspond to the circled numbers on the agenda. There were no handouts for two agenda items.

Please call me if you need additional information at (301) 415-6745.

Sincerely,

Original Signed By

Philip S. Justus, Sr. Geologist
Engineering and Geosciences Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosures: As stated

98-51

9803130290 980213
PDR WASTE
WM-3 PDR

DISTRIBUTION: Central File NMSS r/f ENGB r/f PUBLIC
w/o Enclosure: SWastler CGlenn LMcKague NStablein MBell

DOCUMENT NAME: S:\DWM\ENGB\PSJ\REITER.LTR

OFC	ENGB	ENGB					
NAME	PJustus:cc	DBrooks					
DATE	02/13/98	02/13/98					

OFFICIAL RECORD COPY

1/1
109.3
NL14
WM-3

NRC FILE CENTER COPY

DOE / NRC APPENDIX 7 MEETING

Plans for Geologic Mapping of Subsurface Facilities

DOE Hillshire Office, 2nd Floor Atrium Conference Room

October 16, 1997

Agenda

8:00 – 8:20	**INTRODUCTION – Brent Thomson**
8:20 – 8:30	**KEY TECHNICAL ISSUES – Mark Tynan**
8:30 – 8:50	**PREVIOUS MAPPING EFFORTS – Steve Beason**
8:50 – 9:10	**AVAILABLE REPOSITORY VOLUME – Bob Elayer**
9:10 – 9:30	**CURRENT PROPOSED SUBSURFACE FACILITY – Dan McKenzie**
9:30 – 10:00	Break
10:00 – 10:05	**MAPPING REQUIREMENTS – Brent Thomson**
10:05 – 10:20	**TECHNICAL DATA NEEDS – Brent Thomson**
10:20 – 10:30	**CONFIDENCE IN MODELING AND PREDICTIONS – Brent Thomson**
10:30 – 10:50	**RATIONALE FOR MAPPING FREQUENCY – Steve Beason**
10:50 – 11:05	**STRATEGY FOR MAPPING – Steve Beason**
11:05 – 11:35	Open Discussion, Questions and Answers
11:35 – 1:00	Lunch
1:00 – 1:15	**FRACTURE DATA USED DIRECTLY AND INDIRECTLY IN TSPA: informal discussion – Bob Andrews**
1:15 – 2:00	**USES OF FRACTURE DATA IN ESF AND REPOSITORY DESIGN – John Pye, Gerald Nieder-Westermann, Dwayne Kicker**
2:00 – 5:00	**OPEN DISCUSSION**

0a

YUCCA MOUNTAIN PROJECT

Studies

Introduction

Presented to: DOE/NRC Appendix 7 Meeting on Plans for Geologic Mapping of Subsurface Facilities

Presented by:
Brent H. Thomson
Systems Analysis and Modeling

October 16, 1997

U.S. Department of Energy
Office of Civilian
Radioactive
Waste Management

Objectives

- Provide NRC with status, plan, justification for proposed repository subsurface facilities mapping program.
- Discuss past mapping, and process leading to definition of mapping techniques selected; field visit.
- Discuss how mapping information is to be incorporated into TSPA/VA assessments.

Objectives

(continued)

- Outline mapping requirements and means expected to fulfill needs meeting those requirements.
- Provide support material and discussion of site visit to ESF to examine subsurface structural features.

Objectives
(continued)

- Establish path forward 1) to reach agreement on adequacy and sufficiency of current performance confirmation proposals for future mapping of underground facilities, and 2) to obtain NRC feedback on the adequacy and sufficiency (for intended use and purposes) of the proposed mapping approach.

Performance Confirmation Program Overview

- Site Characterization Plan Section 8.3.5.16 - December 1988
- Performance Confirmation Concepts Study Report - November 1996
- Performance Confirmation Plan - September 1997
- Mapping Strategy Developed as a Part of the Performance Confirmation Program Development

Performance Confirmation Program Overview

(continued)

- Work Performed as an Integrated Product Team consisting of Affected Organizations
  - Systems Engineering - Lead
  - Performance Assessment
  - Site Evaluation Program Operations
  - Repository Design
  - Waste Package Materials and Development
  - Environment, Safety and Regional Programs

Definition of Performance Confirmation

Performance confirmation means the program of tests, experiments, and analyses which is conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure will be met

PC Is Part of Test and Evaluation Program

Test and evaluation program will

- Perform necessary system verification throughout MGDS life cycle to validate the MGDS for receipt, handling, retrieval, disposal, and isolation of waste
- PC focuses on system verification for the isolation of waste function

PC Program Approach

Site Characte ization/License Application/Pre-Construction Phases

A — Establish Performance Confirmation Baseline → **B — Predict Performance** → **C — Establish Tolerances and Guidelines for Corrective Action** → **Interim Period Monitoring during License Application Process (Pre-Construction Authorization)**

A
- Critical performance parameters
- Key Performance Confirmation (observable) parameters
- Analytical models/processes
- Site Characterization baseline (reference)

B
- Post-closure performance of SSCs and natural setting
- Pre-closure performance of SSCs and natural setting (as indicators of post-closure performance)

C
- Parameter Expectations
- Expected Parameter Distribution and Uncertainties
- Statistically Significant Deviations
- Criteria for action if tolerances are exceeded
- Closure criteria

Construction/Operation/Caretaker Phases

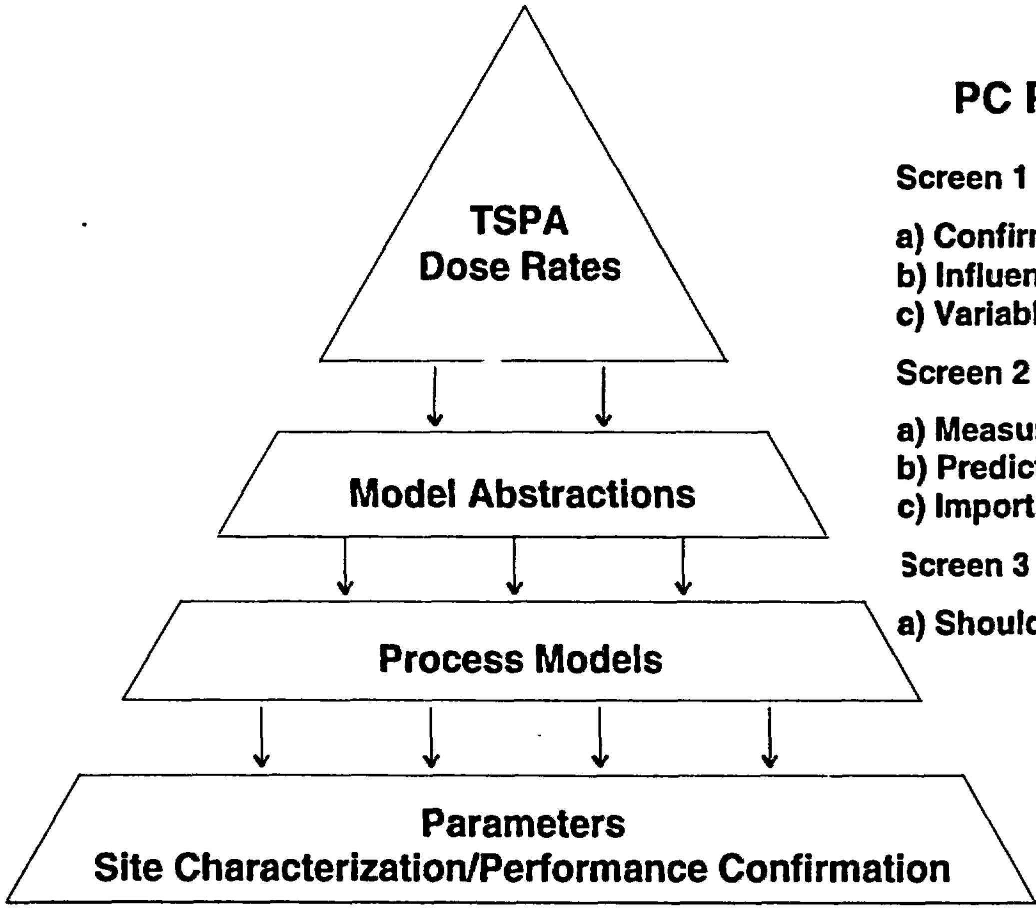
D — Monitor, Test, and Collect Data → **E — Analyze, Evaluate and Assess Data** → **F — Recommend Action**

D
- Continued monitoring and tests
- Observation drifts
- Remote measurements
- WP monitoring and tests
- Thermal measurement
- Environment monitoring
- Backfill, seal field tests
- Laboratory tests

E
- Process analysis
- Statistical tests
- Model Validation
- Total system performance assessment
- Documentation of changes
- Comparisons with predictions
- Regulatory compliance
- Assess deviations
- Closure readiness

F
- Corrective action (mode's, testing, monitoring operations)
- Continued monitoring operation
- Closure retrieve, if necessary

Identification of PC Parameters



PC Parameter Screening

Screen 1

a) Confirm subsurface conditions; or
b) Influenced by construction or emplacement; or
c) Variable that changes with time

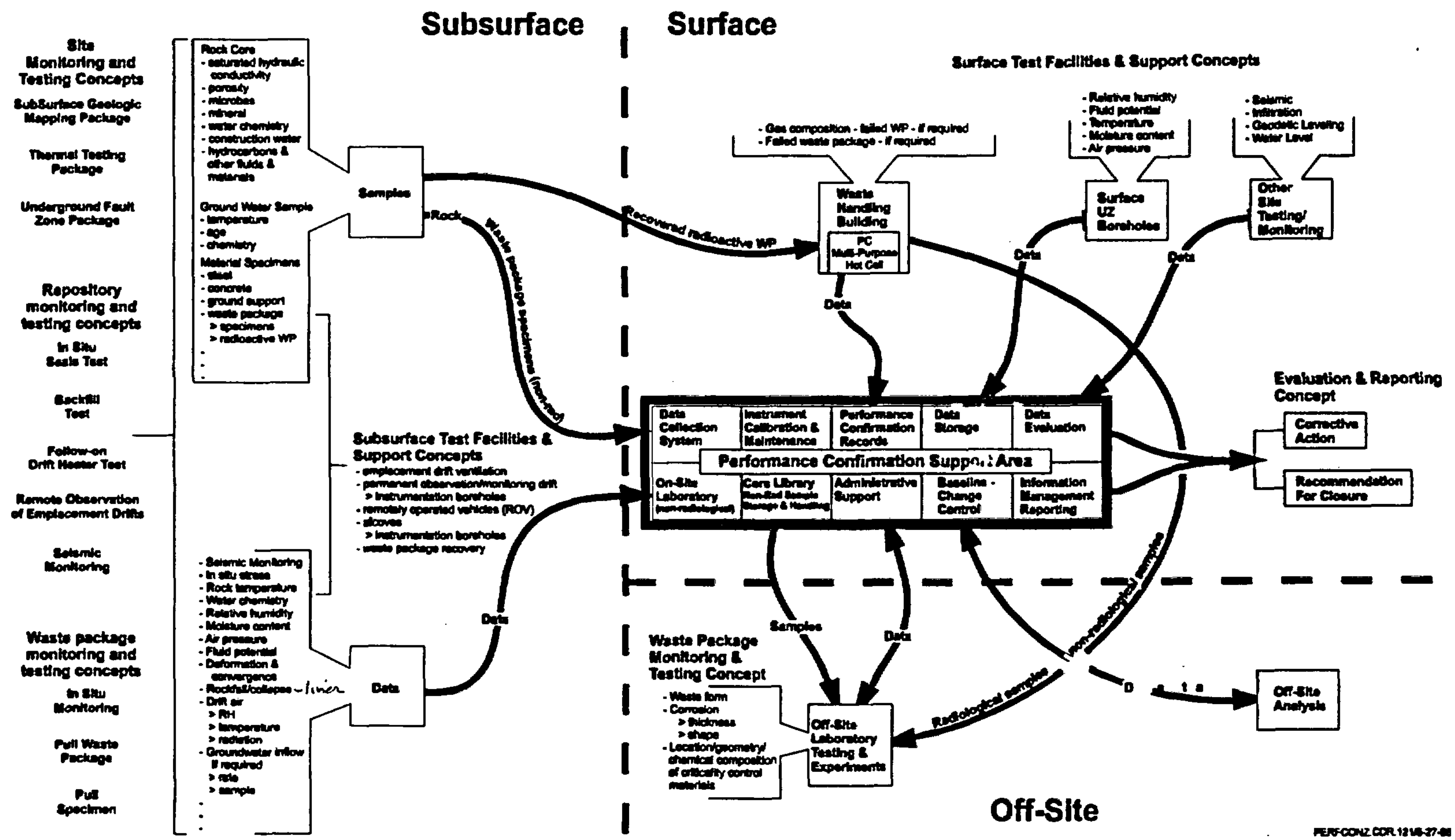
Screen 2

a) Measurable; and
b) Predictable; and
c) Important to performance

Screen 3

a) Should uncertainty be reduced

PC Concepts



Subsurface
Surface
Off-Site
Site Monitoring and Testing Concepts
SubSurface Geologic Mapping Package
Thermal Testing Package
Underground Fault Zone Package
Repository monitoring and testing concepts
In Situ Seals Test
Backfill Test
Follow-on Drift Heater Test
Remote Observation of Emplacement Drifts
Seismic Monitoring
Waste package monitoring and testing concepts
In Situ Monitoring
Pull Waste Package
Pull Specimen
Samples
Data
Subsurface Test Facilities & Support Concepts
Surface Test Facilities & Support Concepts
Waste Handling Building
PC Multi-Purpose Hot Cell
Surface UZ Boreholes
Other Site Testing/ Monitoring
Recovered radioactive WP
Performance Confirmation Support Area
Data Collection System
Instrument Calibration & Maintenance
Performance Confirmation Records
Data Storage
Data Evaluation
On-Site Laboratory
Core Library
Administrative Support
Baseline - Change Control
Information Management Reporting
Evaluation & Reporting Concept
Corrective Action
Recommendation For Closure
Waste Package Monitoring & Testing Concept
Off-Site Laboratory Testing & Experiments
Off-Site Analysis
Radiological samples
Non-radiological samples

Pd Justs

1 6

APPENDIX G
DISCUSSION ON STRATEGY FOR MAPPING

DISCUSSION ON STRATEGY FOR MAPPING

Recommended Strategy and Rationale

The recommended strategy for mapping during repository construction is to: 1) map approximately 10% of emplacement drifts, based on the current drift spacing and layout; 2) map non-emplacement drift openings; and 3) observe rock mass conditions for anomalous conditions during construction. The rationale for mapping 10% of the emplacement drifts is that the frequency of mapped drifts is selected to assure intersection of features anticipated to affect repository performance. Present surface mapping shows several faults with approximately 200 - 300 m fault trace length within the repository block. Most of these faults are expected to penetrate the host repository horizon and extend downward to the water table. The importance of these faults to repository performance is currently uncertain. A frequency of mapping approximately 10% of the emplacement drifts, at the current spacing, would provide reasonable confidence of intersecting these surface mapped features at depth. The specific locations of the mapped emplacement drifts may also depend upon observations at during construction. Also, detailed mapping of an emplacement drift near the Performance Confirmation observation drifts provides needed rock mass characterization for the thermal monitoring and testing of emplacement drifts.

Sequencing Approach

A possible approach will be discussed regarding the sequencing of mapped drifts and contingencies in case an anomalous condition is found in a mapped drift. The recommended strategy includes mapping the non-emplacement perimeter and main drifts first. Then, the approach would sequence emplacement drift construction such that the first emplacement drift is excavated and mapped, then the eleventh emplacement drift is excavated and mapped. If no anomalous conditions are encountered, then the intermediate emplacement drifts can be constructed without the need to map any drifts between the mapped drifts. If an anomalous condition is found, then provisions are made to locate and bound the extent of the anomalous condition. This includes providing for and installation of an alternative ground support system that would allow mapping and characterization, if necessary, in adjacent drifts where the feature is expected to be located. This provision would be continued until the anomalous condition is no longer found and is bounded. When the drifting of the panel between the mapped drifts is complete, then the panel of drifts is released for emplacement of waste.

The next panel of drifts would proceed similarly, e.g., map the twenty-first drift: if OK, the emplacement drift between the eleventh and the twenty-first can be constructed without mapping, etc. Also, any observation drifts or cross-block ventilation drifts near the panel of drifts should be used as mapped drifts to bound the panel.

Current Concerns Regarding Observations During Construction

There are concerns about the ability to observe rock mass conditions during construction with the tunnel boring machine and precast concrete segment lining system that are envisioned for the emplacement drifts. With this strategy, a modified tunnel boring machine is needed which allows the observation of the rock mass during construction for anomalous conditions. The preferred tunnel boring machine for installation of a precast concrete lining would have a shield that covers about 270 degrees of the drift with only the invert area open. This tunnel boring machine design would provide support to the rock mass and allow installation of the precast segments for nearly all expected conditions. Observation of only the invert area is inadequate. There is too much smear and dust in the invert to be able to determine if anomalous rock mass conditions exist. But, it may not be necessary to see above the springline to get this information. The tunnel boring machine shield would need to provide some support below the springline and with an approximately 210-degree shield, most expected ground conditions would be accommodated and the precast segments could be installed. Approximately 150 degrees of viewing should be sufficient to determine if anomalous rock mass conditions exist. The type of anomalous conditions that would be of concern or would lead to mapping in the adjacent drifts includes: active flow of water, evidence of weathering or oxidation, thick fracture coating/minerals, evidence of hydrothermal alteration, and mineral resources.

With this approach, it appears that there is a capability to observe rock mass conditions during construction and have a tunnel boring machine that can efficiently emplace precast concrete linings in most expected ground conditions. In areas where anomalous conditions exist, the tunnel boring machine should also have the capability to change to an alternative ground support system to allow access/viewing/testing of this area. A steel ring support system, or rockbolts and mesh with installation of a heavy invert segment would allow the tunnel boring machine to push off the alternative ground support system in a fashion similar to the precast concrete segments. After viewing/testing is complete, a cast-in-place lining could be installed in the open area.

There are still a number of concerns and details that remain to be resolved to implement this strategy. One concern regards the ability to switch between precast segments and steel sets with cast-in-place concrete lining. In the current design, there is a potential mismatch of sizes. Recent drawings in design review show the minimum excavated diameter of an emplacement drift lined with precast segments to be 5550 mm, and for one containing steel sets and cast-in-place concrete lining to be 5650 mm. These dimensions are for the same inside diameter of 5100 mm. To use the same tunnel boring machine for both support systems requires using the same excavated diameter. Doing so, with the current configuration, results in different inside diameters, which may be acceptable. Maintaining the same inside diameters would require using thicker precast segments. Currently, there is no mismatch with rockbolts and cast-in-place concrete because the cast-in-place lining can be made thinner, but then there is a concern of what the tunnel boring machine pushes off. Having the tunnel boring machine push off of the alternative support system (mostly the precast invert section) can easily cause tunnel boring machine steering problems, and therefore use of this method would be limited to short distances or development of alternative features.

Purpose and Scope

The purpose of this discussion is to develop a recommended strategy for repository subsurface mapping during construction and provide the rationale for the recommendation. The scope of this discussion covers the translation of system level, regulatory requirements related to mapping and of derived requirements from reports or analyses into specific technical data needs. A technical evaluation of the data-needs is covered, and evaluations of criteria important to the mapping strategy are included.

Background

The extent of geologic mapping of emplacement drift wall surfaces required for performance confirmation activities or for other reasons could significantly impact the design and emplacement method of the emplacement drift ground support system. The preferred ground support system for emplacement drifts is a precast concrete lining. This lining is most economically emplaced immediately after the drift is excavated, allowing essentially no time for geological mapping of the drift walls. If a large portion of the drift wall must be mapped, then the advantage of this type of ground support system is reduced and the overall cost of the ground support system could be significantly increased.

A brief description of the terminology for mapping and observations which are used in this discussion is provided below. **Mapping** provides a record of encountered conditions and features for subsurface excavations; provides a database for design, for stability analysis, for confirmation of geotechnical predictions, and for maintenance and monitoring; and a permanent record of construction; per the American Society for Testing and Materials (ASTM) D 4879 - *Standard Guide for Geotechnical Mapping of Large Underground Openings in Rock* (ASTM 1991). Some examples of mapping are full periphery maps, detailed line surveys, and photogrammetry. **Observations** are conducted to provide documentation by qualified personnel to describe characteristics of the rock mass and record anomalous conditions as excavation progresses and to identify reportable geologic conditions. This is typically done by stationing a geologist at the TBM, and often photogrammetry is used to supplement records.

Reference Design and Assumptions

The reference ground support system design is a precast concrete lining in 90% of emplacement drifts, consistent with the mapping strategy. An initial, temporary, support plus cast-in-place concrete lining are used in the remaining 10% of emplacement drifts and in all non-emplacement drifts. There are currently two alternative designs for the ground support system. The first design alternative is a two-pass system with an initial support system consisting of appropriate combinations of steel sets, steel lagging, rock bolts, and welded wire fabric followed by a cast-in-place concrete lining system. This alternative could be used if 100% of the drifts were to be mapped. The second design alternative is a non-concrete alternative. It consists of steel sets, welded wire fabric, and steel lagging. It is assumed that rock samples can be obtained regardless of ground support system installed.

Requirements and Current Regulatory Position

The *Repository Design Requirements Document* (DOE 1994c) is the source of the following requirements related to mapping.

3.4.6 CONSTRUCTION RECORDS

B. Construction records for the GROA shall be prepared and maintained in accordance with 10 CFR 60.72(b) and Section 3.4.5 (of the *Repository Design Requirements Document*) to ensure useability for future generations. The required records include as a minimum, the following:

2. A description of the materials encountered.
3. Geologic maps and geologic cross-sections.
4. Locations and amount of seepage.
5. Details of equipment, methods, progress, and sequence of work.
6. Construction problems.
7. Anomalous conditions encountered.

[MGDS-RD 3.4.6][10 CFR 60.72(a) and (b)]

3.7.6 PERFORMANCE CONFIRMATION REQUIREMENTS

A. General Requirements.

4. The performance confirmation program shall provide data that indicates, where practical, whether:
   a) Actual underground conditions encountered and changes in those conditions during construction and waste emplacement operations are within limits assumed in the licensing review; and
   b) Natural and engineered systems and components required for repository operation, or that are designed or assumed to operate as barriers after permanent closure, are functioning as intended and anticipated.

   [MGDS-RD 3.7.2.7.A.3][10 CFR 60.140(a)]

The current regulatory position on mapping is that the regulations and existing regulatory guides provide limited guidance about level of detail necessary to satisfy requirements. The regulation calls for geologic maps and cross sections, but provides no guidance on the extent of the coverage and level of detail as to scale of the maps. Based on a review of Yucca Mountain Project communications, the project has made no commitments to NRC related to mapping of the repository. The Yucca Mountain Project should establish a position on the appropriate level of detail needed to satisfy performance confirmation requirements, construction records requirements, and design confirmation needs. Once this position is determined, the Yucca Mountain Project should initiate discussions with NRC on the level of detail needed to satisfy regulatory requirements (Younker, et al. 1997).

Technical Data-Needs

The above regulatory requirements lead to several technical data-needs. The identification of Performance Confirmation parameter data-needs, related to mapping, is documented in the *Performance Confirmation Concepts Study Report* (CRWMS M&O 1996f) and earlier in this *Performance Confirmation Plan*. Data-needs related to repository design confirmation are derived from the *Repository Design Data Needs* (CRWMS M&O 1995d) document and the assumption that this data stated as needed for the ESF will also be needed for the repository. The data-needs for construction records are used directly from the above requirement.

Performance Confirmation Parameter Data-Needs

Stratigraphy

Location and Characteristics of Faults and Fault Zones

Location and Characteristics of Fractures and Fracture Zones
Location of Fracture Infillings and Chemical, Mineralogical, and Biological Characteristics
Location and Characteristics of Seeps
Confirm Absence of Hydrocarbons and Mineral Resources

Repository Design Confirmation Data-Needs
Rock Mass Quality

Construction Records Data-Needs
Description of the Materials Encountered
Geologic Maps and Geologic Cross-Sections
Location and Characteristics of Seeps
Details of Equipment, Methods, Progress, and Sequence of Work
Construction Problems
Anomalous Conditions Encountered

Each of these data-needs is discussed in additional detail below. For the performance confirmation parameter data-needs, the current confidence in the data is qualitatively estimated. The use and importance of the data to repository design and performance assessment and process level model is discussed. Finally, the amount of additional data needed through mapping and/or observations is discussed. The repository design confirmation data-needs are covered by the performance confirmation parameter data-needs. All construction record data-needs are addressed as a whole category of information.

Stratigraphy

The current level of confidence in data related to stratigraphy is high, except in the southwest quadrant of the repository block. The importance of stratigraphy for design is that it bounds the vertical volume of rock available for the potential repository within the Topopah Spring thermal/mechanical unit with respect to the needed rock stability. Other stratigraphy related information that is used to limit the design are the minimum of 200 m overburden required by 10 CFR Part 960, and the assumed minimum of 100 m to the water table. The importance of the stratigraphy to the Performance Assessment and Process Modeling is that it defines geometric extent of applicable rock properties for thermal-hydrological and radionuclide transport analyses. The additional data needed for performance confirmation related to stratigraphy can be accommodated by mapping and sampling the non-emplacement drift openings in the reference repository layout. Observations during construction ensure there are no anomalous conditions related to the stratigraphy or indicate when additional mapping is necessary.

Faults and Fault Zones

There is moderate confidence in the faults and fault zones' locations and characteristics, but specific underground locations and the hydrologic importance of faults are uncertain. The importance of faults and fault zones for the design is that they bound the volume of rock available for the potential repository within Topopah Spring in horizontal direction, assuming a standoff of 120 m from the Ghost Dance fault and 60 m from other major faults; smaller faults with trace lengths of approximately 200 - 300 m are expected, but are not currently considered to impact design. The importance of faults and fault zones to Performance Assessment and Process Modeling, including fluid flow and radionuclide transport, is not yet known. Currently, only location and vertical offset of major faults and some pneumatic properties are considered, but not their thermal-hydrological and radionuclide transport properties. Their importance to postclosure performance will depend on the extent of the lateral diversion of flow within hydrogeologic units, which is being investigated now.

A summary of the unsaturated zone flow model relative to faults is provided below and is based on *The Site-Scale Unsaturated Zone Model of Yucca Mountain, Nevada, For the Viability Assessment* (LBNL 1997b). For flow above the repository, most of the fast path flow through the PTn unit is associated with structural features such as faults or fault-associated fractures that cross the various geologic formations comprising the PTn. Related to the percolation flux at the repository, analyses of borehole temperature data provide percolation rate estimates. Many of the high percolation flux estimates are obtained from boreholes that are located near faults. For flow below the repository, flow that encounters a generally eastward-dipping perched layer will be laterally diverted. The diversion continues until the water table is reached or until a fault or an extensive fracture system is encountered that can reinitiate mostly downward vertical flow. The above summary of the unsaturated zone flow model relative to faults is based on the available fault properties. The current fault properties are derived primarily from pneumatic data from the testing of the North Ghost Dance Fault Alcove. Gas permeabilities are on the order of hundreds of darcies and there are significant lateral variations in permeability within fault zones. Additional data on fault properties and processes are needed. Some additional data may be derived from the Enhanced Characterization of the Repository Block effort, which proposed testing in the Solitario Canyon fault. Also, long term fault zone hydrology monitoring and testing are included in this *Performance Confirmation Plan*.

Present surface mapping shows several faults with an approximately 200 - 300 m fault trace length within the repository block. These faults have a predominant north-south orientation. Most faults are expected to penetrate the host repository horizon and extend downward to the water table, and may be large enough to have an influence on repository performance or are candidates for detailed consideration. This evidence and the current uncertainty in the fault and fault zones importance to postclosure performance conservatively leads to a spacing of mapped drifts that would provide a reasonable confidence that these features would be located at the repository horizon and their fault characteristics (width, length, orientation, and displacement) would be established. Mapping all non-emplacement drift openings will provide additional information on some faults. In particular, mapping of the perimeter drifts, the West Main and Exhaust Main, provides an approximate 600 m spacing between mapped drifts. These drifts generally run in the north-south direction nearly parallel to the predominant fault orientation. Mapping of the three non-emplacement ventilation drifts and the five Performance Confirmation observation drifts, based on the current layout, leads to an approximate 600 m spacing in the direction of the emplacement drifts. The emplacement drifts run approximately in an east-west direction. In order to provide a reasonable likelihood that these approximate 200 - 300 m features are mapped, the frequency of mapped emplacement drifts should be on the order of about 300 m. A mapped emplacement drift frequency of approximately once every tenth drift will lead to this spacing given the current repository layout. The specific locations of which emplacement drifts are mapped may also depend upon the observations during construction. It is noted that a reduced frequency of mapped drifts may be possible depending upon the combined coverage of both the mapped non-emplacement drifts and the mapped emplacement drifts.

Fractures and Fracture Zones

Concerning the fractures and fracture zones, there is high confidence in the data near the ESF, but low confidence away from the ESF. Statistics on fractures characteristics are important. Also, the location and characteristics of fracture zones are important. As far as the fracture and fracture zone importance to design, for the ESF, their characteristics were considered in terms of rock stability through the Rock Mass Quality parameter. This parameter was used to evaluate ground support requirements. The information for the potential repository will be extrapolated from the ESF data and needs to be confirmed. For Performance Assessment and Process Modeling, detailed fracture characteristics are currently not used directly, but are considered in terms of equivalent rock matrix properties (e.g., porosity and hydraulic conductivity) which are derived from model calibrations against other data (e.g., measured moisture contents). Detailed fracture information near the instrumented emplacement drifts is needed in full-scale thermal monitoring. The mapping of the non-emplacement drift openings should provide adequate coverage for confirmation of the fracture statistics. Detailed mapping of an emplacement drift, including fracture parameters, provides the needed rock mass characterization for thermal monitoring and testing of emplacement drifts near Performance Confirmation observation drifts. At least one emplacement drift should be mapped near each Performance Confirmation observation drift.

Chemical/Mineralogical and Biological Characteristics of Fracture Infillings

There is high confidence in the ESF on chemical/mineralogical and biological characteristics of fracture infillings, but low confidence away from the ESF. These parameters are currently not considered in the design, because they have no direct impact on the excavation stability. For Performance Assessment and Process Modeling, chemical/mineralogical and biological characteristics of fracture infillings are considered in geochemical and waste package performance testing as a basis for waste package corrosion model development. The characteristics of fracture infillings may also influence fluid flow and radionuclide transport, but are not yet considered explicitly in performance assessments. This data will be collected through the observation of rock mass conditions during construction. If anomalous conditions are observed, then the location will be documented, samples will be taken, and investigation will be conducted.

Locations and Characteristics of Seeps

For the locations and characteristics of seeps, there is low confidence everywhere, including in the ESF. For design the location and characteristic of seeps are considered only as a contingency with respect to water removal from repository to the surface. For Performance Assessment and Process Modeling, seeps are considered in waste package material degradation (i.e., corrosion) and waste form dissolution modeling with respect to potential postclosure performance, without knowledge of actual locations and local variations in seepage rates. The determination of location and characteristics of seeps will be collected through the observation of rock mass conditions during construction. If anomalous conditions are observed, then the location will be documented, samples will be taken, and investigation will be conducted.

Hydrocarbons and Mineral Resources

With regard to hydrocarbons and mineral resources, there is high confidence everywhere of the absence of these resources. These parameters are not considered in current design or performance assessment, but the occurrence of hydrocarbons and mineral resources of economic value would be a site disqualifier per 10 CFR 960.4-8-2-1(d)(2) or a potentially adverse condition per 10 CFR 60.122(c)(17). Confirmation of the absence is needed and will be accommodated through the observation of rock mass conditions during construction. If anomalous conditions are observed, then the location will be documented, samples will be taken, and investigation will be conducted.

Construction Records

The data needs related to a description of the materials encountered; details of equipment, methods, progress, and sequence of work; construction problems; and anomalous conditions encountered will be accommodated through the observation of rock mass conditions during construction. The data-need related to location and characteristics of seeps was addressed as a performance confirmation data-need above. Geologic maps and geologic cross-sections will be supplemented with information developed from the mapped drifts.

Mapping Options

In developing the strategy for mapping the emplacement drifts, several options for mapping were considered and evaluated. The emplacement drift mapping options considered are:

1) Map non-emplacement drifts only; or
2) Map 10% of emplacement drifts (at present drift spacing)[1]; or
3) Map all emplacement drifts.

Each mapping option also includes mapping of non-emplacement drift openings and observation of rock mass conditions during construction. The rationale for option one is that it is the minimum possible amount of mapping of the emplacement drifts. This option should have the least impact on the preferred ground support design for emplacement drifts. The rationale for option two, mapping 10% of the emplacement drifts, is that the frequency of mapped drifts is selected to assure intersection of features that are anticipated to affect repository performance. Present surface mapping shows several faults with approximately 200 - 300 m fault trace length within the repository block. Most faults are expected to penetrate the host repository horizon and extend downward to the wate table. And, the importance of these faults to repository performance is currently uncertain. A frequency of mapping approximately 10% of the emplacement drifts, at the current spacing, would

[1]The option "10% of emplacement drifts" includes any drift in the repository layout that would yield the appropriate frequency of mapped drifts and does not mean that only emplacement drifts should be included. The cross-block ventilation drifts and performance confirmation observations drifts should be included if they are located at the proper frequency.

provide a reasonable confidence of intersecting any of the surface mapped features at depth. Also, detailed mapping of an emplacement drift near the Performance Confirmation observation drifts provides for rock mass characterization for thermal monitoring and testing of emplacement drifts. The rationale for option three is that it is the maximum possible amount of mapping of the emplacement drifts. This option would have the least regulatory risk, regarding regulatory requirements on construction records and mapping for performance confirmation, since all drifts would be mapped.

Evaluation Criteria

The evaluation criteria that will be used to compare the mapping options described above include: the technical criterion of adequacy to meet data-needs; and the programmatic criteria of cost, schedule, regulatory risk, and impacts on design. These evaluations are later assessed to develop some conclusions and provide the overall recommendation for the mapping strategy.

Evaluation of Adequacy of Mapping Options to Meet Technical Data-Needs

This evaluation compares the above identified technical data-needs with the capabilities of each mapping option. For option one, Map Non-Emplacement Drifts Only, unless the size of important features is on the order of 600 m or greater and the need for rock mass characterization of emplacement drifts is later determined to be unnecessary, this option does not meet all the technical data-needs identified. For option two, Map 10% of Emplacement Drifts, this option meets all the technical data-needs identified unless the size of important features is less than 300 m. For option three, Map All Emplacement Drifts, all technical data-needs will be met.

Cost Evaluation of Mapping Options

This evaluation identifies option two as the reference cost and then provides an evaluation of the incremental cost differences to employ the other options. The cost for mapping and sampling is $35 M for the reference design (CRWMS 1997p) which is consistent with option two described above. This reference cost estimate is based on using the reference ground support design, but the lining cost is not included. These costs occur in the years 2004 - 2030. This evaluation has also developed a rough order of magnitude (ROM) estimate for the incremental cost of changing to option one or three.

For option one, Map Non-Emplacement Drifts Only, the estimate is a reduction of $20 M ROM in the years 2010-2030. Most of the cost is due to the change in ground support, from cast-in-place to precast in 10% of the emplacement drifts. The cost for option three, Map All Emplacement Drifts, is an increase of $180 M ROM in the years 2010-2030. Most of the cost is change in ground support from precast to cast-in-place in 90% of the emplacement drifts.

Schedule Evaluation of Mapping Options

This evaluation considers both impacts to the schedule for construction and emplacement of the waste and complexity of the construction logistics. None of the options is expected to influence the ability to meet the overall schedule, but only impact the complexity of the construction logistics. For the repository block which are important to performance. A conservative approach is to assure the ability to map these features in the design until the time that the uncertainty is resolved. For these reasons, option one is concluded to be less favorable and it is not recommended at this time considering this criterion and the current evaluation.

The cost difference, between options two and three, is significant and should be weighed in a decision between these options. The schedule criterion does not appear to be key discriminator between the options and the impacts on construction logistics are manageable. The regulatory risk evaluations for options two and three compare a low risk option vs. a no risk option. Finally, in considering the design impact between options two and three, precluding the preferred ground support option for design is a significant adverse impact for design and construction. In conclusion, option three is a significant cost increase and impact on design to reduce the regulatory risk from a low value to none. Thus, option two, Map 10% of Emplacement Drifts, is recommended, based on the above conclusions.

The recommended strategy for mapping during repository construction is to: 1) map approximately 10% of emplacement drifts, based on the current drift spacing and layout; 2) map non-emplacement drift openings; and 3) observe rock mass conditions during construction. The rationale for mapping 10% of the emplacement drifts is that the frequency of mapped drifts is selected to assure intersection of features anticipated to affect repository performance. Present surface mapping shows several faults with approximately 200 - 300 m fault trace length within the repository block. Most of these faults are expected to penetrate the host repository horizon and extend downward to the water table. The importance of these faults to repository performance is currently uncertain. A frequency of mapping approximately 10% of the emplacement drifts, at the current spacing, would provide reasonable confidence of intersecting these surface mapped features at depth. The specific locations of the mapped emplacement drifts may also depend upon observations during construction. Also, detailed mapping of an emplacement drift near the Performance Confirmation observation drifts provides needed rock mass characterization for the thermal monitoring and testing of emplacement drifts.

It is also recommended that discussions be conducted with the NRC on the mapping strategy and its rationale to reduce the uncertainty in the regulatory risk of the option selected. It is recommended that work be conducted to develop a position on the size and/or characteristics of features which will potentially impact repository performance. After the conduct of the Enhanced Characterization of the Repository Block effort, it is recommended that this discussion be reviewed and updated as necessary.

3a

YUCCA MOUNTAIN PROJECT

Studies

Previous Mapping Efforts

Presented to:
Nuclear Regulatory Commission
Appendix 7 Meetings

Presented by:
Steven C. Beason, USBR
Principal Investigator

October 16, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Previous Mapping Efforts

- Surface Geologic Mapping (Day and others)
- Pavement and Outcrop Fracture Studies (Sweetkind and others)
- Borehole studies (Rautman, Buesch, Brechtel)
- ESF Geologic Mapping

ESF Mapping Requirements

- SCP Requirements
  - Full-periphery geologic mapping
  - Detailed Line Surveys
  - Photography
  - Sampling

ESF Mapping Requirements

- User Requirements
  - Design Requests
    - » Collect and tabulate RQD, Q, and RMR
    - » Generalized cross-section along centerline
    - » Ground support type and locations
    - » Advance rates
  - CMO Requests
    - » Ground Support
    - » Instrumentation Locations

ESF Mapping Requirements

- User Requirements
  - Project Office Requests
    - » Sample Locations on Full-periphery maps

- Requests from Other PIs
  - Add cooling joint classifications
  - Mineral Infilling as a Category

ESF Mapping Techniques

- Full-periphery geologic maps
- Detailed line surveys
- Stereophotography
- Consolidated Sampling (discontinued 9/95)

ESF Mapping Techniques

- Full-periphery geologic maps
  - Discontinuities > 1 m in length are mapped
  - Noteworthy geologic features are mapped and described (fault zones, breccias, etc.) fluorite infillings/dissolution
  - "Q" ground support is mapped
  - A generalized cross-section is developed along centerline

ESF Mapping Techniques

- Detailed Line Surveys =DLS
- Tapeline on right wall ~1 m below springline
- All discontinuities longer than 1 m are documented
- 19 Attributes are described for each feature

Station	Width	Aperture (max).
Type	Ends	Offset
Azimuth	Upper Termination	Infilling Type
Dip	Lower Termination	Infilling thickness
Trace Length above tape	Planarity	Comments
Trace Length below tape	Joint Alteration Number	
Height	Aperture (min.)	

Current Level of Confidence
(continued)

- Chemical/Mineralogical and Biological Characteristics of Fracture Infillings - High Confidence in ESF, Lower Confidence Away from ESF
- Locations and Characteristics of Seeps - Moderate Confidence Everywhere, Including in ESF
- Confirm Absence of Hydrocarbons and Mineral Resources - Moderate to High Confidence Everywhere

Expected Level of Confidence at LA After the Enhanced Characterization of the Repository Block Activities

- Stratigraphy - High Confidence
- Faults and Fault Zones - High Confidence for Major Faults and Moderate Confidence for Minor Faults in Repository Block
- Fractures and Fracture Zones - High Confidence

Expected Level of Confidence at LA After the Enhanced Characterization of the Repository Block Activities
(continued)

- Chemical/Mineralogical and Biological Characteristics of Fracture Infillings - High Confidence
- Locations and Characteristics of Seeps - High Confidence
- Confirm Absence of Hydrocarbons and Mineral Resources - High Confidence

9/10

YUCCA MOUNTAIN PROJECT

Studies

Rationale for Mapping Frequency

Presented to:
Nuclear Regulatory Commission
Appendix 7 Meetings

Presented by:
Steven Beason, C. USBR
Principal Investigator

October 16, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

YUCCA MOUNTAIN PROJECT

Studies

Strategy for Mapping

Presented to:
Nuclear Regulatory Commission
Appendix 7 Meetings

Presented by:
Steven Beason, C. USBR
Principal Investigator

October 16, 1997

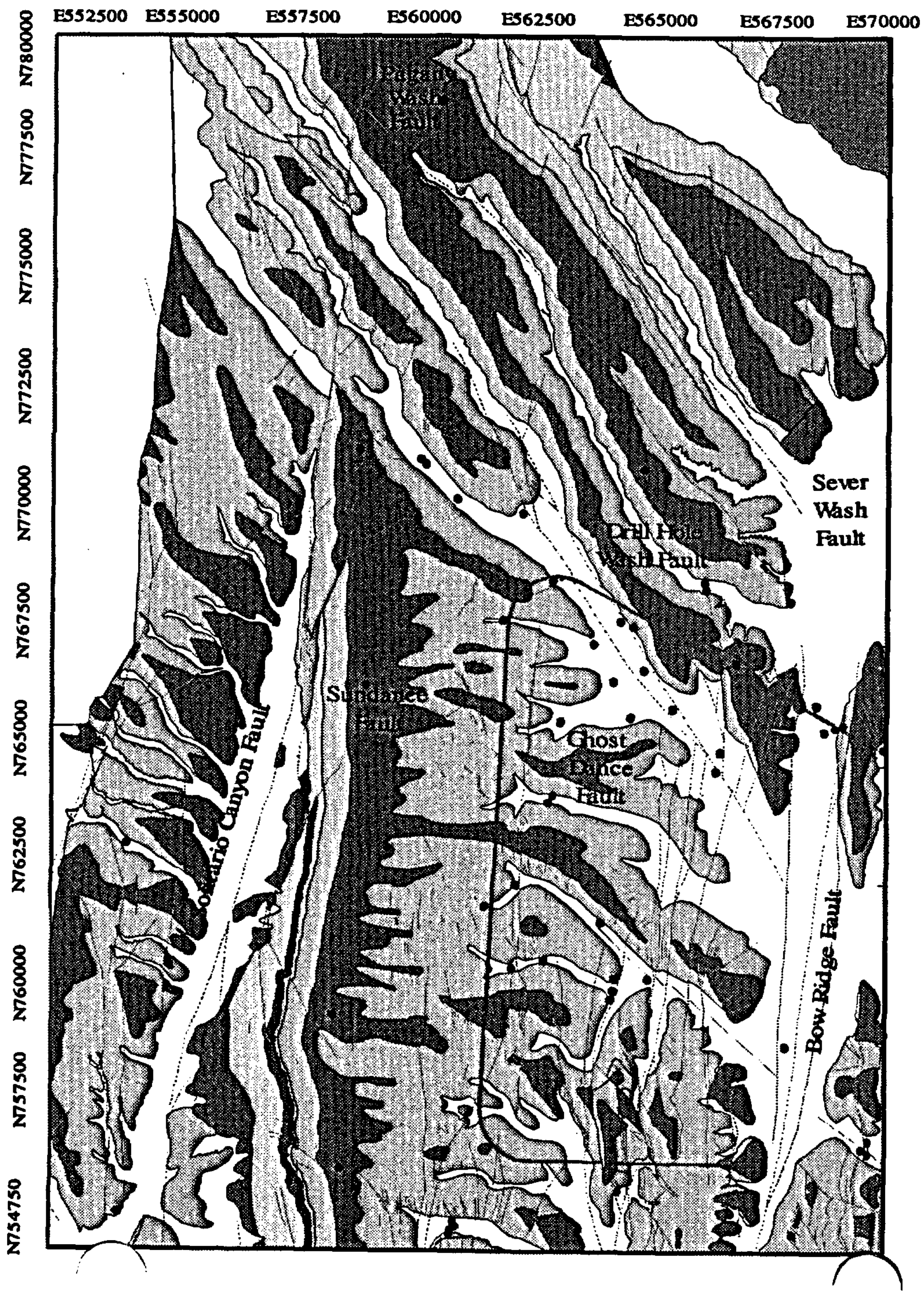
U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Rationale for Mapping Frequency

- OBJECTIVE
  - To capture features that may affect repository performance
  - Faults are the most likely features to impact the performance of the repository
    - no other known geologic or hydrologic features should have unknown characteristics

Rationale for Mapping Frequency

- **Length and Characteristics of Known Faults (based on surface mapping)**
  - There are a number of mapped minor faults in the repository area (Day and others) with surface traces ~200-300 m in length
  - These minor faults are considered to have a possibility of impacting repository performance



Bedrock Geologic Map of the Central Block Area, Yucca Mountain, Nevada

by

W.C. Day, C.J. Potter, D.S. Sweetkind, and R.P. Dickerson

Explanation

Quaternary

- Alluvium & Colluvium

Tertiary

- Rainier Mesa Tuff
- Comb Peak Rhyolite
- Tiva Canyon & Topopah Spring Tuff

Tiva Canyon Tuff

- Crystal - rich member
- Crystal - poor member

Pah Canyon, Yucca Mountain Tuffs - undivided

Topopah Spring Tuff

- Crystal - rich member
- Crystal - poor member

0 2,500 Feet

Rationale for Mapping Frequency

- a) In the repository block, generally, longer faults have greater offsets

- b) Greater offsets have greater likelihood of hydrologic significance

- c) Uncertainty in fault zone hydrology

Strategy for Emplacement Drift Mapping

- Map in detail all non-emplacement drifts
- Map in detail a significant number of drifts to capture significant features on 200-300 m spacing (i.e. approximately every tenth drift)
- In precast drifts, allow for continuous observation (low-detail mapping) of significant anomalous conditions during excavation

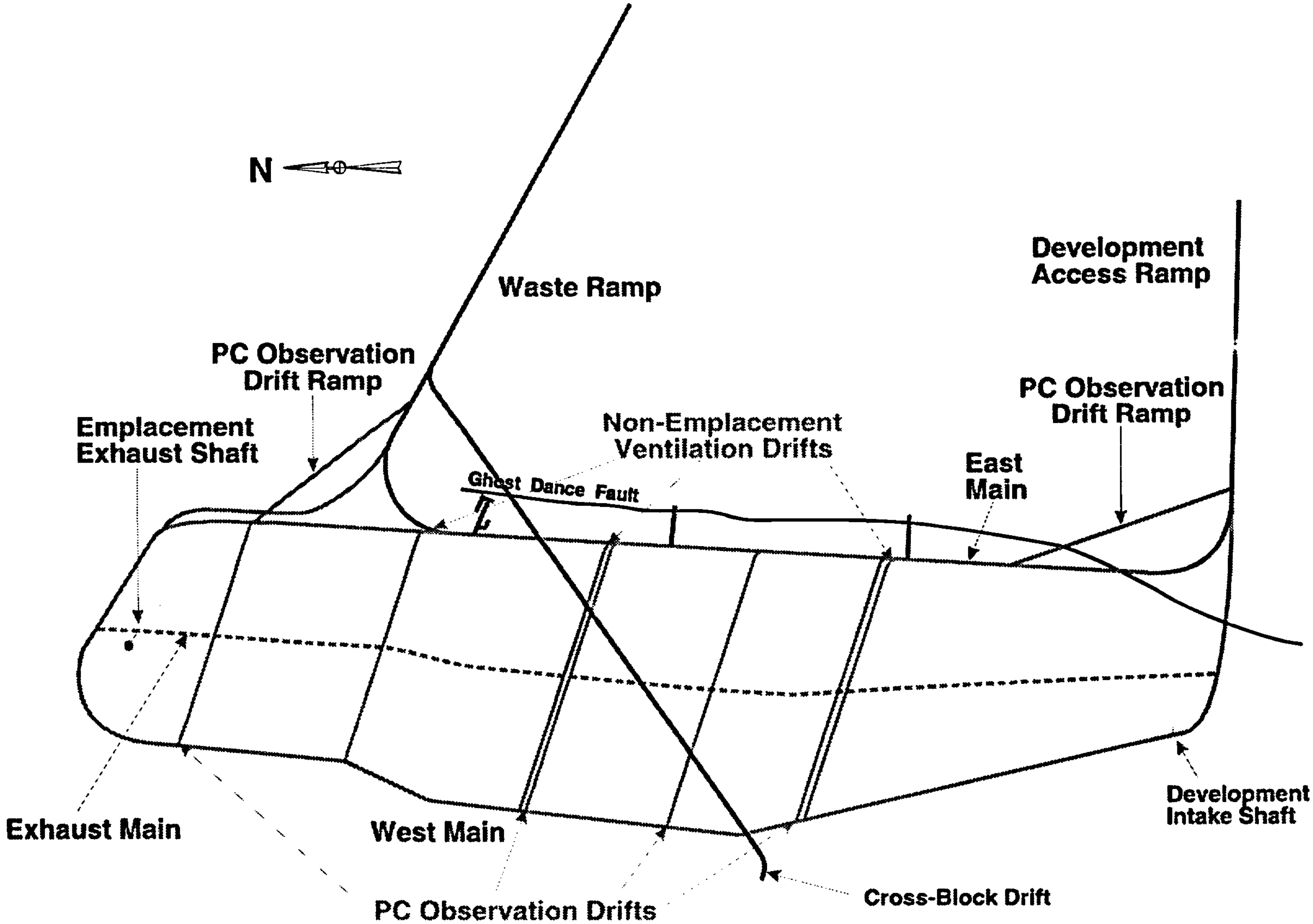
Proposed Construction Sequence and Mapping Options

- Construction logistics and sequences allow completion of drifts in a panel between mapped-in-detail drifts (200-300 m)

- Allow for the ability to change ground support (in precast drifts) if anomalous conditions encountered

Mapping Options

Preliminary Repository Layout

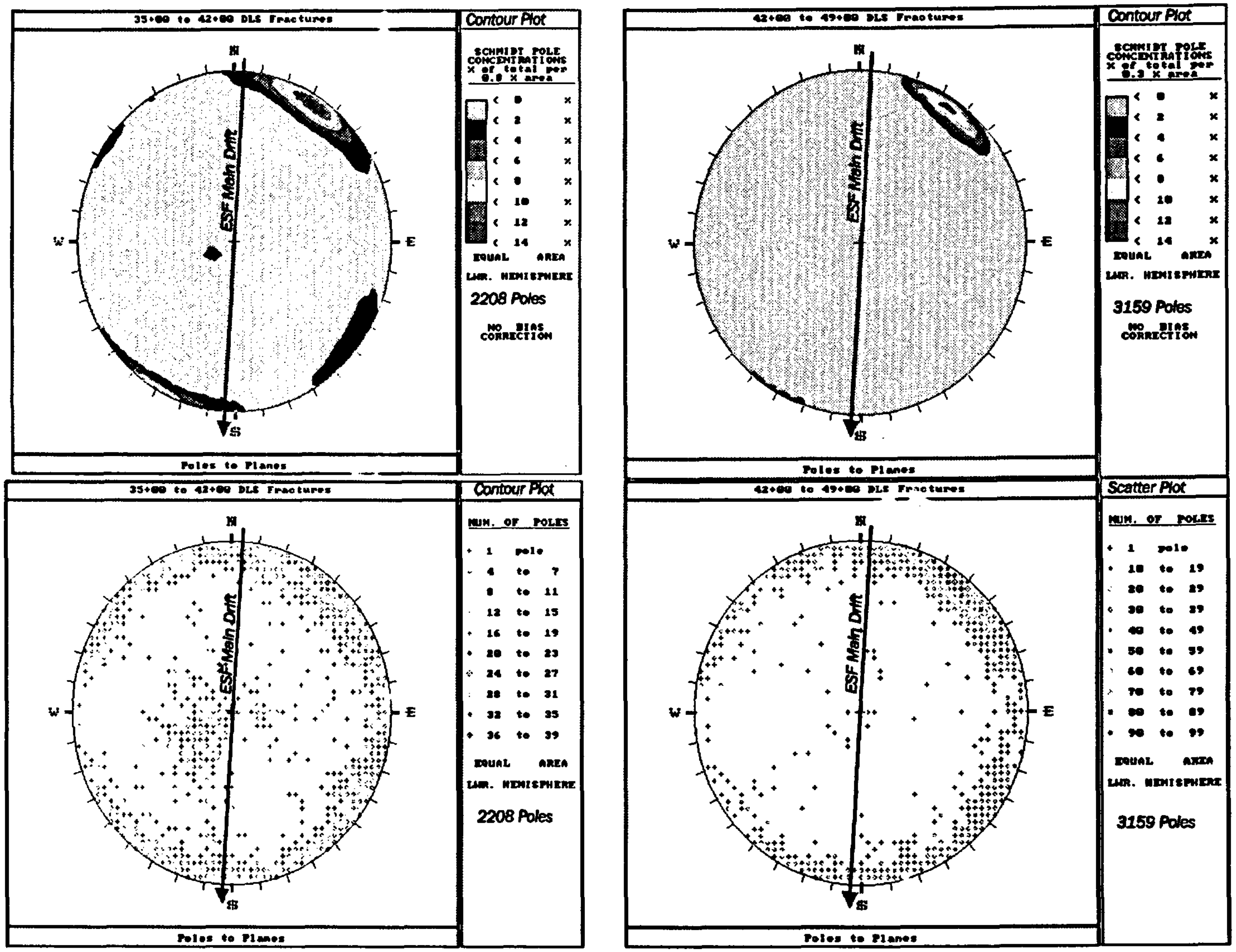


ESF Mapping Products

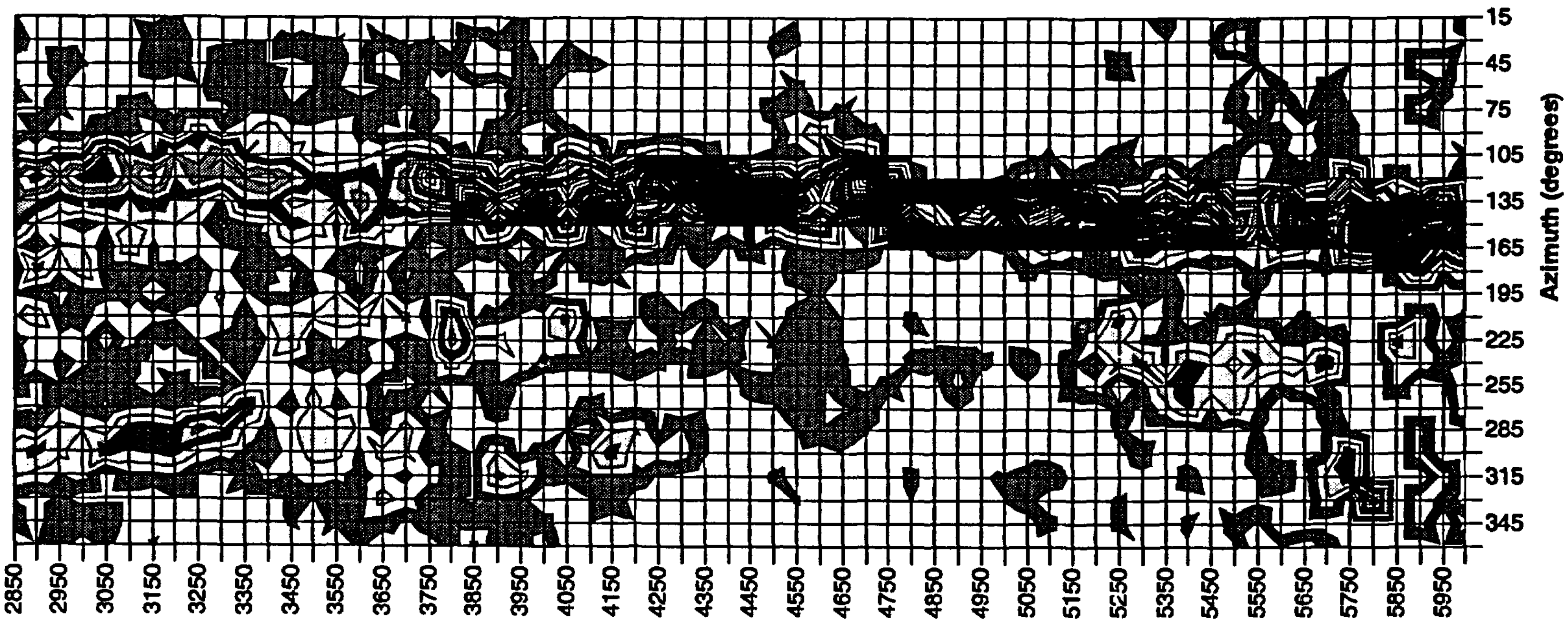
- Full-periphery geologic maps
  - Hard Copy
  - Electronic Formats (.dxf, .dwg)
- Detailed Line Survey
  - Hard Copy
  - Electronic Formats (ASCII, Excel, Access, Wordperfect)

ESF Mapping Products

- Stereonets
- Histograms
- Strike vs. Stationing plots
- Comparitive Cross-section (predicted vs. as-built comparison)
- Full-periphery maps of ground support only


35+00 to 42+00 DLS Fractures
Contour Plot
SCHMIDT POLE CONCENTRATIONS
EQUAL AREA
LWR. HEMISPHERE
2208 Poles
NO BIAS CORRECTION
ESF Main Drift
N
S
E
W
Poles to Planes
42+00 to 49+00 DLS Fractures
Contour Plot
SCHMIDT POLE CONCENTRATIONS
EQUAL AREA
LWR. HEMISPHERE
3159 Poles
NO BIAS CORRECTION
Poles to Planes
35+00 to 42+00 DLS Fractures
Contour Plot
NUM. OF POLES
EQUAL AREA
LWR. HEMISPHERE
2208 Poles
Poles to Planes
42+00 to 49+00 DLS Fractures
Scatter Plot
NUM. OF POLES
EQUAL AREA
LWR. HEMISPHERE
3159 Poles
Poles to Planes

Station 28+00 to 60+00
Percentage Frequency Contoured
Azimuth Versus Stationing

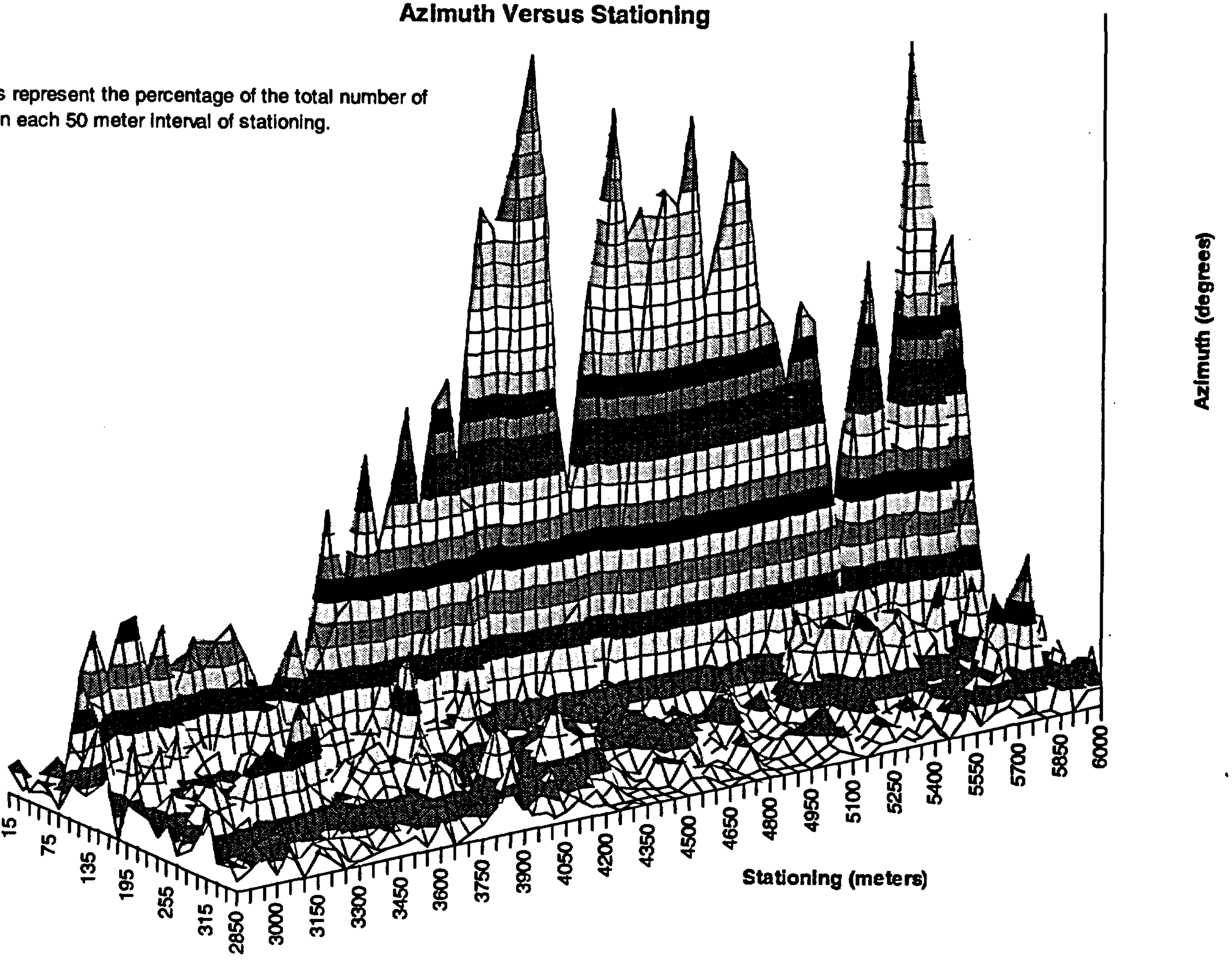


0.00-2.00	2.00-4.00	4.00-6.00	6.00-8.00	8.00-10.00	10.00-12.00	12.00-14.00	14.00-16.00
16.00-18.00	18.00-20.00	20.00-22.00	22.00-24.00	24.00-26.00	26.00-28.00	28.00-30.00	30.00-32.00
32.00-34.00	34.00-36.00	36.00-38.00	38.00-40.00	40.00-42.00	42.00-44.00	44.00-46.00	46.00-48.00
48.00-50.00	50.00-52.00	52.00-54.00	54.00-56.00	56.00-58.00	58.00-60.00	60.00-62.00	62.00-64.00

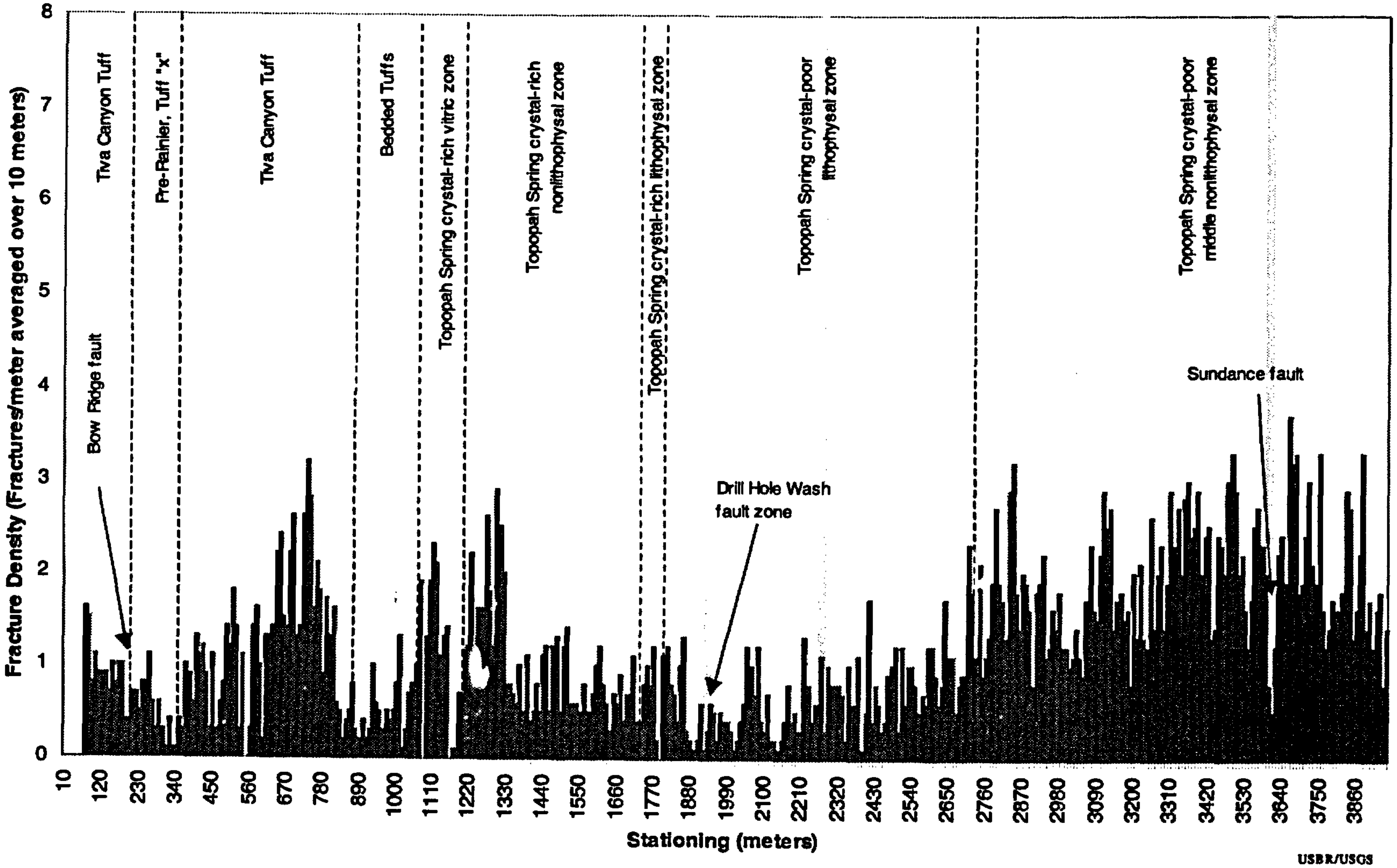
Color contours represent the percentage of the total number of fractures within each 50 meter interval of stationing.

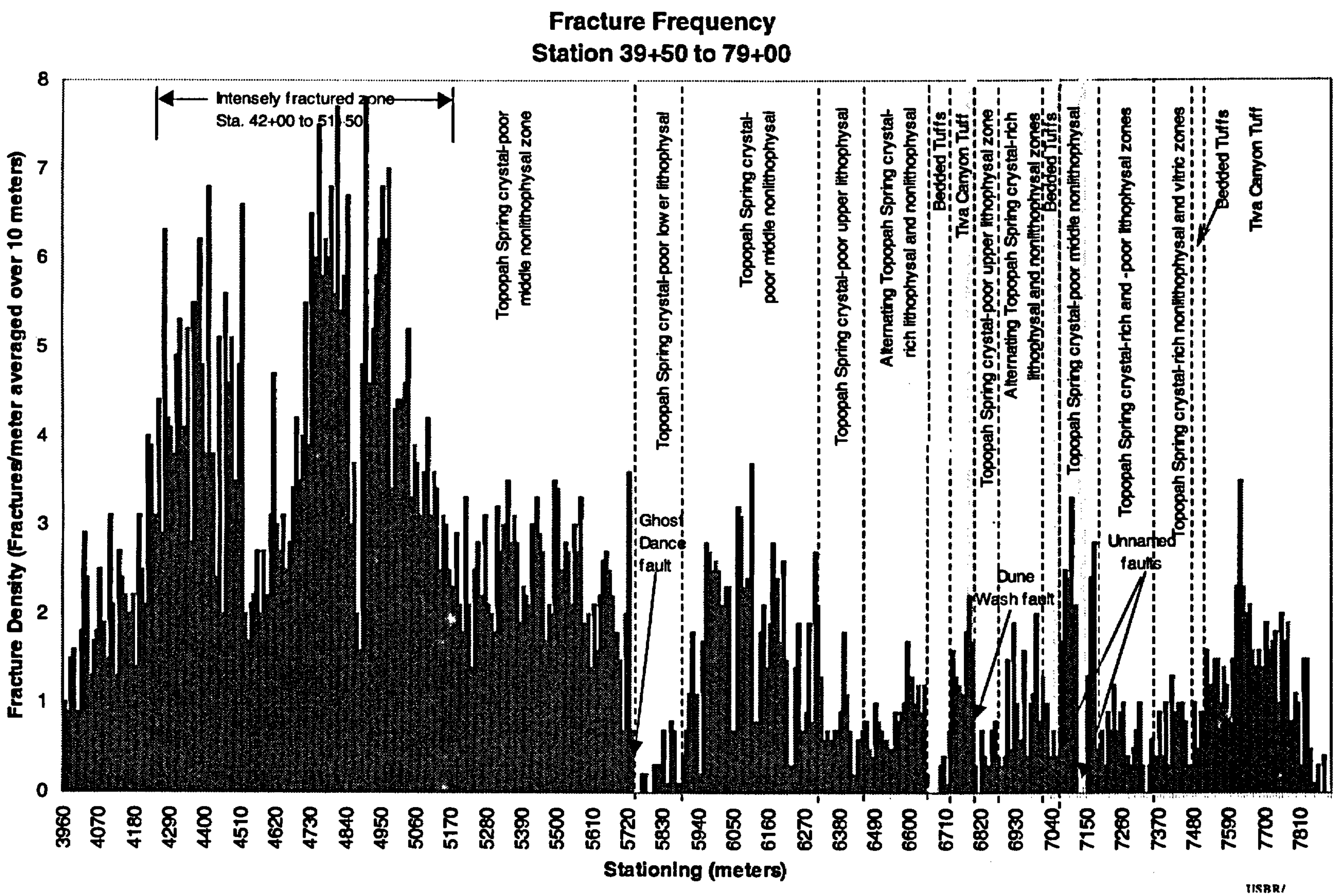
Station 28+00 to 60+00
Percentage Frequency Contoured
Azimuth Versus Stationing

Color contours represent the percentage of the total number of fractures within each 50 meter interval of stationing.



Fracture Frequency
Station 0+00 to 39+50




Fracture Frequency
Station 39+50 to 79+00
Intensely fractured zone
Sta. 42+00 to 51+50
Fracture Density (Fractures/meter averaged over 10 meters)
Stationing (meters)
Topopah Spring crystal-poor middle nonlithophysal zone
Topopah Spring crystal-poor lower lithophysal
Topopah Spring crystal-poor middle nonlithophysal
Topopah Spring crystal-poor upper lithophysal
Alternating Topopah Spring crystal-rich lithophysal and nonlithophysal
Bedded Tuffs
Tiva Canyon Tuff
Topopah Spring crystal-poor upper lithophysal zone
Alternating Topopah Spring crystal-rich lithophysal and nonlithophysal zones
Bedded Tuffs
Topopah Spring crystal-poor middle nonlithophysal
Topopah Spring crystal-rich and -poor lithophysal zones
Topopah Spring crystal-rich nonlithophysal and vitric zones
Bedded Tuffs
Tiva Canyon Tuff
Ghost Dance fault
Dune Wash fault
Unnamed faults
USBR/

ESF Mapping Products

- Geology Reports from the North Ramp, Main Drift, South Ramp, and North & South Portals
  - Fracture "Fingerprint" diagrams
  - Multivariate Statistics
  - Photomosaics of features of interest
  - Summary of Q and RMR ratings

ESF Mapping Products

- USERS for Mapping Data
  - Repository Design
  - Design Confirmation
  - Fracture Network Modellers
  - Construction Management
  - Unsaturated Zone Hydrologic Modellers
  - Structural Framework Modellers

3b

YUCCA
MOUNTAIN
PROJECT

Studies

Underground Geologic Mapping of the ESF

Presented to:

NRC Appendix 7 Meeting
on Geologic Mapping

Presented by:
Steven C. Beason, USBR
Principal Investigator

October 15, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

FULL-PERIPHERY GEOLOGIC MAPPING

- Maps are compiled into 100-m sections
- Discontinuities longer than 1 m are mapped
- Noteworthy geologic features are mapped and described, i.e. fracture zones, fault zones, shear zones, and breccia zones
- Sample and geotechnical instrumentation locations are included
- "Q" ground support is mapped
- A generalized geologic cross-section is included
- Excavation rates and rock mass classification data are displayed at the top of the map

Detailed Line Surveys

- Tapeline on right wall ~1 m below springline
- All discontinuities longer than 1 m are documented
- 19 Attributes are described for each feature

Station	**Width**	**Aperture (max).**
Type	**Ends**	**Offset**
Azimuth	**Upper Termination**	**Infilling Type**
Dip	**Lower Termination**	**Infilling thickness**
Trace Length above tape	**Planarity**	**Comments**
Trace Length below tape	**Joint Alteration Number**	
Height	**Aperture (min.)**	

- **Over 21,000 fractures have been characterized**

Faults and Shears

- Structures with undeterminable offset or offsets less than 0.1 m are designated as shears
- Structures with greater than 0.1 m offset are designated as faults
- Several criteria used to determine offset
  - Displacement of lithology
  - Displacement of discontinuities (fractures, joints, vapor-phase partings)
  - Pumice and lithic clasts
- Strike-slip is the most difficult to discern due to lack of markers.
  - Slickensides may indicate direction of last movement, but not amount

Correlation Between Surface and ESF mapping

- Imbricate fault zone
  - Surface mapping helped define faults obscured by ground support in the ESF at station 5+50
  - Underground mapping showed several faults not easily visible at the surface
- Drill Hole Wash faults
  - Surface and underground mapping agreed on location of the main faults
  - Underground mapping defined the limited size of the faults
- Northern Extent of the Ghost Dance fault
  - Both surface and underground mapping confirm that the fault does not extend as far north as the ESF

Correlation Between Surface and ESF mapping (cont.)

- Sundance fault
  - Surface and underground mapping confirmed the minor and discontinuous nature of the fault zone
  - The difference in fault location between the surface and underground suggests a vertically discontinuous nature   off by 30-40m.
- Intensely Fracture zone
  - Surface and borehole data confirm that the zone is apparently stratabound (limited to the Tptpmn)   Not seen initially in SD-
  - Data from Alcove #7 indicates the zone is bounded on the east by the Ghost Dance fault

Correlation Between Surface and ESF mapping (cont.)

- Ghost Dance fault
  - Where the fault crosses the ESF (station 57+30), the offset and location match well with surface mapping
  - In Alcove #6, offset and location of the zone match predictions from surface mapping. The zone underground is narrow -- about 0.6 m.
  - In Alcove #7, offset and location (station 1+67) of the main splay of the fault correlate well
    - The western splay of the GDF, visible in the UZ-7A pad exposure, is not present at depth.

Correlation Between Surface and ESF mapping (cont.)

- Dune Wash fault
  - Surface and underground mapping confirm both the location of the fault zone and the relative offset. The location predicted within 5 m by surface mapping
  - Underground mapping revealed the zone to be composed of two smaller faults, ~3 m apart
- Fault at station 70+58
  - Surface and underground mapping confirm the location of the fault and relative offset. The location predicted within 2 m by surface mapping.

Correlation Between Surface and ESF mapping (cont.)

- Fault at 71+31
  - Underground mapping revealed this zone to have significantly less offset than that predicted by surface in alluviated valley mapping. In the ESF, this area turned out to have only one fault rather than 2-3 faults as predicted by surface work.

ESF Notable Structural Features

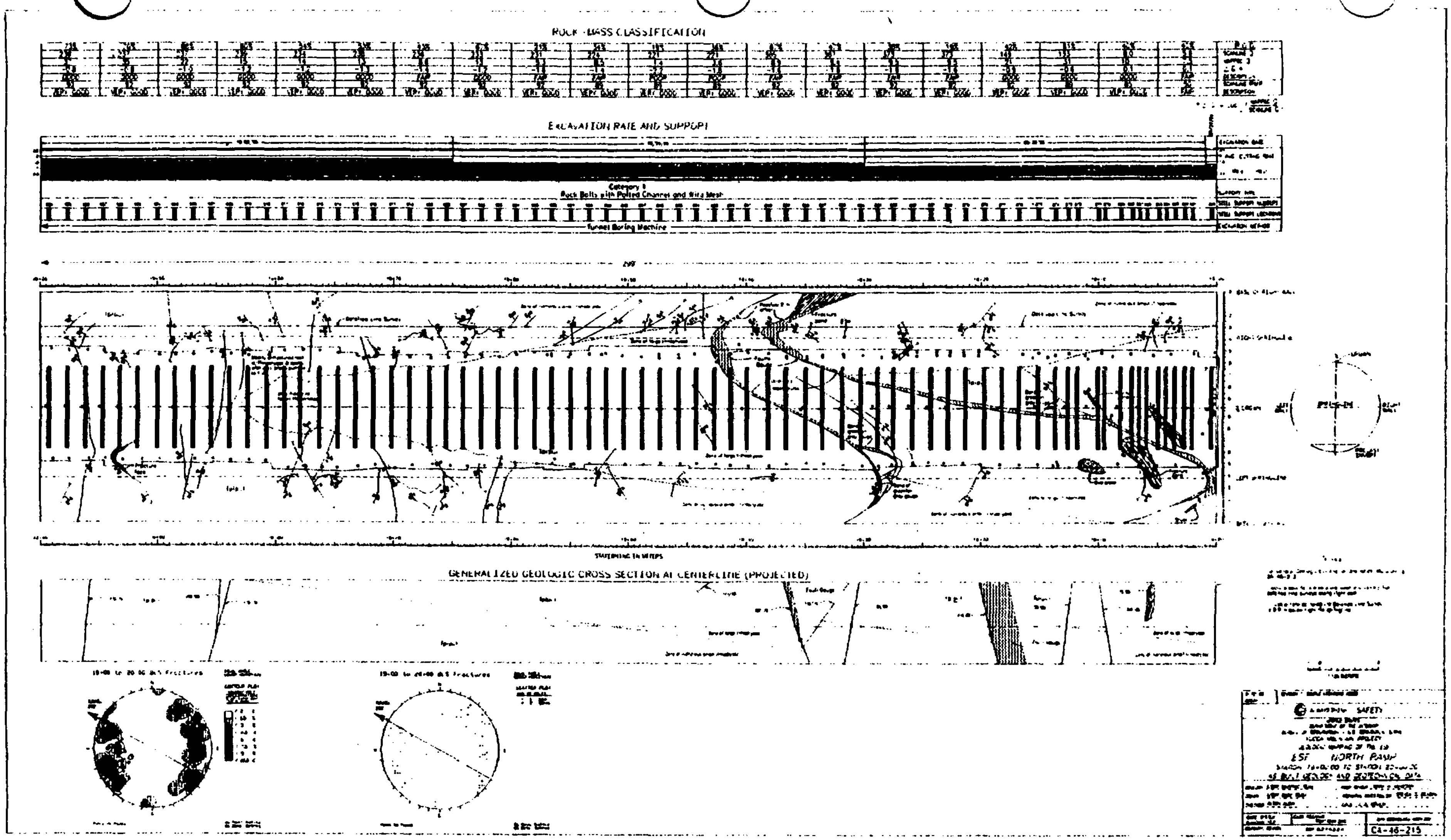
Name	Station	Thickness	Offset	Characteristics
Bow Ridge fault	2+00	2 m	100 m	Uncemented breccia - Wall rock relatively unfractured, no distinct calcite veins visible associated with the zone
"Imbricate" fault zone	4+30-11+70	Multiple zones up to 5 m thick	Multiple offsets up to 18 m	Numerous individual faults, many with offsets >5 m offset typically uncemented fault rubble with little or no cemented breccia
Drill Hole Wash fault zone	19+00	0.5 m	6 m	Composed of 2 separate faults, horizontal slickensides no mineralization along fault trace ~ 20m Dpslip
Sundance fault	35+94	0. 5m	<1 m	Composed of a series of discontinuous shears and small fault planes, no mineralization along fault trace
Ghost Dance fault	57+30	1-2 m disturbed 5-10 cm gouge	2 m max. , normal	Distinct low-angle slickensides, no mineralization in zone

Name	Station	Thickness	Offset	Characteristics
Ghost Dance fault	1+52 (Alcove #6)	0.6 m	~6 m	No mineralization, composed a single zone of matrix-supported fault rubble, intensely fractured in hanging wall, but footwall is only slightly to mod. fractured
Ghost Dance fault	1+67 (Alcove #7)	0.6 m	~25 m	No mineralization, fault plane is very planar and smooth, intensely fractured zone from Main Drift is not evident on th footwall side of the fault
Dune Wash fault	67+88-67+91	5-10 cm gouge	52 m, normal	Composed of 2 distinct planes. oriented 140°/86° and 175°/60°
Unamed Dol's Fault	70+58	20 cm gouge	50 m, normal	No mineralization, damp *
Unamed	71+30	~2 m	2 m??	Matrix-supported breccia, uncemented

Main Drift, Exploratory Studies Facility, Alcove 6
Yucca Mountain Project, Detailed Line Survey-Data Collected from Station 0+03.56 to 1+73.87
Collected under GP-32,R0,SCP Study Number 8.3.1.4.2.2.4

Station	Typ	Attitude		Trace Length		Ht(m)	Wd(m)	E	UT	LT	Pl	Ja	Rgh	Aptr mm		Off set	Infill type	Infill thick	Comments
		Str	Dip	A (m)	B (m)									Min	Max	m			
0+03.56	F	121	84	0.58	0.00	0.54	0.14	2	Rk	Rk	I	11	3	0	0	NA	S	1mm	LT is 0.17m above tapeline
0+04.13	F	124	86	0.75	0.00	0.59	0.11	2	Rk	Tf	P	12	2	0	0	NA	S	1.5mm	LT is 0.15m above tapeline, 4mm light beige weathered zone
0+04.27	F	029	88	0.49	0.89	1.38	0.23	2	Yf	Tf	I	11	4	0	0	NA	NA	NA	No comments
0+05.52	F	087	07	2.21	0.00	2.17	0.09	1	Rk	Air	P	11	5	0	0	NA	S	1mm	LT is 0.08m above tapeline
0+06.61	SH	088	11	0.79	4.57	3.41	0.83	2	Rk	Rk	P	11	4	0	0	0.015	NA	NA	normal offset
0+06.68	F	112	77	2.08	0.00	1.14	1.23	1	Air	Tf	I	11	3	0	0	NA	S	1mm	LT is at tapeline
0+06.80	F	156	82	0.78	0.49	1.11	0.22	2	Yf	Rk	I	11	1	0	0	NA	S	1-2mm	No comments
0+06.81	F	204	81	1.28	0.43	1.40	0.21	2	Rk	Tf	I	11	3	0	0	NA	NA	NA	No comments

Traceline Location: ESF Tunnel, Main Drift, Station 0+03.56 to 1+73.87
Dates Mapped: September 10, 1996 to July 22, 1997
Compiled by: Sheldon K Johnson



FULL PERIPHERY GEOLOGIC MAP

with Excavation Rates, Ground Support, and Rock Mass Classification

YUCCA MOUNTAIN PROJECT

Studies

Available Repository Volume LYNX Model YMP.MO3 (Design Model)

Presented to:
DOE/NRC Appendix 7 Discussions
on Plans for Geologic Mapping of Subsurface Facilities

Presented by:
Bob Elayer, M&O
Geologist, Subsurface Repository Design

October 16, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Purpose of the Design Model

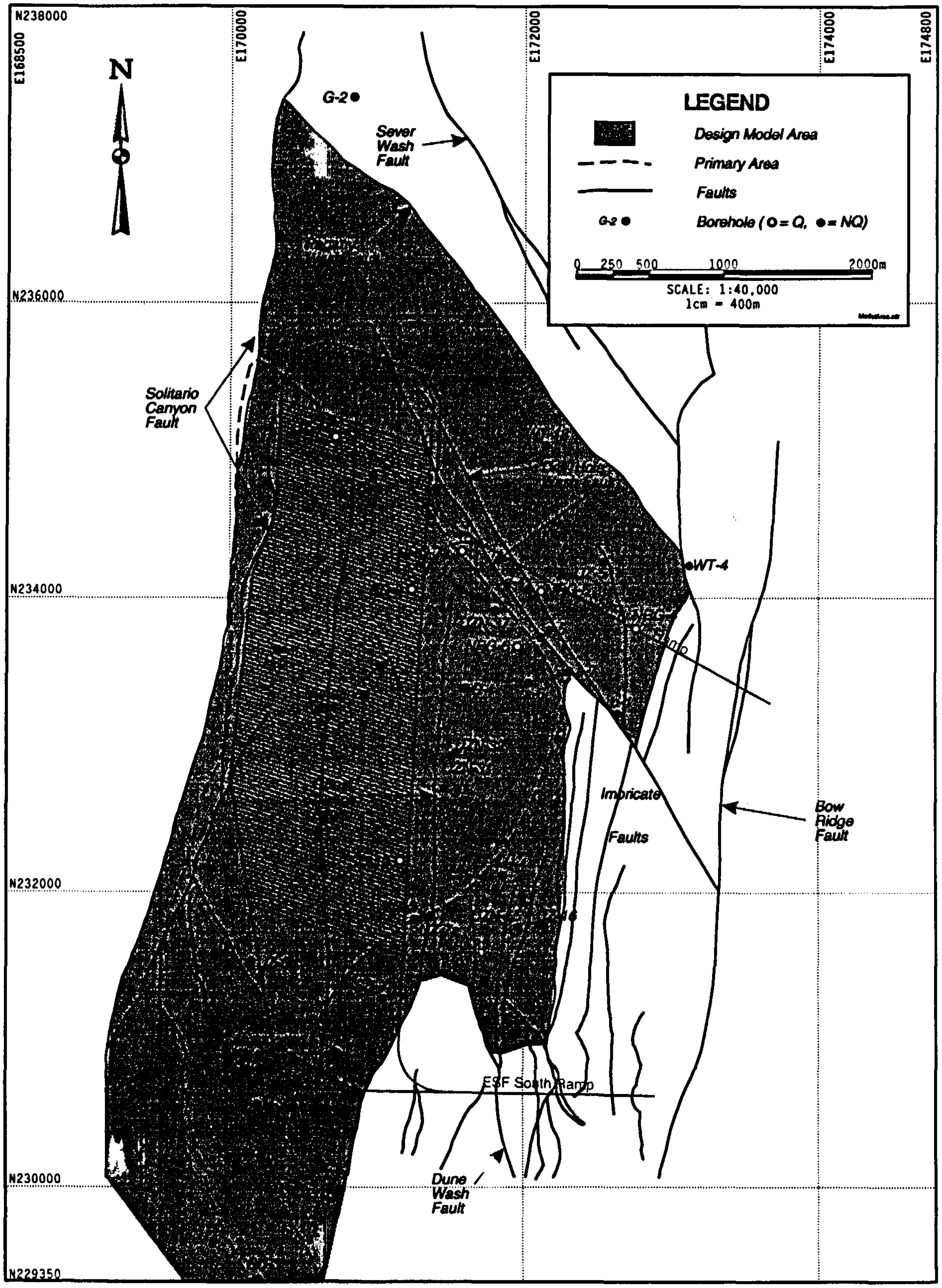
- Identify the geologic horizon suitable for hosting the repository (Repository Host Horizon, RHH)
- Define the three-dimensional volume for repository siting
- Provide additional support to repository design as required

Data Input to Design Model

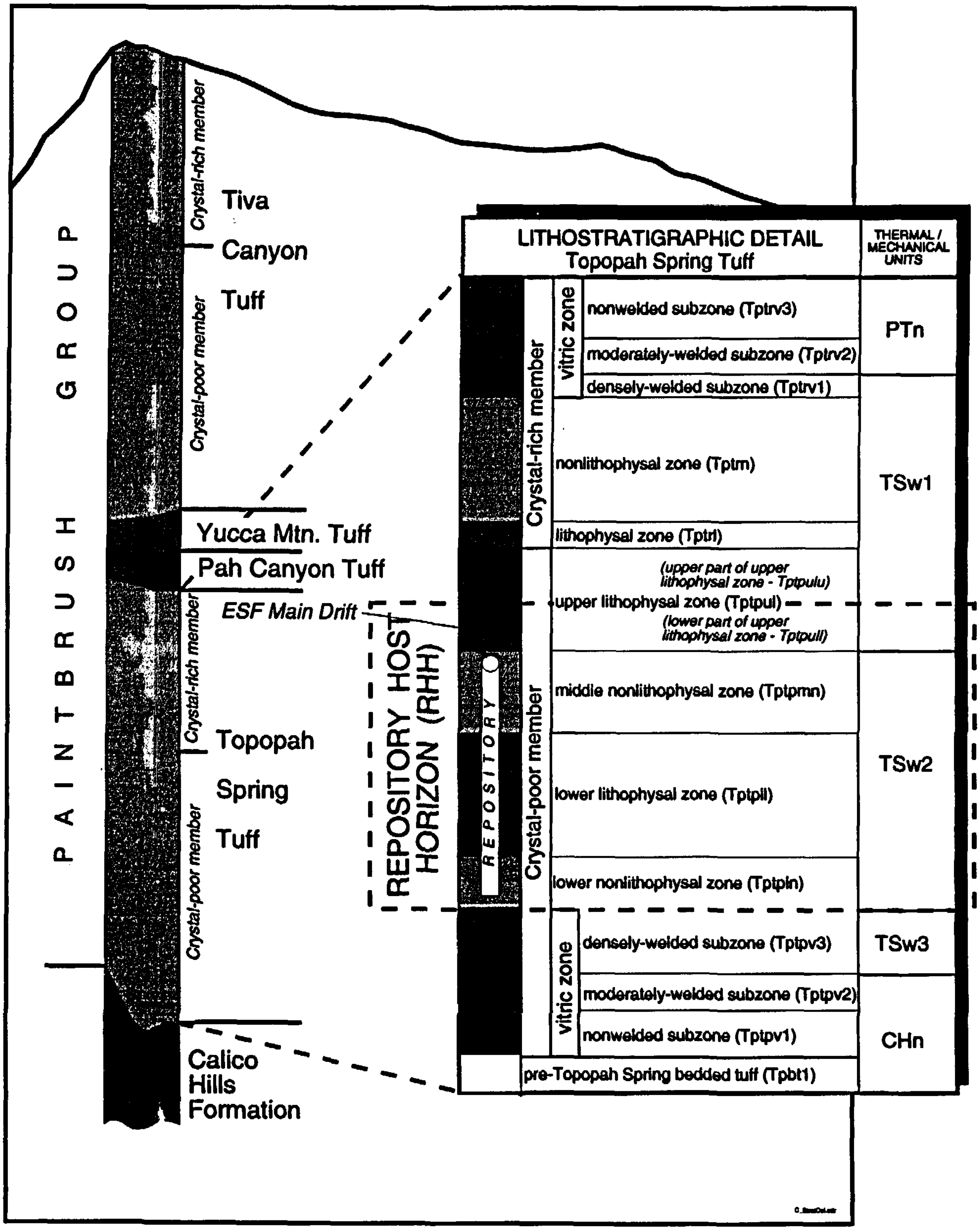
- Topography
- Borehole stratigraphy
- Outcrops
- ESF mapping
- Surface faults
- Groundwater surface

Limits for Repository Siting

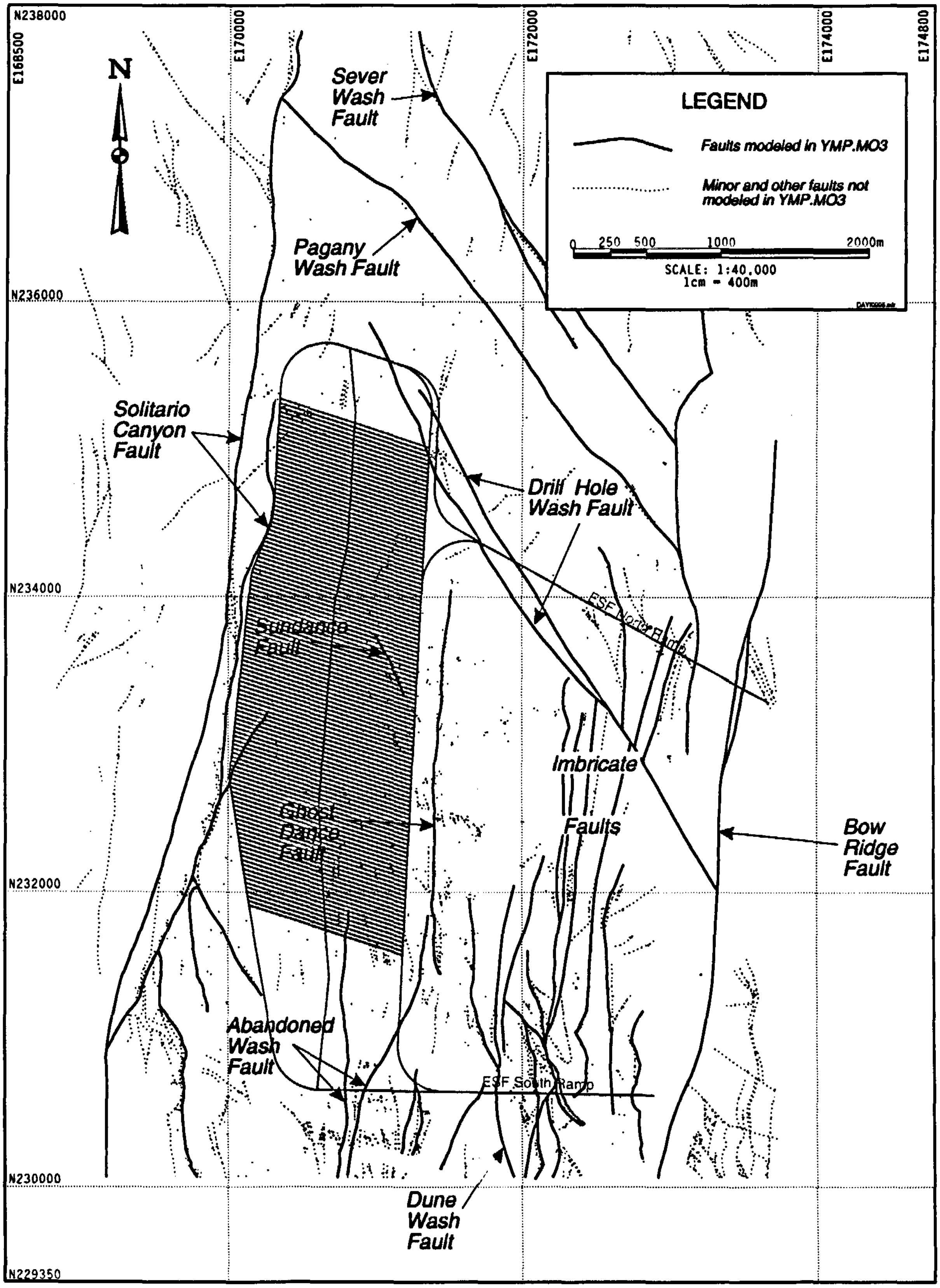
- Overburden (200m minimum)
- Repository host horizon top (-5m standoff)
- Repository host horizon bottom (+10m standoff)
- Groundwater surface (100m minimum standoff)
- Major bounding faults (60m standoff, 120m standoff west side of Ghost Dance Fault)



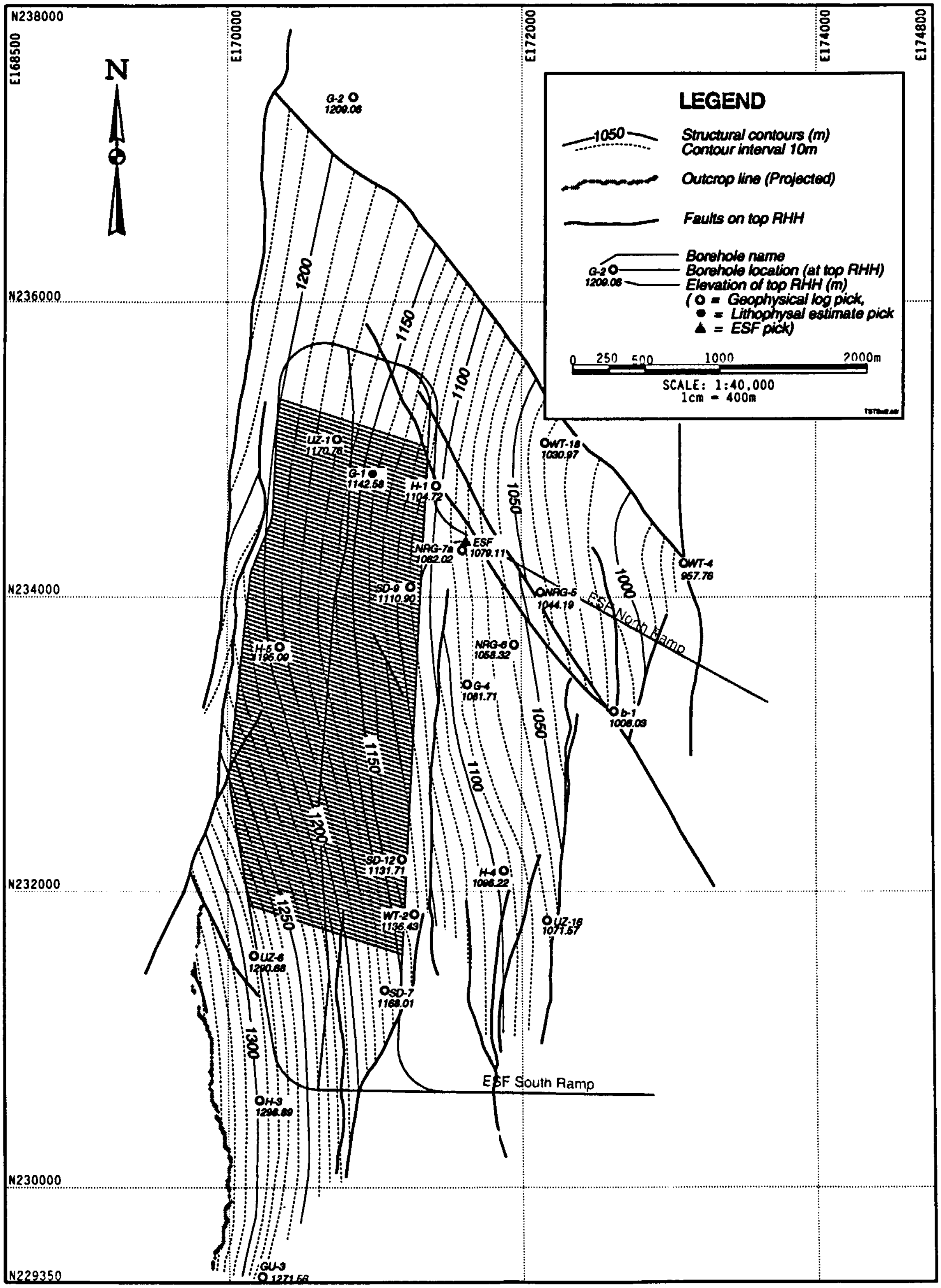
Design Model Area



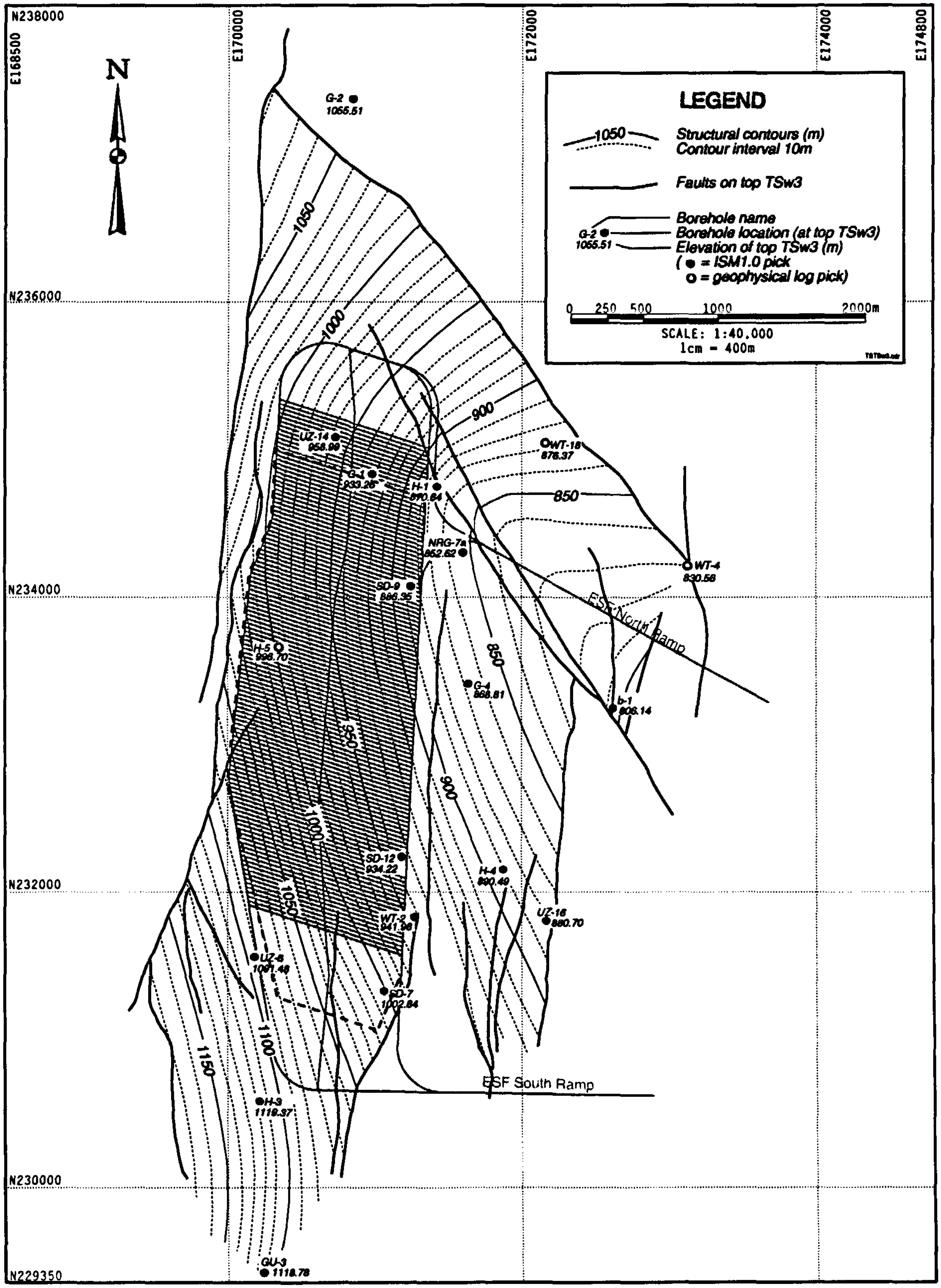
General Stratigraphic Column



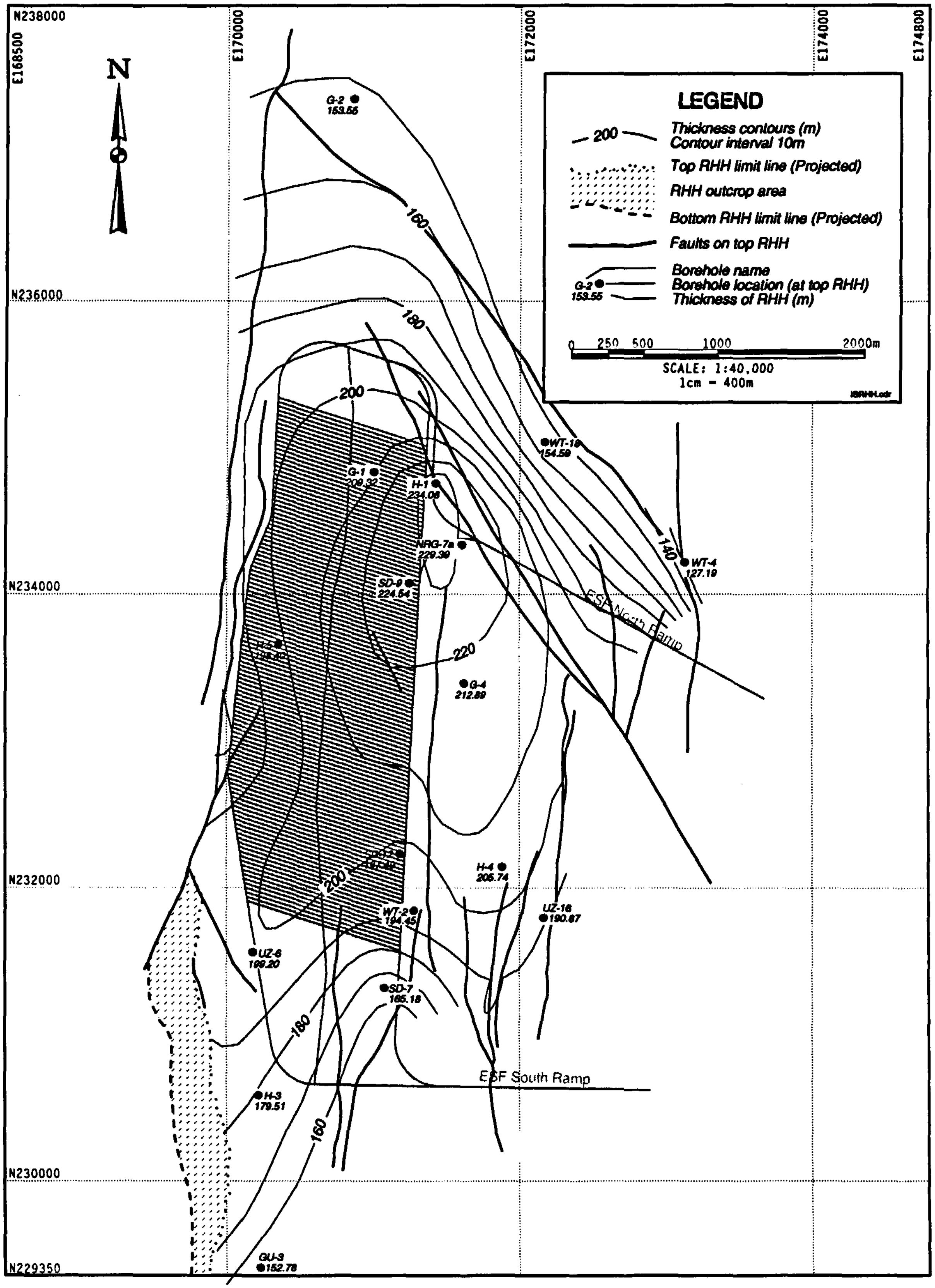
Surface Faults



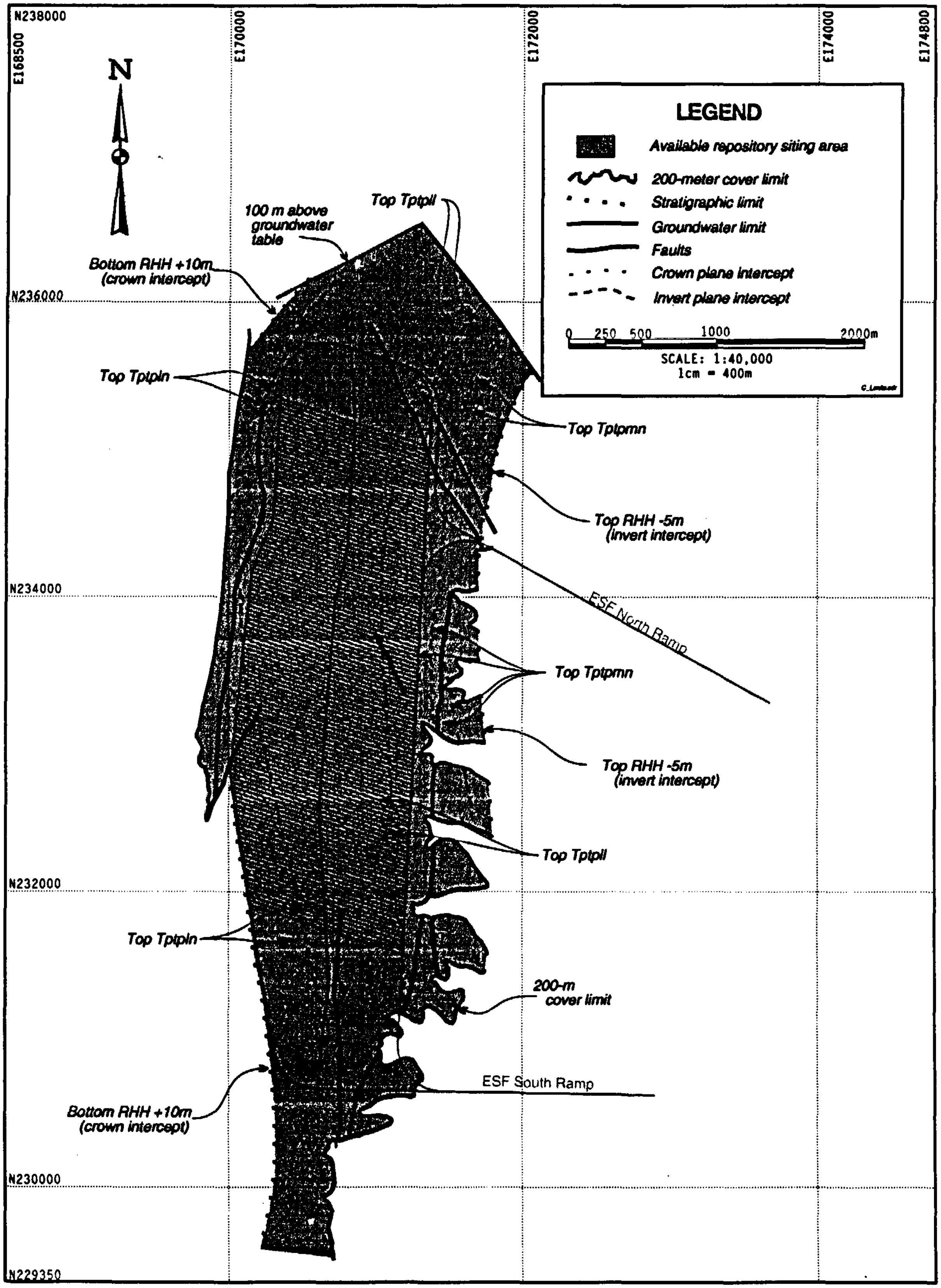
Repository Host Horizon Top Surface



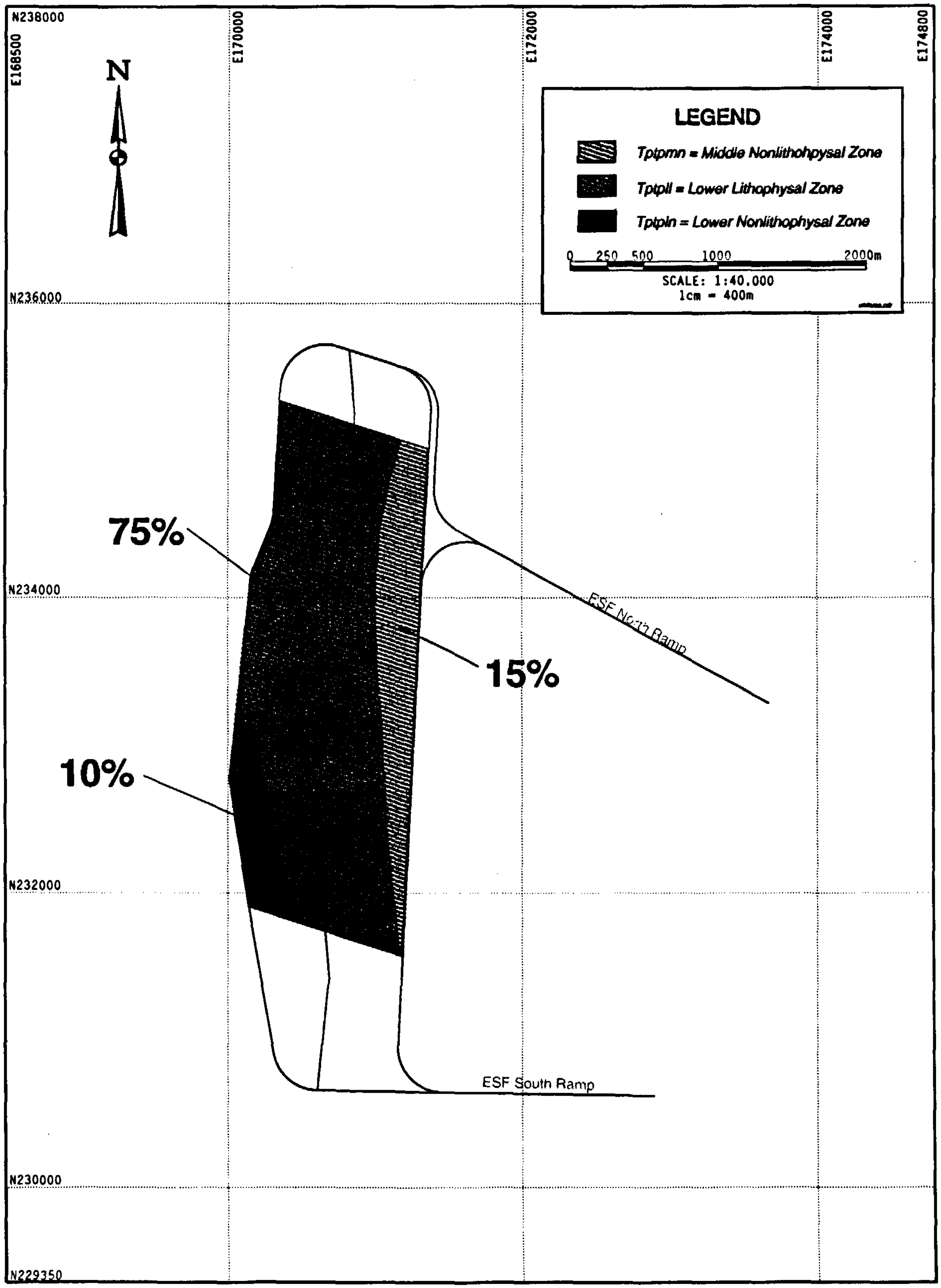
Repository Host Horizon Bottom Surface



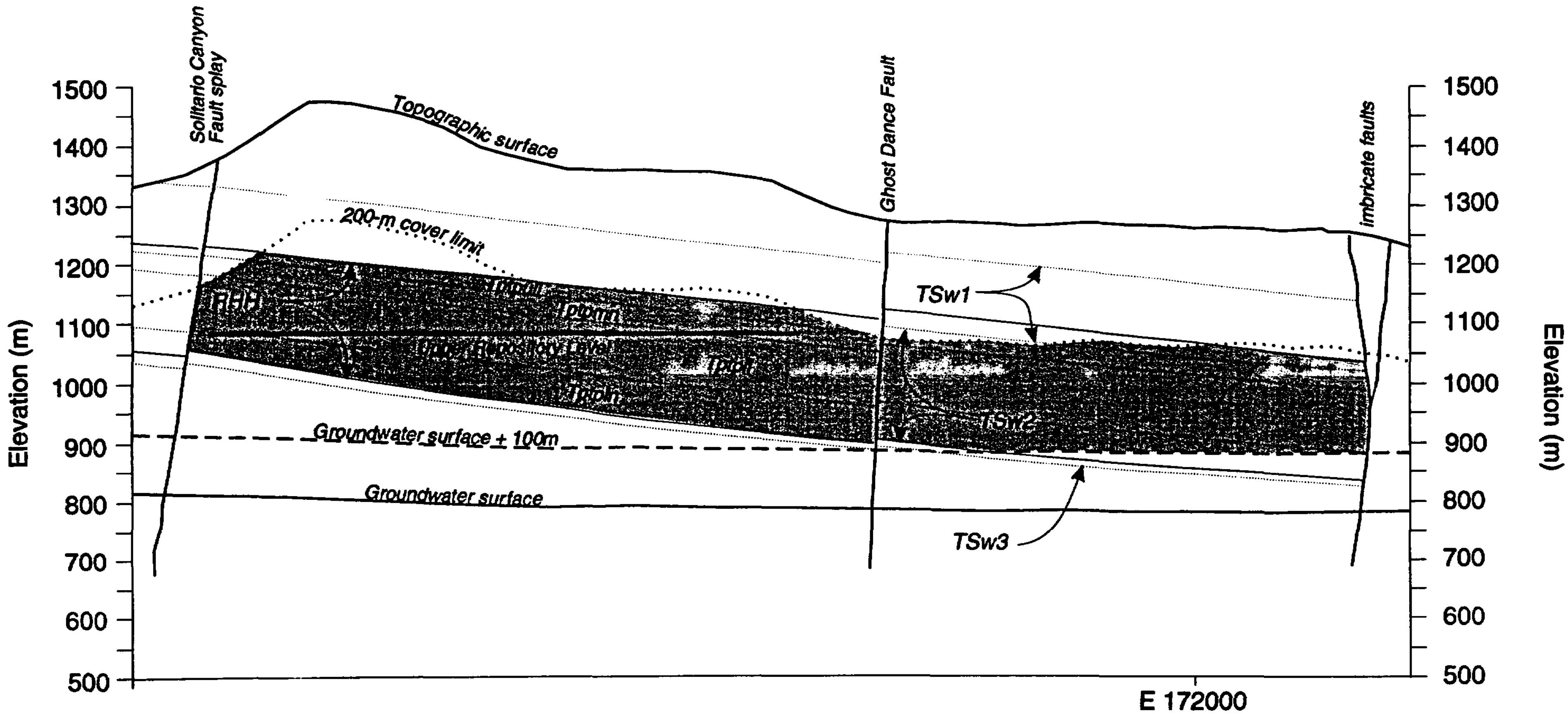
Repository Host Horizon Thickness

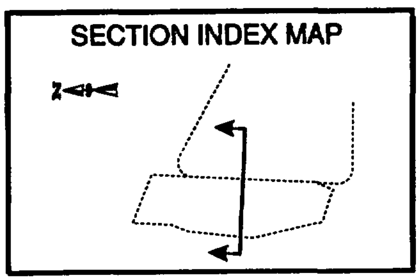


Available Upper Repository Level Siting Area



Relative Areas of Rock Units within the Upper Repository Block at Invert Level

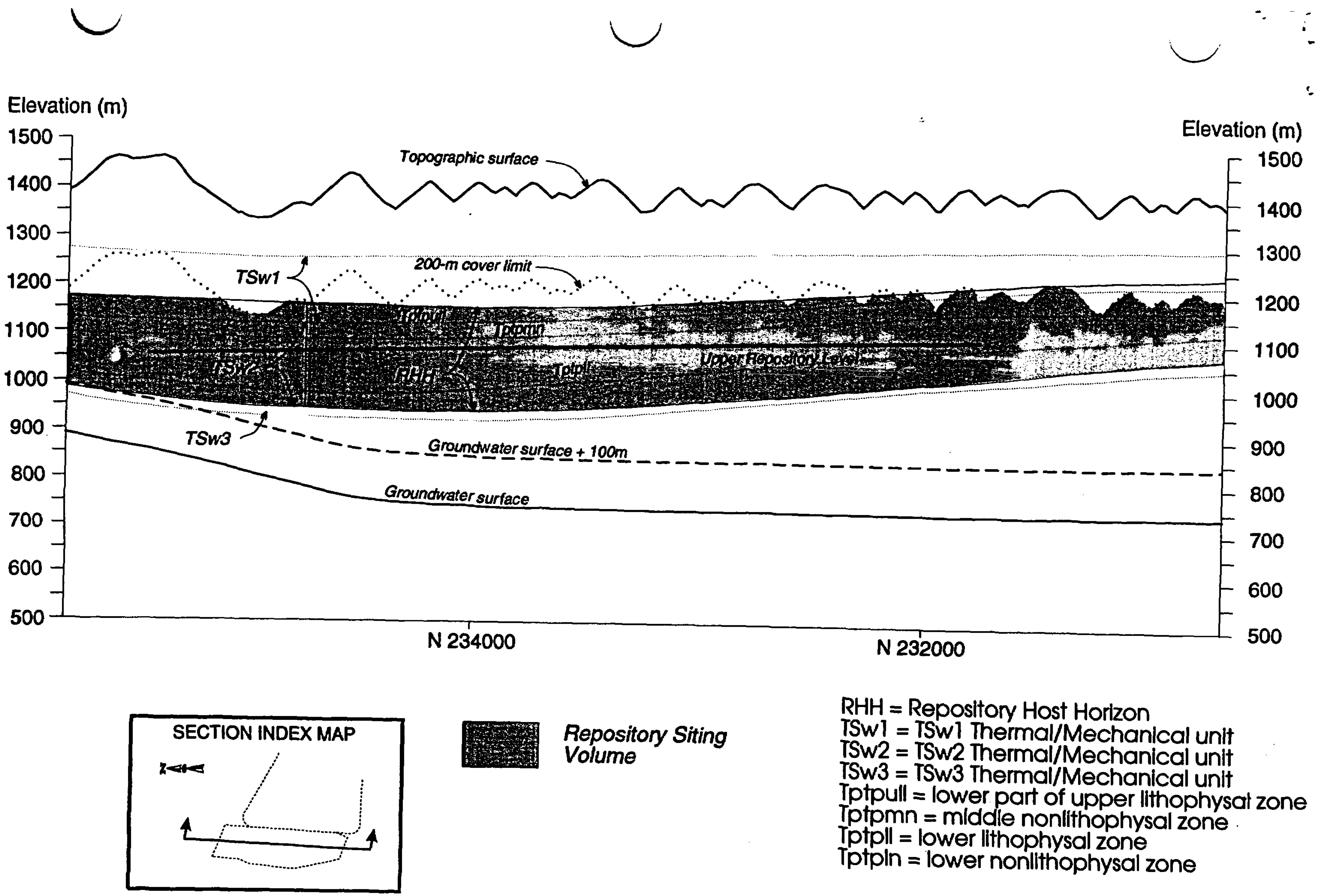




Repository Siting Volume

RHH = Repository Host Horizon
TSw1 = TSw1 Thermal/Mechanical unit
TSw2 = TSw2 Thermal/Mechanical unit
TSw3 = TSw3 Thermal/Mechanical unit
Tptpull = lower part of upper lithophysal zone
Tptpmn = middle nonlithophysal zone
Tptpll = lower lithophysal zone
Tptpln = lower nonlithophysal zone

West-East Cross Section Through Repository Siting Volume



North-South Cross Section Through Repository Siting Volume

YUCCA MOUNTAIN PROJECT

Studies

Current Subsurface Facility Layout

Presented to:
NRC Appendix 7 Meeting
on Geologic Mapping

Presented by:
Daniel G. McKenzie, III
Manager, Subsurface Repository Design

October 16, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

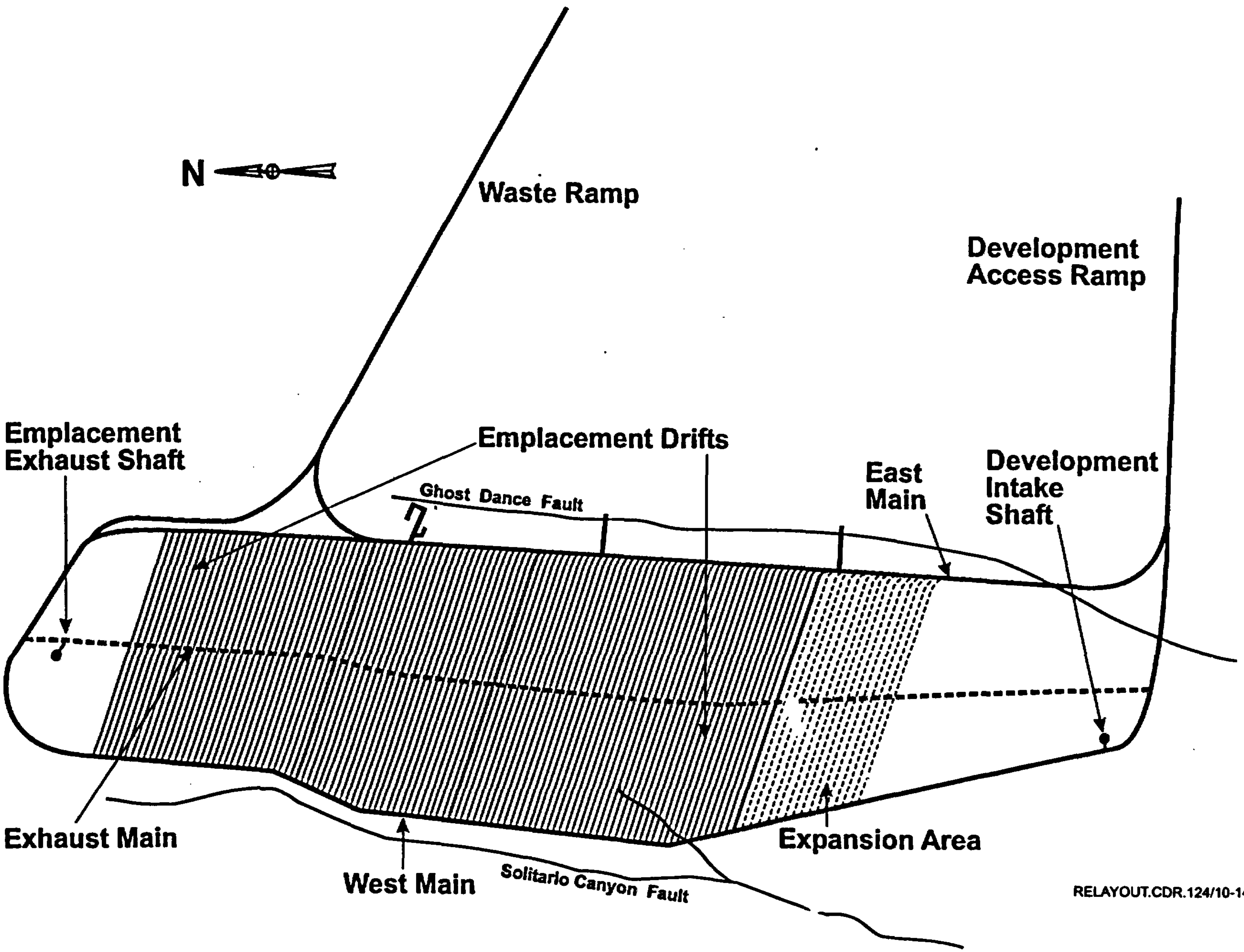
Objectives

- Discuss the "Design Drivers" which strongly influence the repository configuration
- Describe the basic repository layout for VA
- Show the sequence in which the subsurface layout will be constructed

Design Drivers

- Geologic setting
- Waste inventory, heat output, variability, areal thermal loading
- Waste package physical characteristics
- WASTE Transportation system ~ Rail
- Mechanical excavation
- Post-closure drainage control
- Performance Confirmation program requirements
- Retrievability requirement

Preliminary Repository Layout

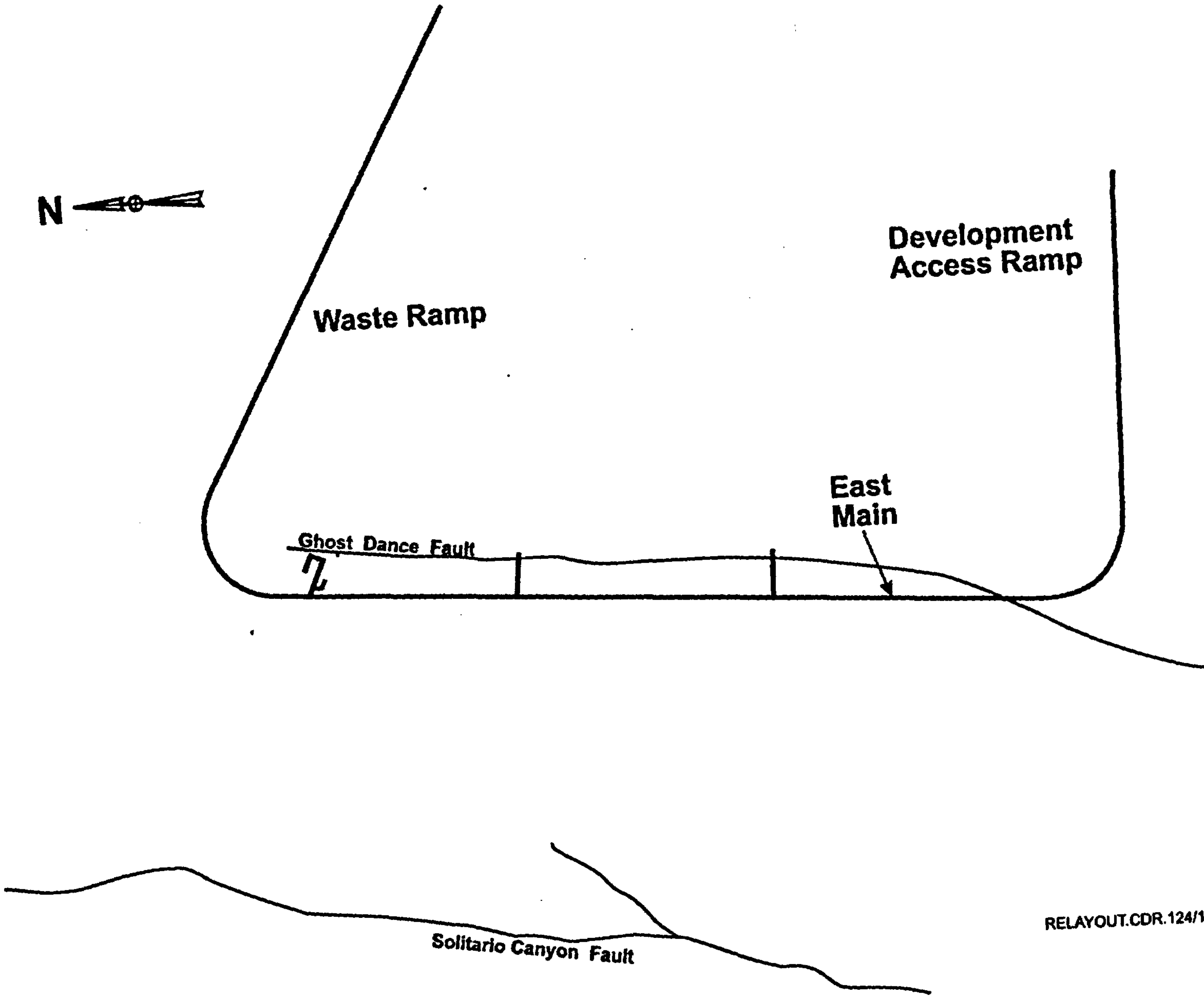


RELAYOUT.CDR.124/10-14-97

Repository Layout Physical Data

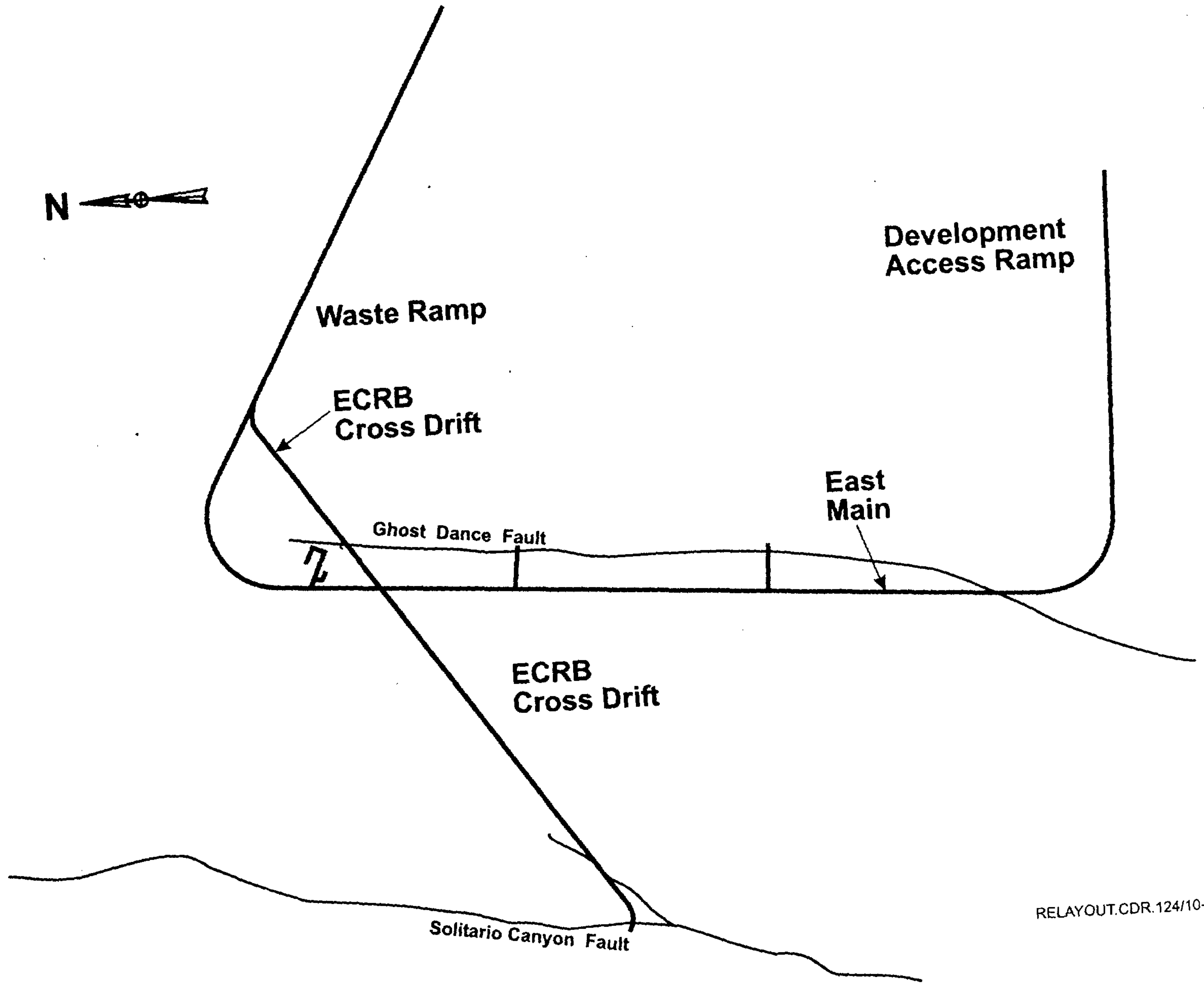
- Total length of drifting: 157,400 meters (including existing ESF loop and Performance Confirmation drifting)
- 10.3 million metric tons of excavation
- 95% TBM excavation - 5% roadheader
- Main drifts 7.6 m diameter
- Emplacement and PC drifts 5.5 m diameter
- 100 emplacement drifts (105)
- 741 acres of emplacement area required for 63,000 MTU at 85 MTU/acre
- DHLW/DOE-SNF placed between CSNF without additional space allocation

Pre-Emplacement Development



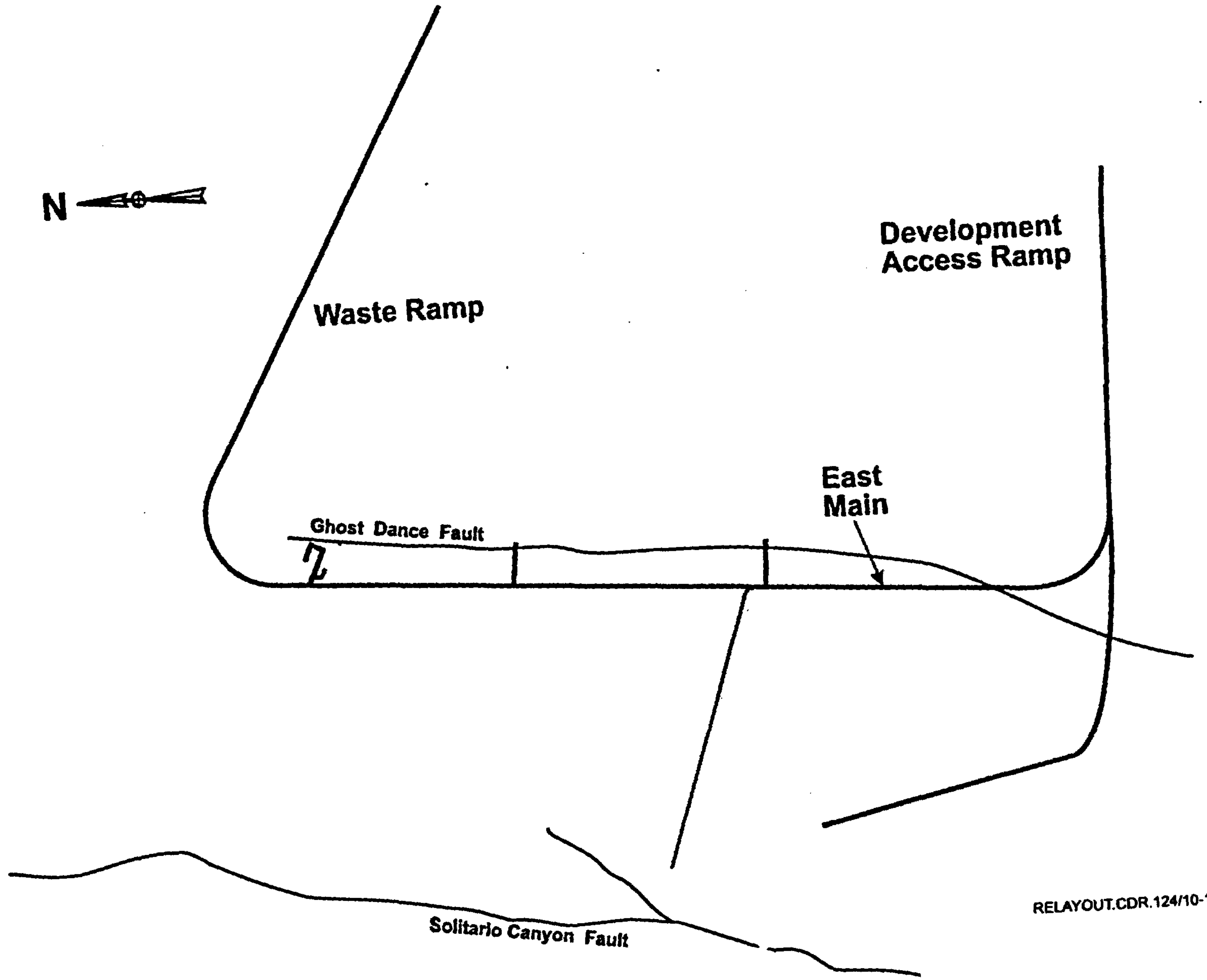
RELAYOUT.CDR.124/10-14-97

Pre-Emplacement Development



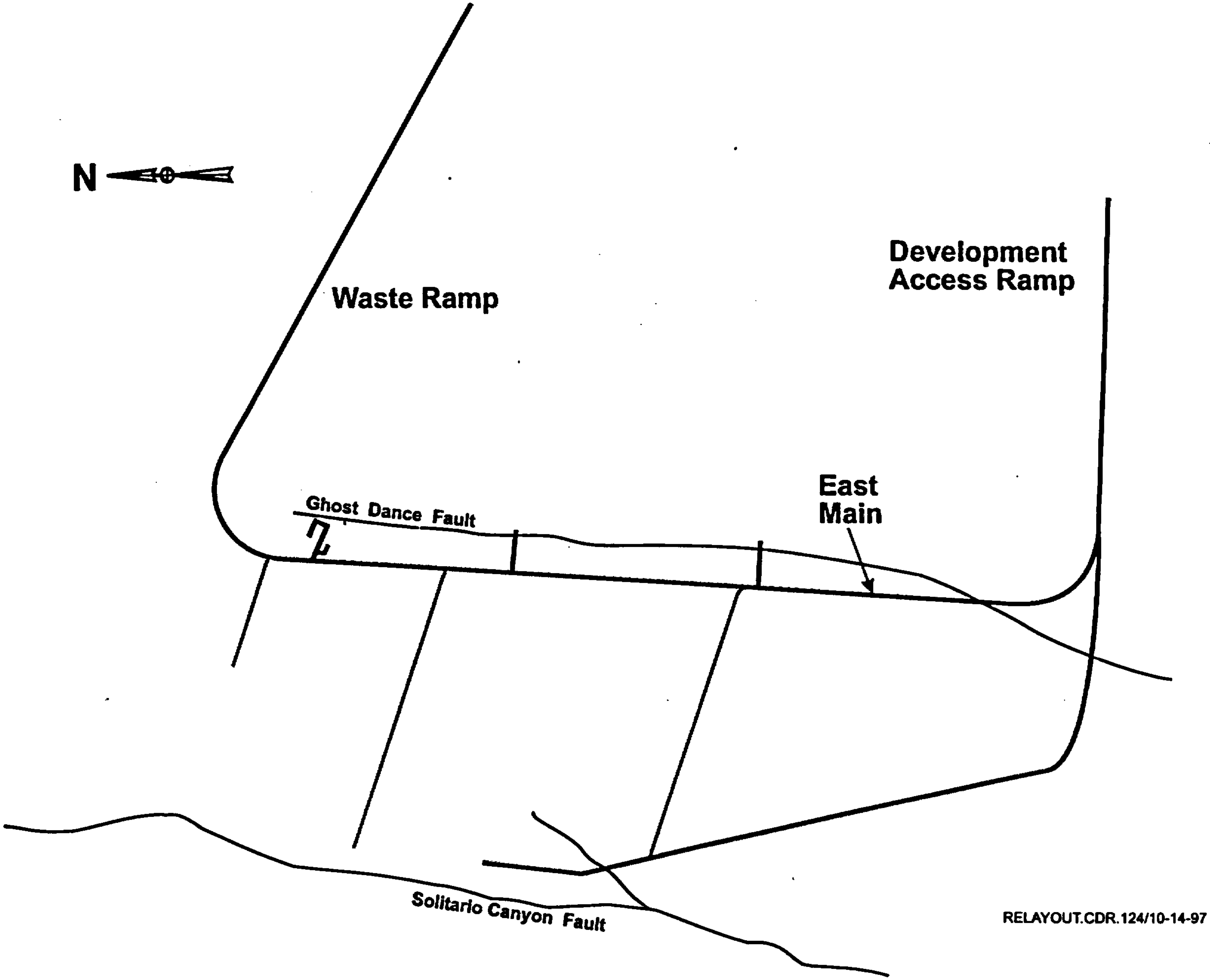
RELAYOUT.CDR.124/10-14-97

Pre-Emplacement Development

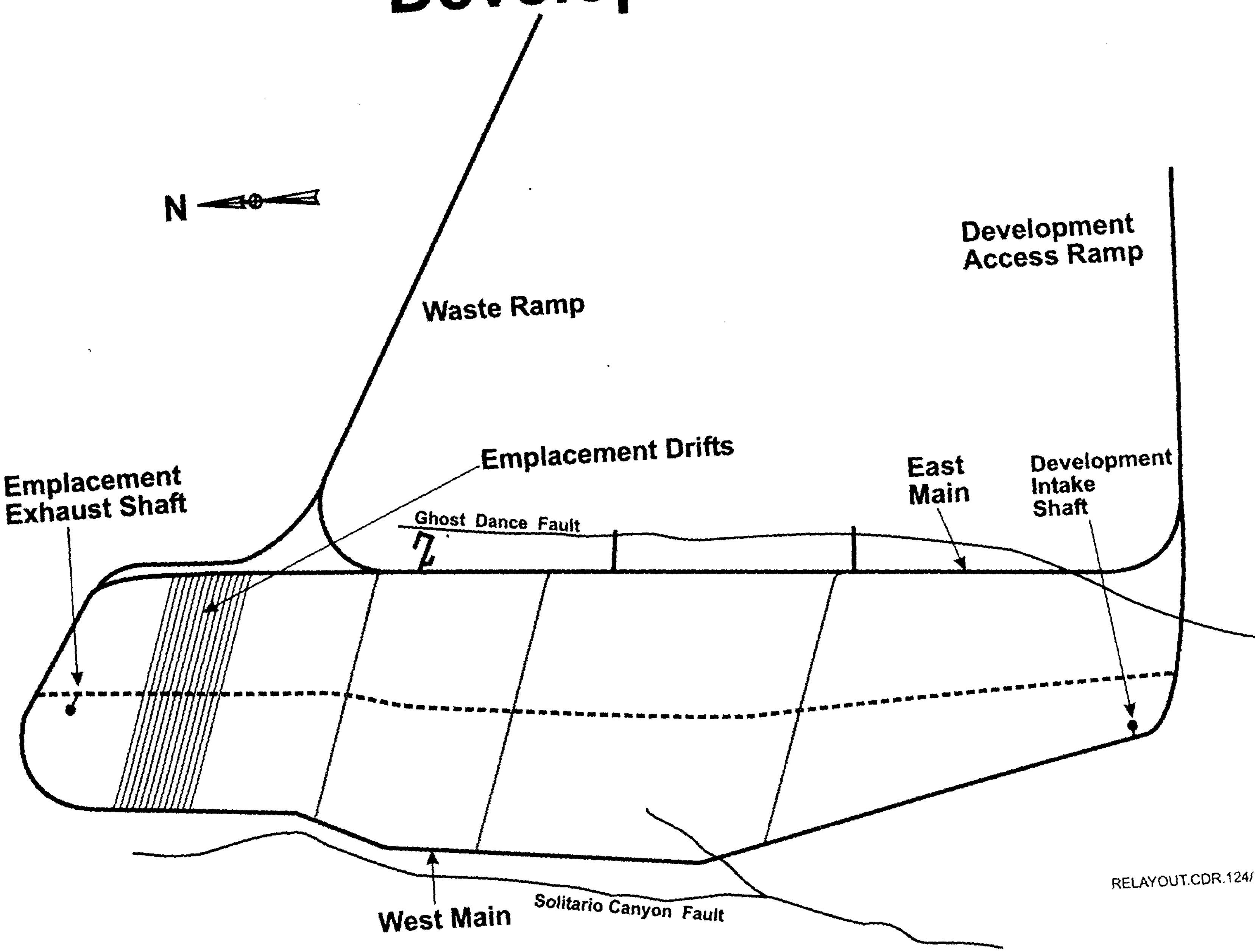


RELAYOUT.CDR.124/10-14-97

Pre-Emplacement Development

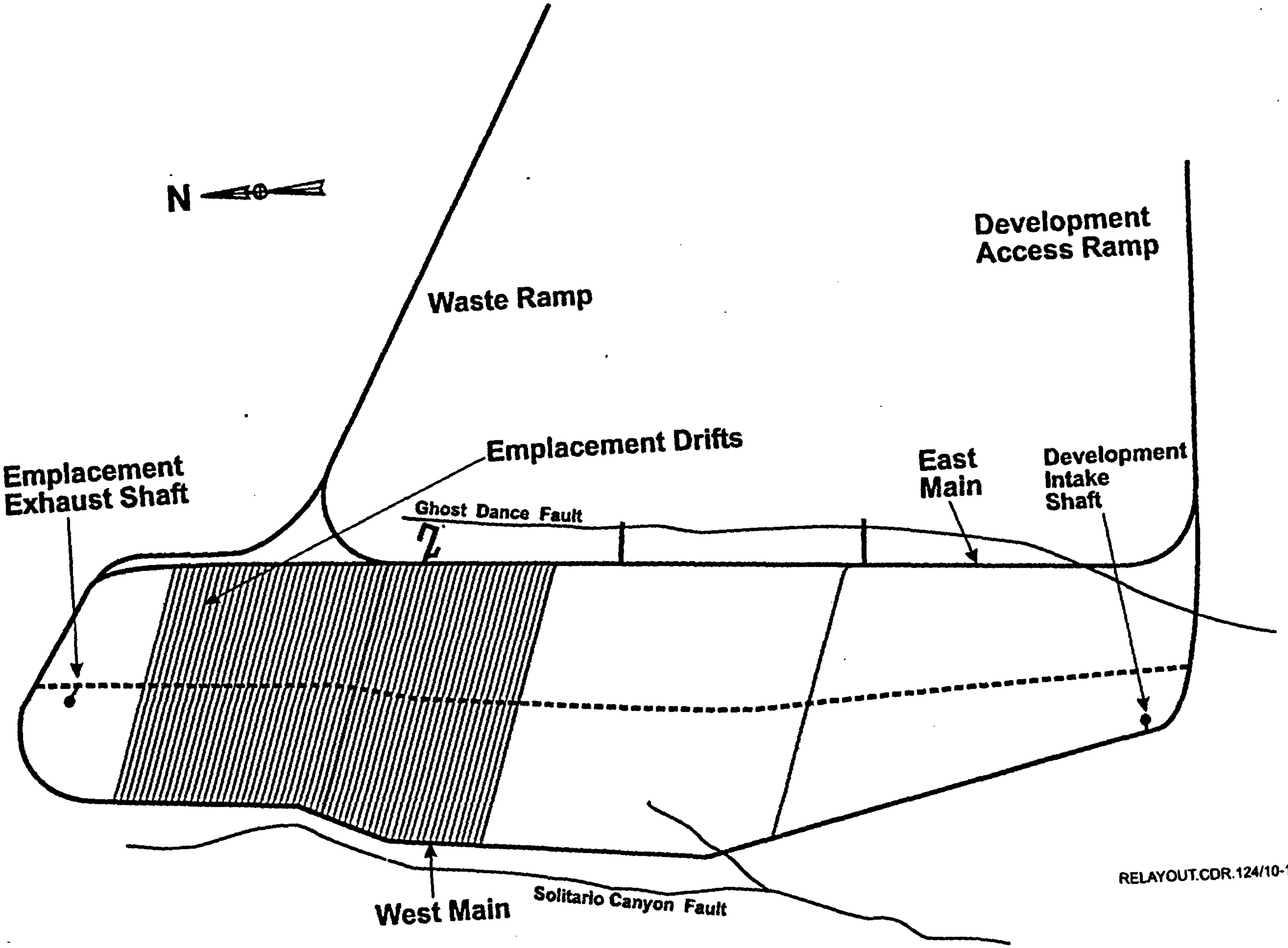


Start of Simultaneous Emplacement & Development



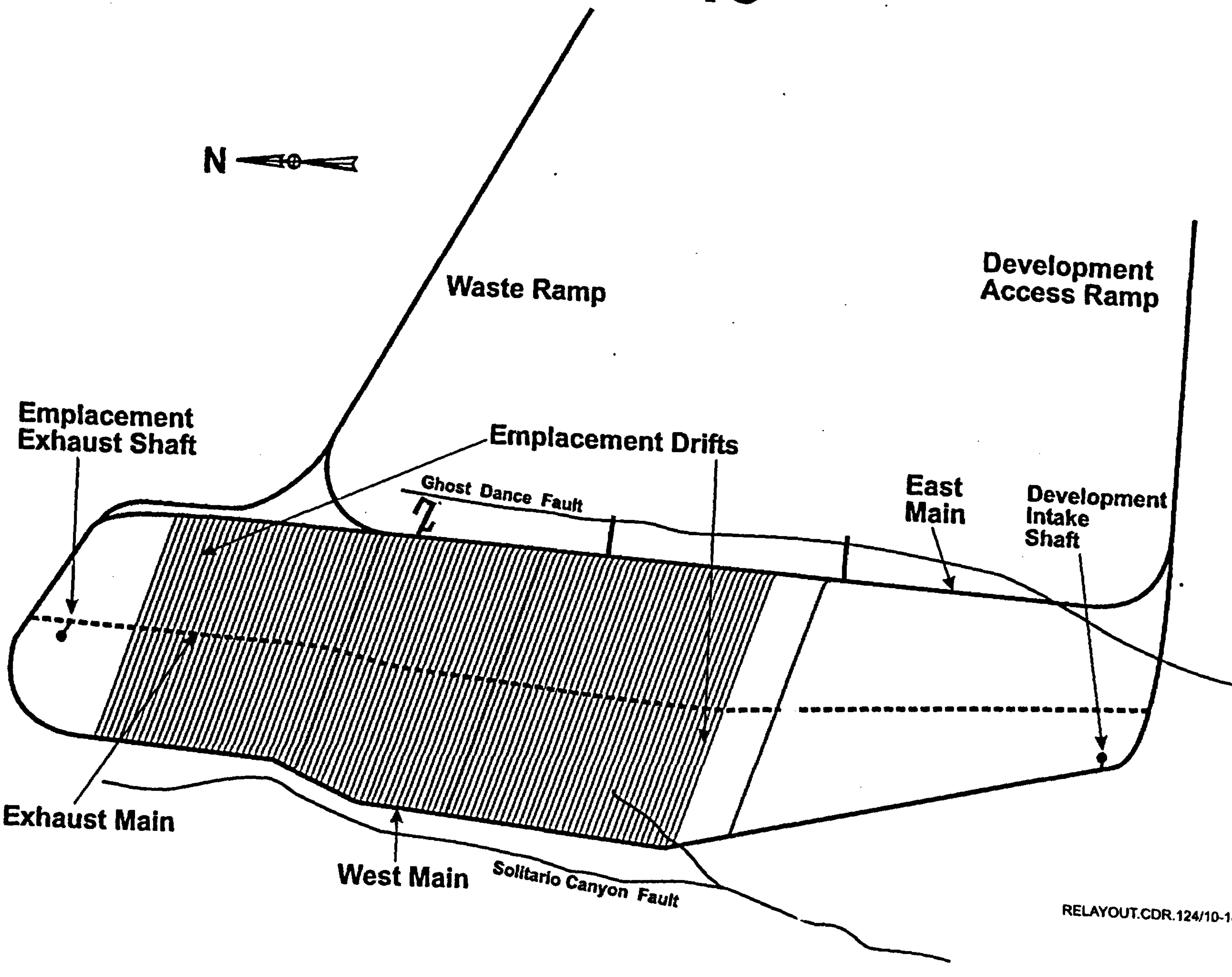
RELAYOUT.CDR.124/10-14-97

Simultaneous Emplacement/Development Year 10



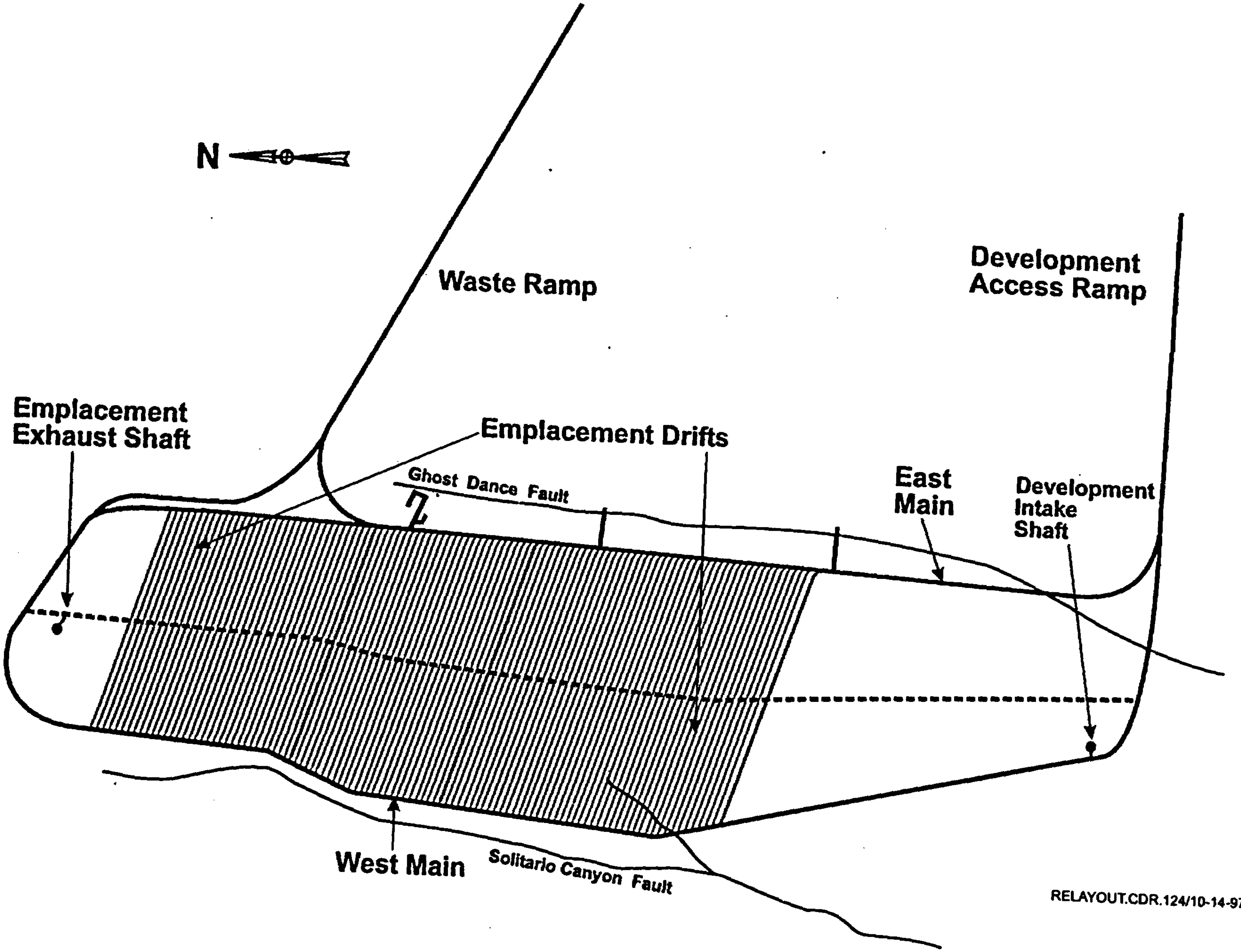
RELAYOUT.CDR.124/10-14-97

Simultaneous Emplacement/Development Year 15



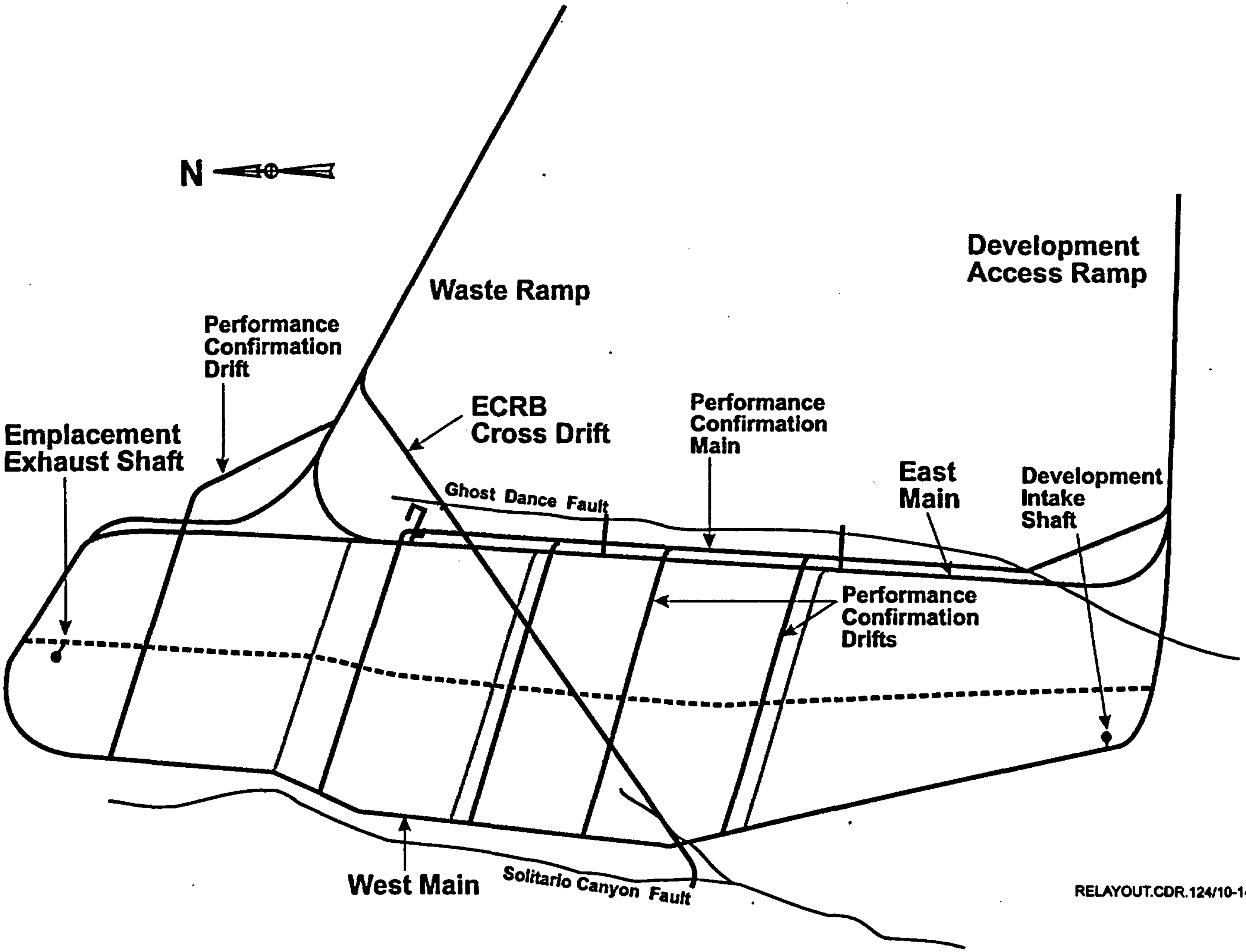
RELAYOUT.CDR.124/10-14-97

Caretaker



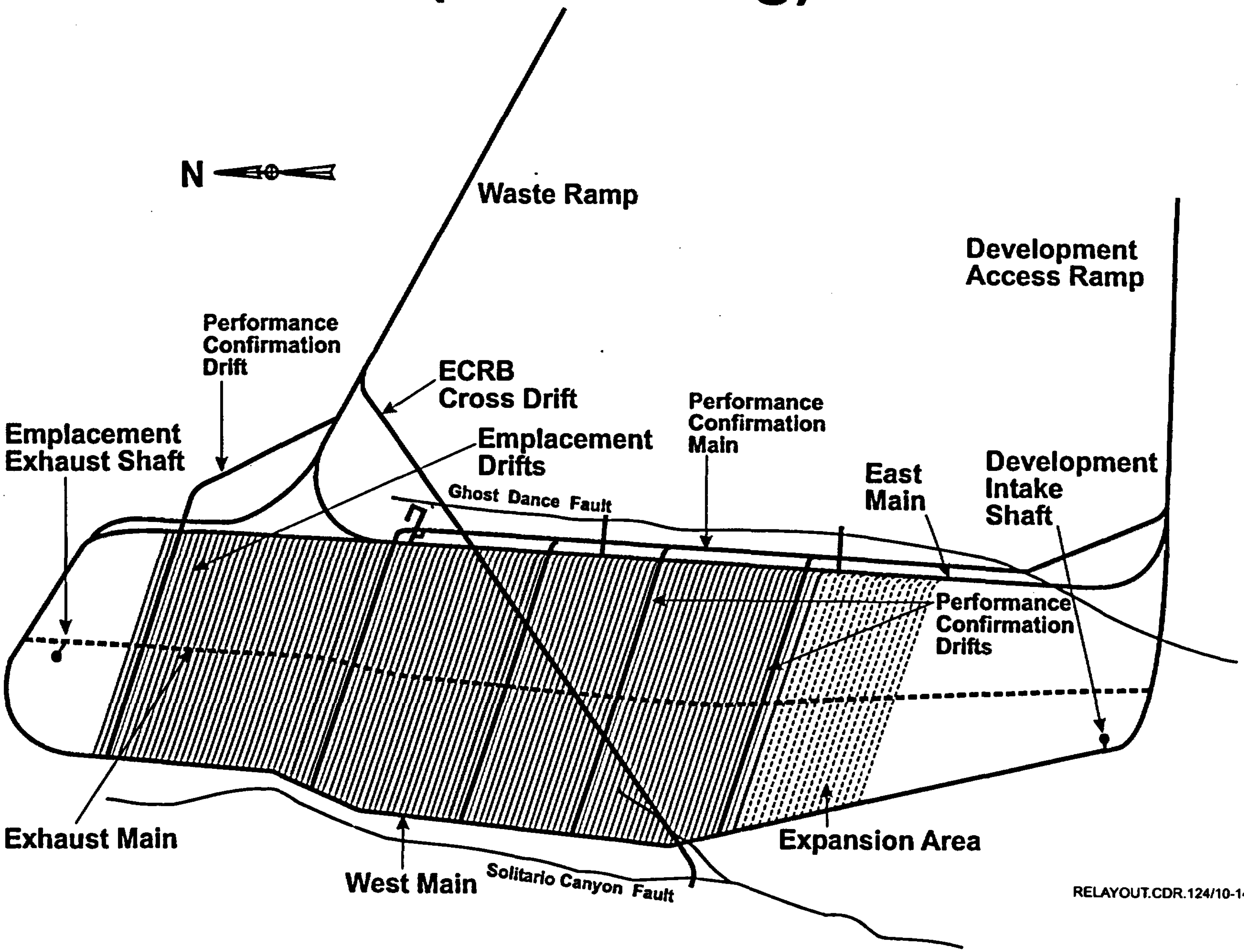
RELAYOUT.CDR.124/10-14-97

Mapped Drifting

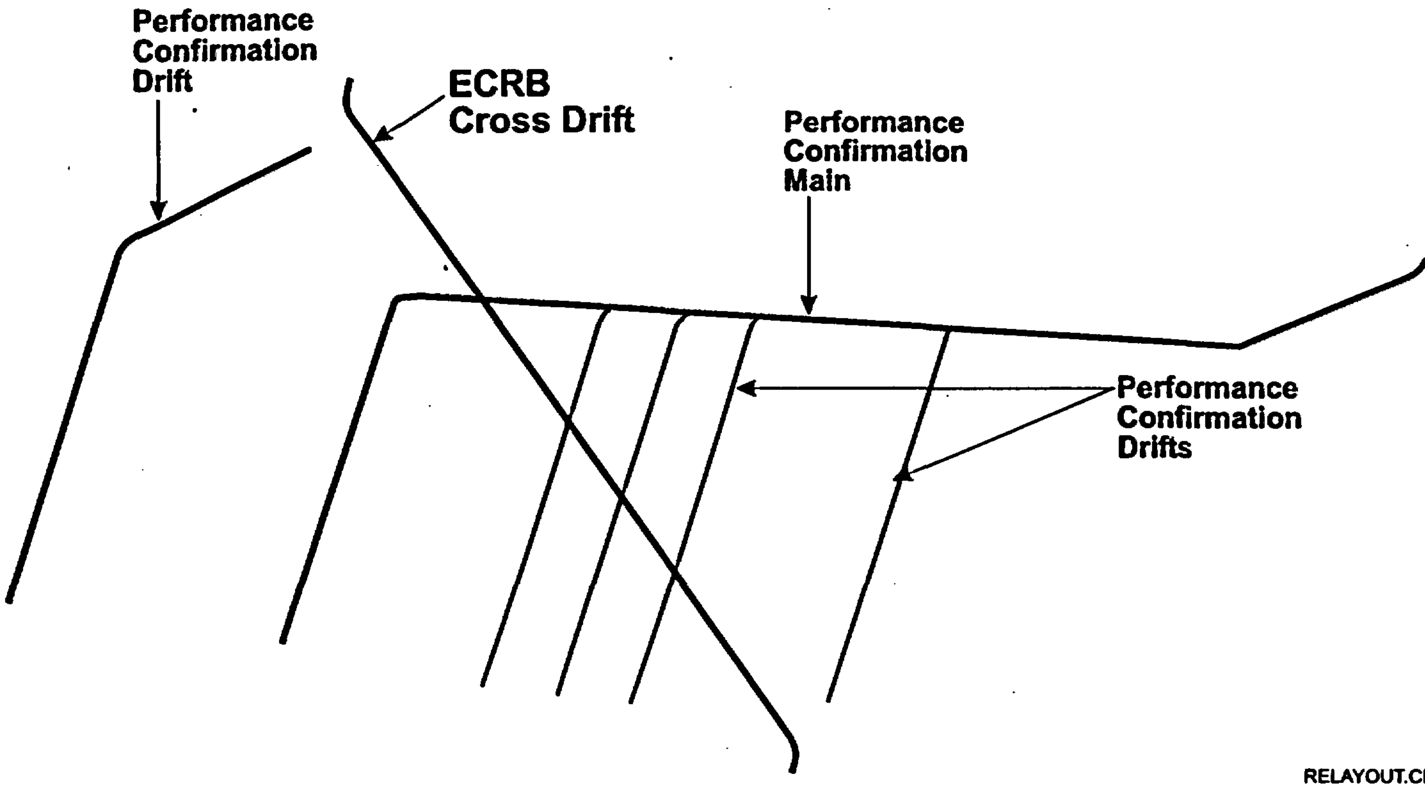


RELAYOUT.CDR.124/10-14-97

Preliminary Repository Layout (All Drifting)



RELAYOUT.CDR.124/10-14-97



RELAYOUT.CDR.124/10-14-97

TRW Environmental
Safety Systems Inc.

1180 Town Center Drive
Las Vegas, NV 89134
702.295.5400

TRW

(6)

WBS: 1.2.5
QA: N/A

Contract #: DE-AC01-91RW00134
LV.LI.JLY.03/97-008

March 13, 1997

Stephan J. Brocoum
Assistant Manager, Licensing
U.S. Department of Energy
Yucca Mountain Site Characterization Office
P.O. Box 30307
North Las Vegas, NV 89036-0307

Dear Dr. Brocoum:

Subject: Analysis of Requirements for Mapping of the Emplacement Drifts

As requested, the Management and Operating Contractor (M&O) Licensing Office has completed an analysis of the requirements contained in the disposal regulations (10 CFR Part 60) for mapping of the emplacement drifts. Site Evaluation Program Operations and Repository Design staff have developed options for mapping of the drifts that are described in the attached white paper. Potential design and construction considerations that must be evaluated to implement the mapping of the emplacement drifts are also included in the white paper. This evaluation includes consideration of the regulatory requirements for scientific data needed for site characterization, performance assessment, and performance confirmation. Additional evaluations of these data needs and design options that could be implemented to provide the data will be presented in a position paper on critical design issues for Viability Assessment (VA) that is scheduled for delivery to the U.S. Department of Energy (DOE) at the end of April.

Agreement on the level of detail necessary to satisfy the regulatory requirements for mapping of the emplacement drifts would be highly desirable before the mapping option is selected and repository design finalized. We urge DOE to pursue negotiations with the U.S. Nuclear Regulatory Commission (NRC) to determine the level of detail necessary to satisfy the regulatory requirements.

If you have any questions about the regulatory requirements, mapping options, or design and construction considerations, please call Terry Crump at 295-4886 or any of the following Operations Managers.

Sincerely,

Jean L. Younker, Manager
Regulatory Operations
Management and Operating Contractor

Richard D. Snell, Manager
Engineering & Integration Operations
Management and Operating Contractor

Larry R. Hayes, Manager
Site Evaluation Program Operations
Management and Operating Contractor

Enclosure:
Regulatory Requirements, Mapping Options, and
Design Considerations for Mapping of the Emplacement Drifts

cc w/encl:
K. L. Ashe, M&O, Las Vegas, Nevada, M/S 423
S. C. Beason, USGS, Denver, Colorado, M/S 771
A. B. Brandstetter, M&O, Las Vegas, Nevada, M/S 423
T. R. Crump, M&O, Las Vegas, Nevada, M/S 423
A. V. Gil, DOE/YMSCO, Las Vegas, Nevada, M/S 523
P. G. Harrington, DOE/YMSCO, Las Vegas, Nevada, M/S 523
M. A. Lugo, M&O, Las Vegas, Nevada, M/S 423
D. G. McKenzie, M&O, Las Vegas, Nevada, M/S 423
R. D. Memory, M&O, Las Vegas, Nevada, M/S 423
R. M. Nolting, M&O, Las Vegas, Nevada, M/S 423
R. C. Quittmeyer, M&O, Las Vegas, Nevada, M/S 423
T. R. Scotese, M&O, Las Vegas, Nevada, M/S 423
D. J. Soeder, USGS, Las Vegas, Nevada, M/S 527
J. T. Sullivan, DOE/YMSCO, Las Vegas, Nevada, M/S 523
B. H. Thomson, M&O, Las Vegas, Nevada, M/S 423
R. C. Wagner, M&O, Las Vegas, Nevada, M/S 423
RPC = 6 pages

JLY:mp

Regulatory Requirements, Mapping Options, and Design Considerations for Mapping of the Emplacement Drifts

Summary

The intent of this paper is to identify the regulatory requirements to map the emplacement drifts, mapping options to provide appropriate levels of detail, and design considerations needed to accommodate the mapping options. The regulatory requirements, mapping options, and design considerations summarized below are currently being carried in the form of design and construction options for the repository and are being included in the plans for performance confirmation. The design and mapping options are described in the draft Subsurface Repository Performance Confirmation Facilities report (BCA000000-01717-0200-00011).

An analysis of 10 CFR Part 60 has identified three types of regulatory requirements that apply to mapping the emplacement drifts. Two of the requirements fall within the scope of performance confirmation activities: (a) show that data have not changed beyond the limits assumed for facility design, and (b) show that actual subsurface conditions and changes to those conditions are within the limits assumed for design and construction. The third type of requirement is to provide records of construction which include geologic maps and cross sections. The intent of this type of requirement is clearly indicated in the supplemental information accompanying 10 CFR Part 60 (48 FR 28194). However, the regulations provide no guidance about the level of detail that will be necessary to satisfy this requirement. A Project position should be determined on the appropriate level of detail needed to satisfy design and performance confirmation requirements. Once this position has been determined, negotiations between the DOE and the NRC staff should be initiated concerning the level of detail that will be necessary to satisfy the regulatory requirements for mapping of the emplacement drifts. (See Regulatory Requirements.)

Site Evaluation Program Operations and Repository Design staffs have identified options for mapping the emplacement drifts that could satisfy the regulatory requirements. However, agreement between the DOE and the NRC is needed on the extent of mapping necessary to satisfy the requirements before an option can be selected. It is important to note that the amount of mapping that is necessary prior to emplacement of the ground support system could affect selection of the ground control system, its installation, and may even affect overall effectiveness. Hence, the mapping requirements will drive several design considerations, at least some aspects of construction sequencing, and repository development costs.

Regulatory Requirements

There are three types of regulatory requirements for mapping the emplacement drifts. The first two items are requirements applicable to Performance Confirmation. The third requirement is applicable to construction records.

1. Demonstrate that data obtained about the site during construction are within the predicted limits assumed for facility design (10 CFR 60.32(b)(2), 10 CFR 60.44(b), 10 CFR 60.133(b)).

2. Demonstrate that actual subsurface conditions encountered and changes in those conditions are within the limits assumed for design and construction (10 CFR 60.51(a)(3), 10 CFR 60.133(b), 10 CFR 60.140(a)(1)).

The contrast between these two types of requirements may not be intuitively clear, but the distinction reflects the differences established in the regulatory language.

3. Explicit requirements to map and provide descriptions of materials encountered (10 CFR 60.72(b)(1)-(4)).

The NRC's intent in including the explicit requirement, according to the supplementary information for 10 CFR Part 60, was to specify that the construction records include "a description of materials encountered rather than the materials themselves" (48 FR 28194, p. 33-34). This specification precludes merely keeping track of the material excavated by monitoring and sampling the muck. To fulfill this requirement the regulation specifies production of geologic maps and geologic cross sections of underground excavations. In any case, this requirement apparently goes beyond the requirements of items 1 and 2 because demonstrations that either (a) geologic features do not differ from those that were assumed for design and construction, or (b) conditions are within the limits assumed for design and construction but may not be sufficient to fulfill the requirement to provide geologic maps as part of the records of construction of the GROA.

Performance confirmation calculations may be sufficient to demonstrate both that conditions have not changed beyond the bounds assumed for design and construction, and that conditions are within the limits assumed for design and construction. For the explicit mapping requirements, the regulations do not specify the level of detail that is expected. Therefore, there are several mapping and/or observation options that might provide adequate levels of detail in the form of maps and other records to fulfill the requirements. The mapping options and design considerations are identified in the following sections.

Mapping Options

Site Evaluation Program Operations and Repository Design staffs have indicated that there are two general approaches to mapping: (1) systematic mapping that involves mapping only non-emplacement drifts, which are in the emplacement area, and (2) emplacement drift mapping that would include mapping all repository drifts.

Systematic Mapping

For systematic mapping, excavation, mapping and support of drifts selected for mapping would be separated from excavation and support of the emplacement drifts. Drifts selected for mapping, such as perimeter drifts, ventilation mains, observation drifts, and possibly including specified drifts in the emplacement network, would be excavated using a two-pass method. In the first pass, these drifts would be excavated, and temporary ground support would be installed. Once the drifts were stabilized, they would be mapped. After mapping had been concluded, a second pass would be made to install permanent ground support, likely in the form of cast-in-place concrete lining.

The emplacement drifts would be excavated, and the precast concrete segments would be installed as permanent ground support as the excavation progressed. This system optimizes construction efficiency by minimizing the number of separate operations and associated costs. Mapping would not be conducted in these drifts, but it might be possible to have an observer on the TBM to document changes in the rock. Repository Design does not favor this option because of the potential difficulties associated with the need to observe features as they are intersected. From a regulatory perspective, the decisions of an observer about whether to map or not map a feature could be viewed by the NRC and intervenors as arbitrary decisions.

Systematic mapping could be used if agreement with the NRC is reached such that continuous mapping of each drift is not required. This option may have cost and schedule advantages and could provide access for observation and testing throughout the operational period.

Emplacement Drift Mapping

For emplacement drift mapping, a two-pass system would be used for all drifts. The drifts would be excavated, and temporary ground support would be installed. Once the drifts were stabilized, they would be mapped. After mapping had been concluded, the drifts could be permanently supported. Emplacement drift mapping, provides for mapping of each drift but would preclude direct observation after the drifts had been mapped. A possible alternative would be to install a lining in one pass, but to conduct limited mapping and/or sampling through windows left in selected segments. (Note: The technical feasibility of this option has not been established.) Once mapping had been completed, the windows would be permanently sealed. Underground mapping experience in the ESF indicates that mapping through the windows alone would not provide sufficient information to fulfill documentation requirements because some underground features, especially fractures, are not sufficiently continuous to be mapped in one rib and projected successfully to other drifts, or fractures are not oriented such that they can be mapped in one rib.

Conclusions

Any plan for mapping of drifts in the proposed emplacement area should clearly describe the purpose and basis for the mapping. Mapping of non-emplacement drifts, resulting in a system of mapped drifts, is considered a sufficient strategy by both Repository Design and the Yucca Mountain Project Repository Design Consulting Board. Costs and construction integration problems are likely to be greater with a multi-pass system. In any case mapping should be consistent with nationally accepted standards for mapping underground excavations (e.g., ASTM Standard 4879-89: Geotechnical Mapping of Large Underground Openings in Rock).

TRW Environmental
Safety Systems Inc.

1180 Town Center Drive
Las Vegas, NV 89134
702.295.5400

TRW

6

WBS: 1.2.5
QA: N/A

Contract #: DE-AC01-91RW00134
LV.LI.JLY.03/97-008

March 13, 1997

Stephan J. Brocoum
Assistant Manager, Licensing
U.S. Department of Energy
Yucca Mountain Site Characterization Office
P.O. Box 30307
North Las Vegas, NV 89036-0307

Dear Dr. Brocoum:

Subject: Analysis of Requirements for Mapping of the Emplacement Drifts

As requested, the Management and Operating Contractor (M&O) Licensing Office has completed an analysis of the requirements contained in the disposal regulations (10 CFR Part 60) for mapping of the emplacement drifts. Site Evaluation Program Operations and Repository Design staff have developed options for mapping of the drifts that are described in the attached white paper. Potential design and construction considerations that must be evaluated to implement the mapping of the emplacement drifts are also included in the white paper. This evaluation includes consideration of the regulatory requirements for scientific data needed for site characterization, performance assessment, and performance confirmation. Additional evaluations of these data needs and design options that could be implemented to provide the data will be presented in a position paper on critical design issues for Viability Assessment (VA) that is scheduled for delivery to the U.S. Department of Energy (DOE) at the end of April.

Agreement on the level of detail necessary to satisfy the regulatory requirements for mapping of the emplacement drifts would be highly desirable before the mapping option is selected and repository design finalized. We urge DOE to pursue negotiations with the U.S. Nuclear Regulatory Commission (NRC) to determine the level of detail necessary to satisfy the regulatory requirements.

If you have any questions about the regulatory requirements, mapping options, or design and construction considerations, please call Terry Crump at 295-4886 or any of the following Operations Managers.

Sincerely,

Jean L. Younker, Manager
Regulatory Operations
Management and Operating Contractor

Richard D. Snell, Manager
Engineering & Integration Operations
Management and Operating Contractor

Larry R. Hayes, Manager
Site Evaluation Program Operations
Management and Operating Contractor

Enclosure:
Regulatory Requirements, Mapping Options, and
Design Considerations for Mapping of the Emplacement Drifts

cc w/encl:
K. L. Ashe, M&O, Las Vegas, Nevada, M/S 423
S. C. Beason, USGS, Denver, Colorado, M/S 771
A. B. Brandstetter, M&O, Las Vegas, Nevada, M/S 423
T. R. Crump, M&O, Las Vegas, Nevada, M/S 423
A. V. Gil, DOE/YMSCO, Las Vegas, Nevada, M/S 523
P. G. Harrington, DOE/YMSCO, Las Vegas, Nevada, M/S 523
M. A. Lugo, M&O, Las Vegas, Nevada, M/S 423
D. G. McKenzie, M&O, Las Vegas, Nevada, M/S 423
R. D. Memory, M&O, Las Vegas, Nevada, M/S 423
R. M. Nolting, M&O, Las Vegas, Nevada, M/S 423
R. C. Quittmeyer, M&O, Las Vegas, Nevada, M/S 423
T. R. Scotese, M&O, Las Vegas, Nevada, M/S 423
D. J. Soeder, USGS, Las Vegas, Nevada, M/S 527
J. T. Sullivan, DOE/YMSCO, Las Vegas, Nevada, M/S 523
B. H. Thomson, M&O, Las Vegas, Nevada, M/S 423
R. C. Wagner, M&O, Las Vegas, Nevada, M/S 423
RPC = 6 pages

JLY:mp

Regulatory Requirements, Mapping Options, and Design Considerations for Mapping of the Emplacement Drifts

Summary

The intent of this paper is to identify the regulatory requirements to map the emplacement drifts, mapping options to provide appropriate levels of detail, and design considerations needed to accommodate the mapping options. The regulatory requirements, mapping options, and design considerations summarized below are currently being carried in the form of design and construction options for the repository and are being included in the plans for performance confirmation. The design and mapping options are described in the draft Subsurface Repository Performance Confirmation Facilities report (BCA000000-01717-0200-00011).

An analysis of 10 CFR Part 60 has identified three types of regulatory requirements that apply to mapping the emplacement drifts. Two of the requirements fall within the scope of performance confirmation activities: (a) show that data have not changed beyond the limits assumed for facility design, and (b) show that actual subsurface conditions and changes to those conditions are within the limits assumed for design and construction. The third type of requirement is to provide records of construction which include geologic maps and cross sections. The intent of this type of requirement is clearly indicated in the supplemental information accompanying 10 CFR Part 60 (48 FR 28194). However, the regulations provide no guidance about the level of detail that will be necessary to satisfy this requirement. A Project position should be determined on the appropriate level of detail needed to satisfy design and performance confirmation requirements. Once this position has been determined, negotiations between the DOE and the NRC staff should be initiated concerning the level of detail that will be necessary to satisfy the regulatory requirements for mapping of the emplacement drifts. (See Regulatory Requirements.)

Site Evaluation Program Operations and Repository Design staffs have identified options for mapping the emplacement drifts that could satisfy the regulatory requirements. However, agreement between the DOE and the NRC is needed on the extent of mapping necessary to satisfy the requirements before an option can be selected. It is important to note that the amount of mapping that is necessary prior to emplacement of the ground support system could affect selection of the ground control system, its installation, and may even affect overall effectiveness. Hence, the mapping requirements will drive several design considerations, at least some aspects of construction sequencing, and repository development costs.

Regulatory Requirements

There are three types of regulatory requirements for mapping the emplacement drifts. The first two items are requirements applicable to Performance Confirmation. The third requirement is applicable to construction records.

1. Demonstrate that data obtained about the site during construction are within the predicted limits assumed for facility design (10 CFR 60.32(b)(2), 10 CFR 60.44(b), 10 CFR 60.133(b)).

2. Demonstrate that actual subsurface conditions encountered and changes in those conditions are within the limits assumed for design and construction (10 CFR 60.51(a)(3), 10 CFR 60.133(b), 10 CFR 60.140(a)(1)).

The contrast between these two types of requirements may not be intuitively clear, but the distinction reflects the differences established in the regulatory language.

3. Explicit requirements to map and provide descriptions of materials encountered (10 CFR 60.72(b)(1)-(4)).

The NRC's intent in including the explicit requirement, according to the supplementary information for 10 CFR Part 60, was to specify that the construction records include "a description of materials encountered rather than the materials themselves" (48 FR 28194, p. 33-34). This specification precludes merely keeping track of the material excavated by monitoring and sampling the muck. To fulfill this requirement the regulation specifies production of geologic maps and geologic cross sections of underground excavations. In any case, this requirement apparently goes beyond the requirements of items 1 and 2 because demonstrations that either (a) geologic features do not differ from those that were assumed for design and construction, or (b) conditions are within the limits assumed for design and construction but may not be sufficient to fulfill the requirement to provide geologic maps as part of the records of construction of the GROA.

Performance confirmation calculations may be sufficient to demonstrate both that conditions have not changed beyond the bounds assumed for design and construction, and that conditions are within the limits assumed for design and construction. For the explicit mapping requirements, the regulations do not specify the level of detail that is expected. Therefore, there are several mapping and/or observation options that might provide adequate levels of detail in the form of maps and other records to fulfill the requirements. The mapping options and design considerations are identified in the following sections.

Mapping Options

Site Evaluation Program Operations and Repository Design staffs have indicated that there are two general approaches to mapping: (1) systematic mapping that involves mapping only non-emplacement drifts, which are in the emplacement area, and (2) emplacement drift mapping that would include mapping all repository drifts.

Systematic Mapping

For systematic mapping, excavation, mapping and support of drifts selected for mapping would be separated from excavation and support of the emplacement drifts. Drifts selected for mapping, such as perimeter drifts, ventilation mains, observation drifts, and possibly including specified drifts in the emplacement network, would be excavated using a two-pass method. In the first pass, these drifts would be excavated, and temporary ground support would be installed. Once the drifts were stabilized, they would be mapped. After mapping had been concluded, a second pass would be made to install permanent ground support, likely in the form of cast-in-place concrete lining.

The emplacement drifts would be excavated, and the precast concrete segments would be installed as permanent ground support as the excavation progressed. This system optimizes construction efficiency by minimizing the number of separate operations and associated costs. Mapping would not be conducted in these drifts, but it might be possible to have an observer on the TBM to document changes in the rock. Repository Design does not favor this option because of the potential difficulties associated with the need to observe features as they are intersected. From a regulatory perspective, the decisions of an observer about whether to map or not map a feature could be viewed by the NRC and intervenors as arbitrary decisions.

Systematic mapping could be used if agreement with the NRC is reached such that continuous mapping of each drift is not required. This option may have cost and schedule advantages and could provide access for observation and testing throughout the operational period.

Emplacement Drift Mapping

For emplacement drift mapping, a two-pass system would be used for all drifts. The drifts would be excavated, and temporary ground support would be installed. Once the drifts were stabilized, they would be mapped. After mapping had been concluded, the drifts could be permanently supported. Emplacement drift mapping, provides for mapping of each drift but would preclude direct observation after the drifts had been mapped. A possible alternative would be to install a lining in one pass, but to conduct limited mapping and/or sampling through windows left in selected segments. (Note: The technical feasibility of this option has not been established.) Once mapping had been completed, the windows would be permanently sealed. Underground mapping experience in the ESF indicates that mapping through the windows alone would not provide sufficient information to fulfill documentation requirements because some underground features, especially fractures, are not sufficiently continuous to be mapped in one rib and projected successfully to other drifts, or fractures are not oriented such that they can be mapped in one rib.

Conclusions

Any plan for mapping of drifts in the proposed emplacement area should clearly describe the purpose and basis for the mapping. Mapping of non-emplacement drifts, resulting in a system of mapped drifts, is considered a sufficient strategy by both Repository Design and the Yucca Mountain Project Repository Design Consulting Board. Costs and construction integration problems are likely to be greater with a multi-pass system. In any case mapping should be consistent with nationally accepted standards for mapping underground excavations (e.g., ASTM Standard 4879-89: Geotechnical Mapping of Large Underground Openings in Rock).

YUCCA MOUNTAIN PROJECT

Studies

Technical Data Needs

Presented to: DOE/NRC Appendix 7 Meeting on Plans for Geologic Mapping of Subsurface Facilities

Presented by:
Brent H. Thomson
Systems Analysis and Modeling

October 16, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Types of Data-Needs

- **Confirmatory Type of Data-Needs**
  - Confirm Assumptions
  - Confirm Data Within Design Requirements
  - Confirm Data Within Model Data Inputs Used
  - Confirm Spatial Interpolation and Extrapolation of Point Measurements is Within Predefined Bounds of Error
- **Surveillance Type of Data-Needs**
  - Detect, Document, and Understand Anomalous Conditions During Construction

Mapping

- Mapping, per ASTM D 4879 - Standard Guide for Geotechnical Mapping of Large Underground Openings in Rock
  - Provides a record of encountered conditions and features for subsurface excavations
  - Provides a database for design, for stability analysis, for confirmation of geotechnical predictions, for maintenance and monitoring, and a permanent record of construction
  - Examples: Full periphery maps, detailed line surveys, photography

Observations

- Observations provide documentation by qualified personnel to describe characteristics of the rock mass and record anomalous conditions as excavation progresses and to identify reportable geologic conditions
  - Examples: Stationing a geologist at the TBM, photography for supplemental records

Technical Data-Needs

- **Performance Confirmation Parameter Data-Needs**
  - Stratigraphy, Contact Locations
  - Location and Characteristics of Faults and Fault Zones
  - Location and Characteristics of Fractures and Fracture Zones
  - Location of Fracture Infillings and Chemical, Mineralogical, and Biological Characteristics
  - Location and Characteristics of Seeps
  - Confirm Absence of Hydrocarbons and Mineral Resources

Technical Data-Needs
(continued)

- **Other Data-Needs Including Repository Design Confirmation Data and Construction Records**
  - Rock Mass Quality
  - Geologic Maps and Cross Sections
  - Description of the Materials Encountered
  - Record of Construction Conditions/Problems
  - Observation of Anomalous Conditions
  - Drawings of As-Built Excavations and Descriptions of Installed Systems

Importance of Data

- Stratigraphy
  - Design - bounds vertical volume of rock available for potential repository within Topopah Spring thermal/mechanical unit with respect to needed rock stability, minimum of 200 m overburden required by 10 CFR Part 960, and assumed minimum of 100 m to water table
  - Performance Assessment and Process Modeling - defines geometric extent of applicable rock properties for thermal-hydrological and radionuclide transport analyses, but not a major issue for performance confirmation in waste emplacement drifts because only Topopah Spring hydrogeologic subunits will be intersected

Importance of Data

(continued)

- **Faults and Fault Zones**
  - Design - bounds volume of rock available for potential repository within Topopah Spring in horizontal direction, assuming a standoff of 120 m from the Ghost Dance fault and 60 m from other major faults; smaller faults with trace lengths of 200-300 m are expected, but not currently considered to impact design
  - Performance Assessment and Process Modeling - importance of faults for postclosure performance, including fluid flow and radionuclide transport, uncertain; currently, only location and vertical offset of major faults and some pneumatic properties are considered, but not their thermal-hydrological and radionuclide transport properties; postclosure importance will depend on extent of lateral diversion of flow within hydrogeologic units, being investigated now.

Importance of Data

(continued)

Summary of UZ Flow Model Relative to Faults

- Flow above repository
  - Most of the fast path flow through the PTn unit is associated with structural features such as faults or fault-associated fractures that cross the various geologic formations comprising the PTn
- Percolation flux at the repository
  - Analyses of borehole temperature data provide percolation rate estimates
  - Many of the high percolation flux estimates are obtained from boreholes that are located near faults
- Flow below the repository
  - Flow that encounters a generally eastward-dipping perched layer will be laterally diverted
  - Diversion continues until the water table is reached or until a fault or extensive fracture system is encountered that can reinitiate mostly vertical flow

Importance of Data
(continued)

Fault Properties in UZ Flow Model

- Current fault properties derived primarily from pneumatic data from the testing of the North Ghost Dance Fault Alcove
  - Gas permeabilities on the order of hundreds of darcies
  - Significant lateral variations in permeability within fault zones
- Additional data on fault properties and processes are needed
  - Some can be derived from the proposed cross drift testing in the Solitario Canyon fault

Importance of Data
(continued)

- Fractures and Fracture Zones
  - Design - for the ESF, considered in terms of rock stability through the Rock Mass Quality parameter, used to evaluate ground support requirements; extrapolated for potential repository from ESF data
  - Performance Assessment and Process Modeling - use and evaluation of detailed fracture characteristics to develop statistics for equivalent rock matrix properties (e.g., porosity and hydraulic conductivity) derived from model calibration against other data (e.g., measured moisture contents.) Detailed fracture information near instrumented emplacement drifts needed in full-scale thermal monitoring

Importance of Data
(continued)

- **Chemical/Mineralogical and Biological Characteristics of Fracture Infillings**
  - Design - for the ESF, considered in terms of rock stability through the Rock Mass Quality parameter, used to evaluate ground support requirements; extrapolated for potential repository from ESF data
  - Performance Assessment and Process Modeling - chemical/mineralogical and biological characteristics of fracture infillings considered in geochemical and waste package performance testing as basis for waste package corrosion model development; may also influence fluid flow and radionuclide transport, but not yet considered explicitly in performance assessments

Importance of Data

(continued)

- **Locations and Characteristics of Seeps**
  - Design - considered with respect to drainage and water removal from repository
  - Performance Assessment and Process Modeling - considered in waste package material degradation (i.e., corrosion) and waste form dissolution modeling with respect to potential postclosure performance, without knowledge of actual locations and local variations in seepage rates

Importance of Data
(continued)

- Confirm Absence of Hydrocarbons and Mineral Resources
  - Not considered in current design or performance assessment; occurrence of hydrocarbons and mineral resources of economic value would be a potentially adverse condition

YUCCA MOUNTAIN PROJECT

Studies

Confidence in Modeling and Predictions

Presented to: DOE/NRC Appendix 7 Meeting on Plans for Geologic Mapping of Subsurface Facilities

Presented by:
Brent H. Thomson
Systems Analysis and Modeling

October 16, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Current Level of Confidence

- Stratigraphy - High Confidence, except in western part of repository block
- Faults and Fault Zones - Moderate Confidence, specific underground locations and hydrologic importance of faults are less certain
- Fractures and Fracture Zones - High Confidence in ESF, lower confidence away from ESF

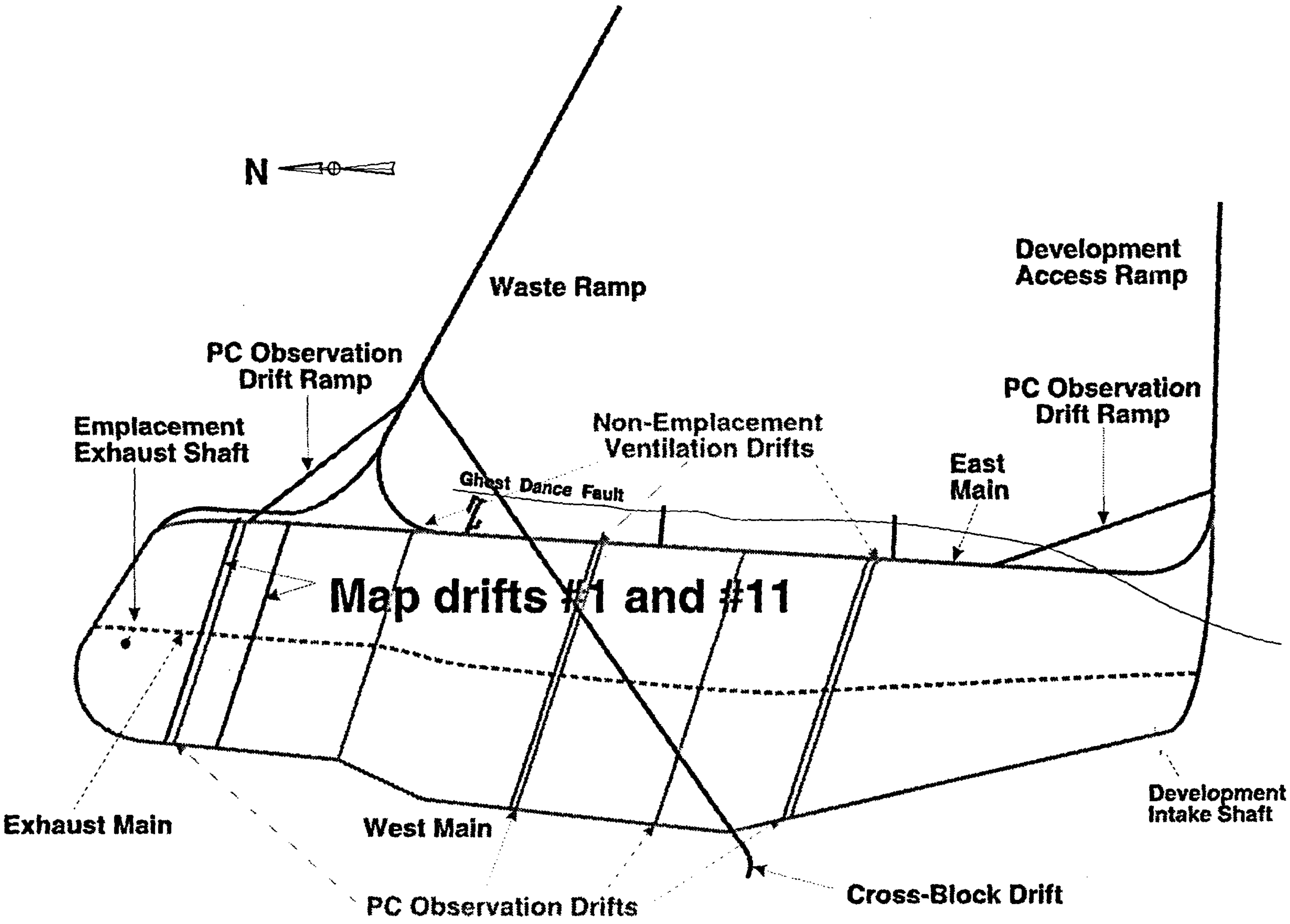
Proposed Construction Sequence and Mapping Options

- 1. Construct and Map Drift #1 with temporary ground support
- 2. Construct and Map Drift #11 with temporary ground support
- 3. If #1 and #11 OK, then construct drifts #2-#10 with
- precast lining
- 4. Construct and Map drift #21 with temporary ground support
- 5. If #21 is OK, then construct drifts #12-#20 with precast lining

Proposed Construction Sequence and Mapping Options

- **Goal** - Based on current understanding, map in detail a drift every 200-300 m to meet 10 CFR 60 requirements

Mapping Options
Preliminary Repository Layout



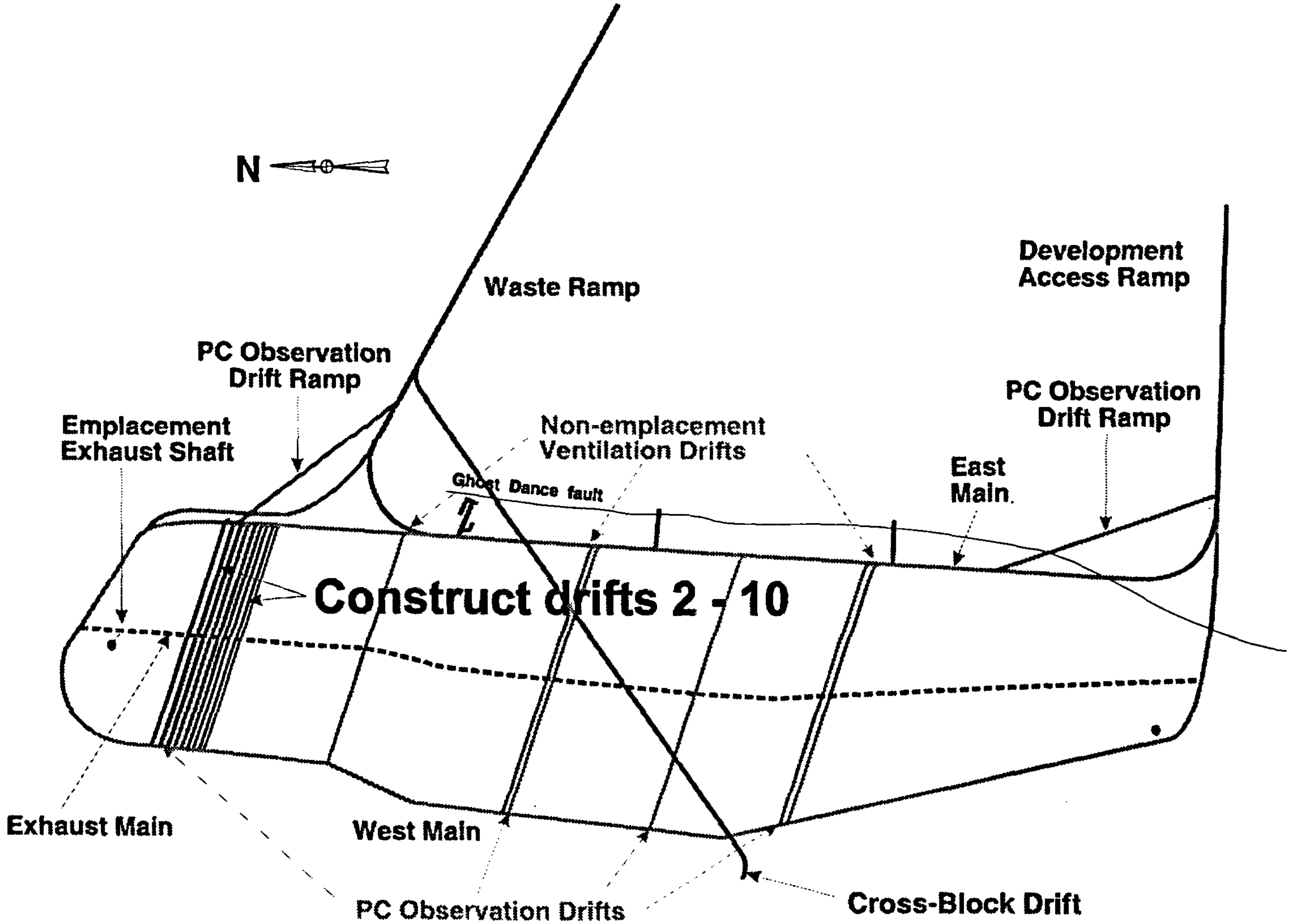
Proposed Construction Sequence and Mapping Options

- Where the 200-300 m spacing of mapped drifts coincides with existing ventilation or storage drifts, no additional mapping is necessary
  - assuming that no anomalous conditions are encountered in the vent and storage drifts

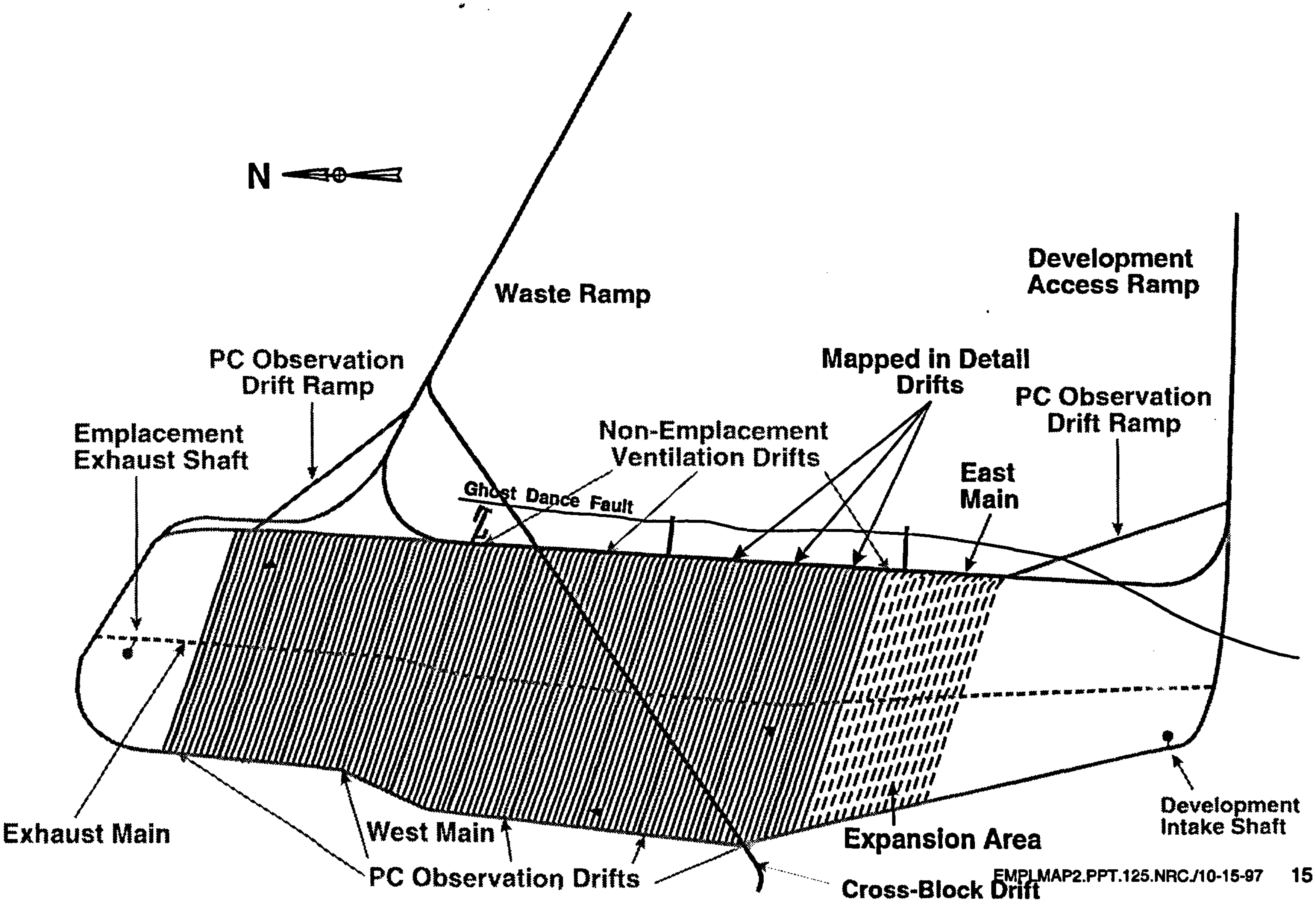
Proposed Construction Sequence and Mapping Options

- Mapping entails
  - Detailed mapping in unlined drifts and drifts with temporary support including:
    - Full-periphery geologic mapping
    - Detailed line surveys
  - Drifts with precast lining
    - Continuous observation (low-detail mapping)

Mapping Options
Preliminary Repository Layout



Mapping Options
Preliminary Repository Layout



Summary

- Continuous observation of all drifts
- Detailed mapping of non-emplacement drifts (Including performance confirmation drifts)
- Initially map in detail emplacement drifts on ~200-300 m centers
- This mapping approach satisfies mapping regulatory requirements

12

YUCCA MOUNTAIN PROJECT

Studies

Use of Fracture Data in ESF Design

Presented to:

DOE / NRC APPENDIX 7 DISCUSSIONS
Plans for Mapping of Subsurface Facilities

Presented by:

John H. Pye
Dwayne C. Kicker
Gerald H. Nieder-Westermann

MGDS — ESF Design Confirmation

October 16, 1997

U.S. Department of Energy
Office of Civilian Radioactive
Waste Management

Use of Fracture Data in ESF Design

- Overview
  - Background
  - Rock Mass Quality and Properties
  - Joint Distributions
  - Key Block Analysis

Use of Fracture Data in ESF Design

- ESF Design
  - core-based data
    - define geology
    - rock mass quality
    - rock mass properties
  - sampling limitations
    - orientatior.al effects
    - core loss, rubble zones
    - intact material only

Use of Fracture Data in ESF Design

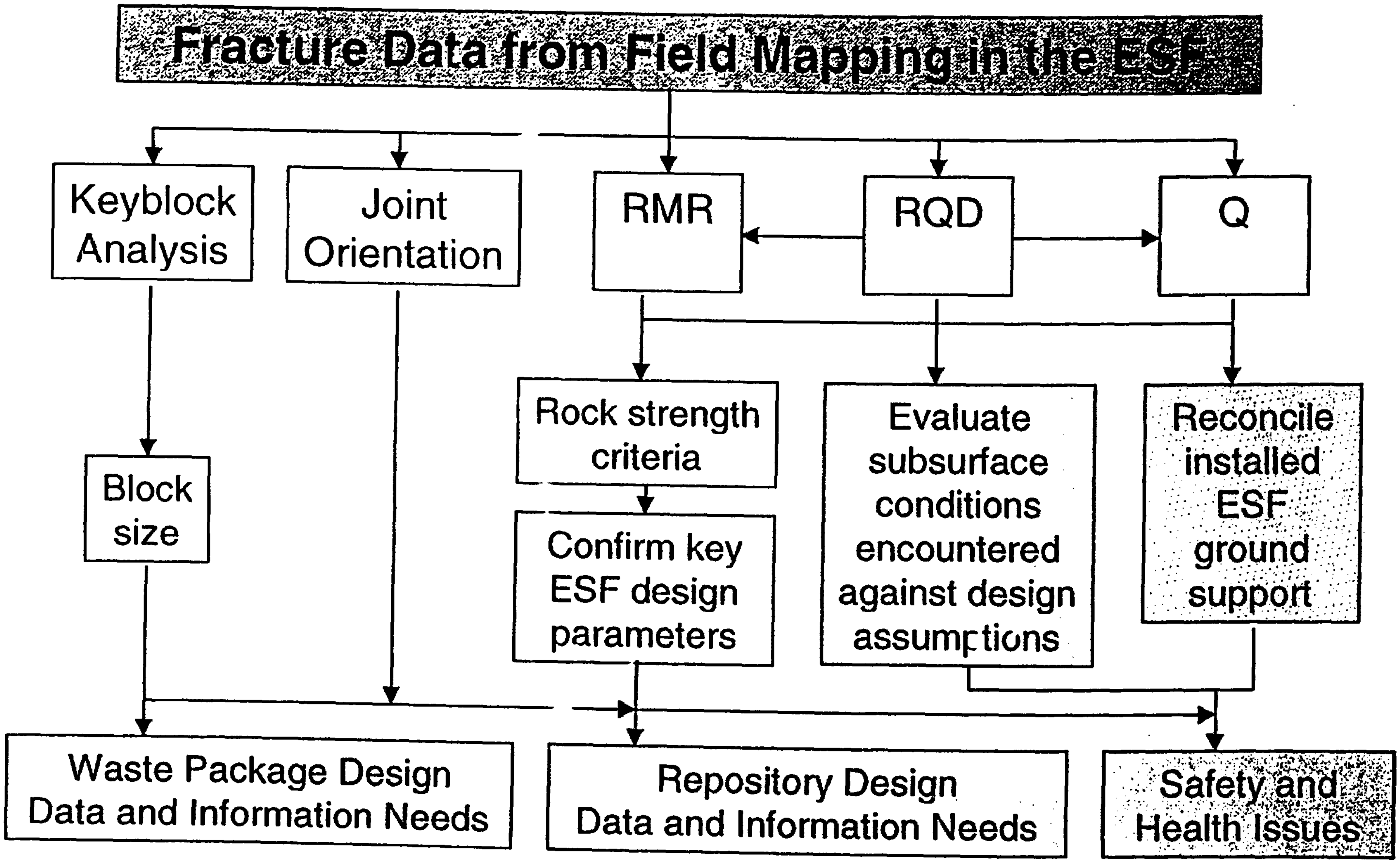
- ESF Design Confirmation
  - full-peripheral tunnel mapping
    - detailed line survey
    - scanline
  - construction records
    - surveys
    - description of materials encountered
    - geological maps and cross-sections
    - construction problems
    - anomalous conditions
    - instrumentation locations and readings
    - location and description of ground support systems

Use of Fracture Data in ESF Design

- Performance Confirmation
  - ESF Design Confirmation
  - confirm geology
  - confirm empirical-based rock mass properties
  - provide a complete statistical description of the rock mass (bounding)
  - assess opening stability and key structural features
  - provide as-built geotechnical drawings and ground support
  - assess constructibility — TBM performance
  - define anomalies and off-normal conditions

Use of Fracture Data in ESF Design

- ESF Ground Support and Opening Design *(based on borehole fracture logging)*
  - determine key design parameters
  - preliminary ground support estimates
  - guidelines for recommended ground support
- ESF Design Confirmation *(based on fracture mapping in the tunnel)*
  - confirm key design parameters
  - evaluate actual subsurface conditions encountered against design assumptions
  - reconcile installed ground support


Fracture Data from Field Mapping in the ESF
Keyblock Analysis
Joint Orientation
RMR
RQD
Q
Block size
Rock strength criteria
Confirm key ESF design parameters
Evaluate subsurface conditions encountered against design assumptions
Reconcile installed ESF ground support
Waste Package Design Data and Information Needs
Repository Design Data and Information Needs
Safety and Health Issues

Use of Fracture Data in ESF Design

- Rock Quality Designation, RQD
  - core
    $$RQD = \frac{\sum \text{Length of Core Pieces} > 10\text{ cm (4 in)}}{\text{Total Core Run Length}} \times 100$$
  - scanline
    $$RQD_{Linear} = 100e^{-0.1\lambda_j}(0.1\lambda_j + 1)$$
    $$RQD_{Volumetric} = 115 - 3.3\lambda_V$$
    λ = fracture frequency
  - full-peripheral
    $$RQD = \frac{\sum \text{Length of Rock Between Fractures} > 10\text{ cm (4 in)}}{\text{Total Interval Length}} \times 100$$

Use of Fracture Data in ESF Design

- **Rock Mass Quality, Q**

$$Q = \left(\frac{RQD}{Jn}\right) \times \left(\frac{Jr}{Ja}\right) \times \left(\frac{Jw}{SRF}\right)$$

- RQD = rock quality designation
- Jn = joint set number
- Jr = joint roughness number
- Ja = joint alteration number
- Jw = joint water reduction factor
- **SRF = stress reduction factor**

[illegible] data from field mapping in the ESF

Use of Fracture Data in ESF Design

- Rock Mass Rating, RMR

$$RMR = C + RQD_i + JS + JC + JW + AJO$$

- C = unconfined compressive rock strength index
- RQD_i = rock quality designation index
- JS = joint spacing index
- JC = joint condition index
- JW = groundwater index
- AJO = adjustment for joint orientation

[illegible] from field mapping in the ESF

Use of Fracture Data in ESF Design

- Geological Strength Index, GSI

$$GSI = 9 \ln Q' + 44$$

$$GSI = RMR' - 5$$

  - Q' $= \left(\frac{RQD}{Jn}\right) \times \left(\frac{Jr}{Ja}\right)$
  - RMR' $= C + RQD_i + JS + JC + JW'$
  - JW' = groundwater index for dry conditions = 15

Use of Fracture Data in ESF Design

- **Rock Mass Index, RMi**

$$\mathbf{RMi} = \sigma_c \cdot \mathbf{JP}$$

- σ_c = **intact unconfined compressive strength of rock**
- JP = jointing parameter $= 0.2\sqrt{jC} \cdot Vb^D$
- jC = joint condition parameter $= jL \cdot \left(\frac{jR}{jA}\right)$
- Vb = block size (m^3)
- D = $0.37jC^{-0.2}$
- jL = joint size and continuity factor
- jR = joint roughness factor
- jA = joint alteration factor

[illegible] from field mapping in the ESF

Use of Fracture Data in ESF Design

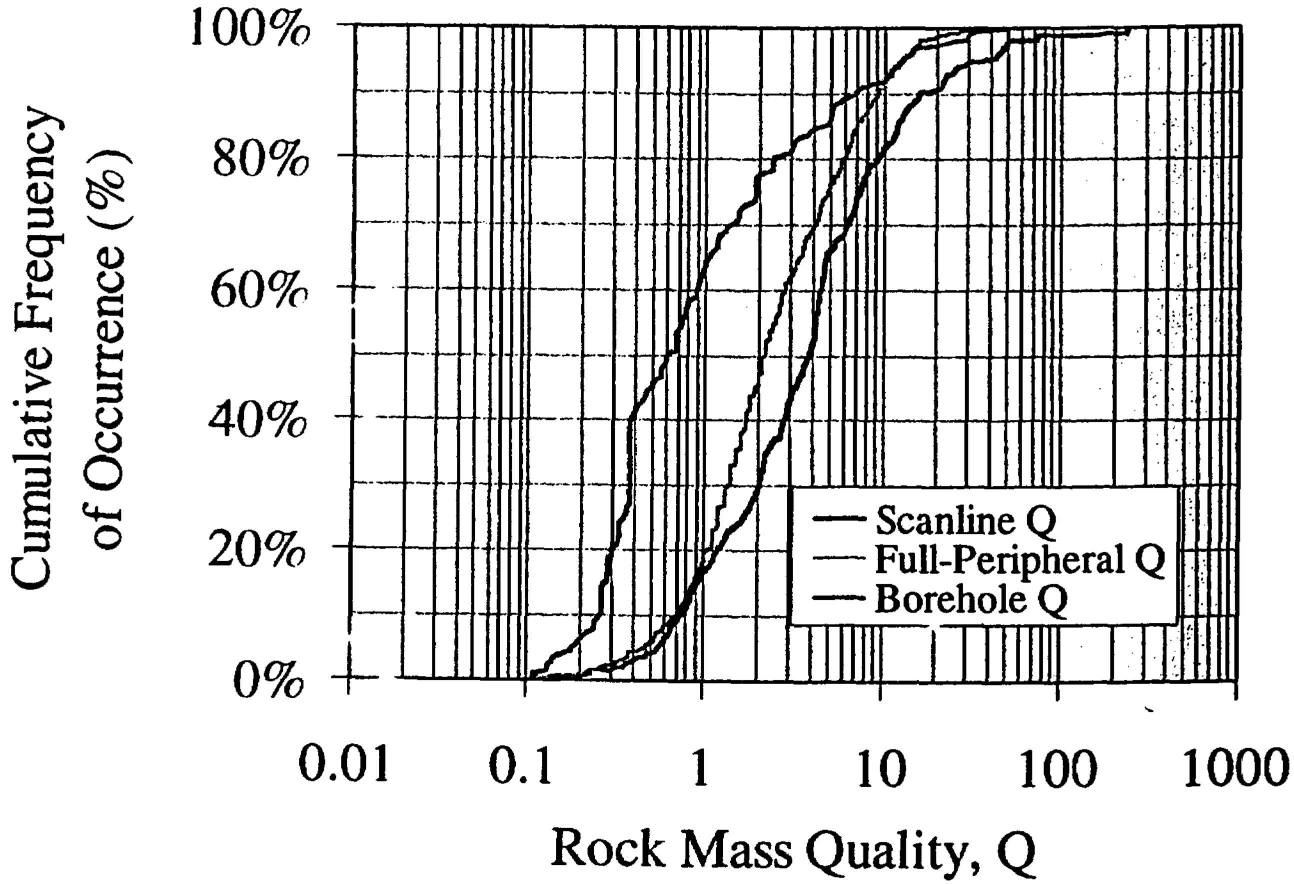
- Behavior of Discontinuous Rock Masses
  - Hoek-Brown Rock Mass Strength Criterion
  - Mohr-Coulomb Shear Strength Criterion
  - Serafim-Pereira Rock Mass Deformation Modulus
  - Barton Joint Shear Strength Criterion

Use of Fracture Data in ESF Design

- Assessment of Key Ground Support and Opening Design Parameters
  - Rock Mass Modulus of Deformation
  - Rock Mass Cohesion and Friction Angle
  - Rock Mass Unconfined Compressive and Tensile Strengths
  - Joint Shear (Cohesion and Friction Angle) and Tensile Strengths

Use of Fracture Data in ESF Design

- Cumulative Distribution of Q Values in the TSw2 Unit



Use of Fracture Data in ESF Design

- Fracture Orientations of the ESF
  - Detailed Line Survey (DLS) Data Set – Over 18,000 Fractures
  - TSw2 along Main Drift (Station 28+04 to 59+35) - 11,127 Fractures

Use of Fracture Data in ESF Design

- Use of Stereo Graphic Projections in Determining Primary Joint Sets
  - Schmidt Equal Area Lower Hemisphere Projection
  - Contouring Pole Projections as Percent of Total per 1% of Area
  - Vary Contour Interval to Determine Primary and Secondary Joint Sets

Use of Fracture Data in ESF Design

- Types of Fractures and Primary Orientations Identified in DLS Data
  - "Fractures"
  - Faults and Shears
  - Vapor Phase Partings
  - Cooling Joints

Use of Fracture Data in ESF Design

- Joint Spacing Distributions for DLS Data Subsets
- Joint Spacings Follow Log Normal Distributions
- Average Spacings for DLS Data Subsets
    - TSw2 Main Drift – 0.28 Meters
    - "Fractures" – 0.31 Meters
    - Faults and Shears – 7.35 Meters
    - Vapor Phase Partings – 10.87 Meters
    - Cooling Joints – 12.35 Meters

Use of Fracture Data in ESF Design

- Fracture Orientations of the ESF
  - Examined by Equal (500 Meter) Intervals
  - Examined by Thermal Mechanical Units

Use of Fracture Data in ESF Design

- Assessment of Rock Mass Block Size Distribution based on Scanline Joint Frequency Data
  - block size at 95% probability of occurrence
    - TCw $\geq$ 4 m^3
    - TSw1 $\geq$ 10 m^3
    - TSw2 $\geq$ 0.6 m^3
- Tunnel orientation has significant effect on block size
- Joint distribution has significant effect on the size and number of blocks

Use of Fracture Data in ESF Design

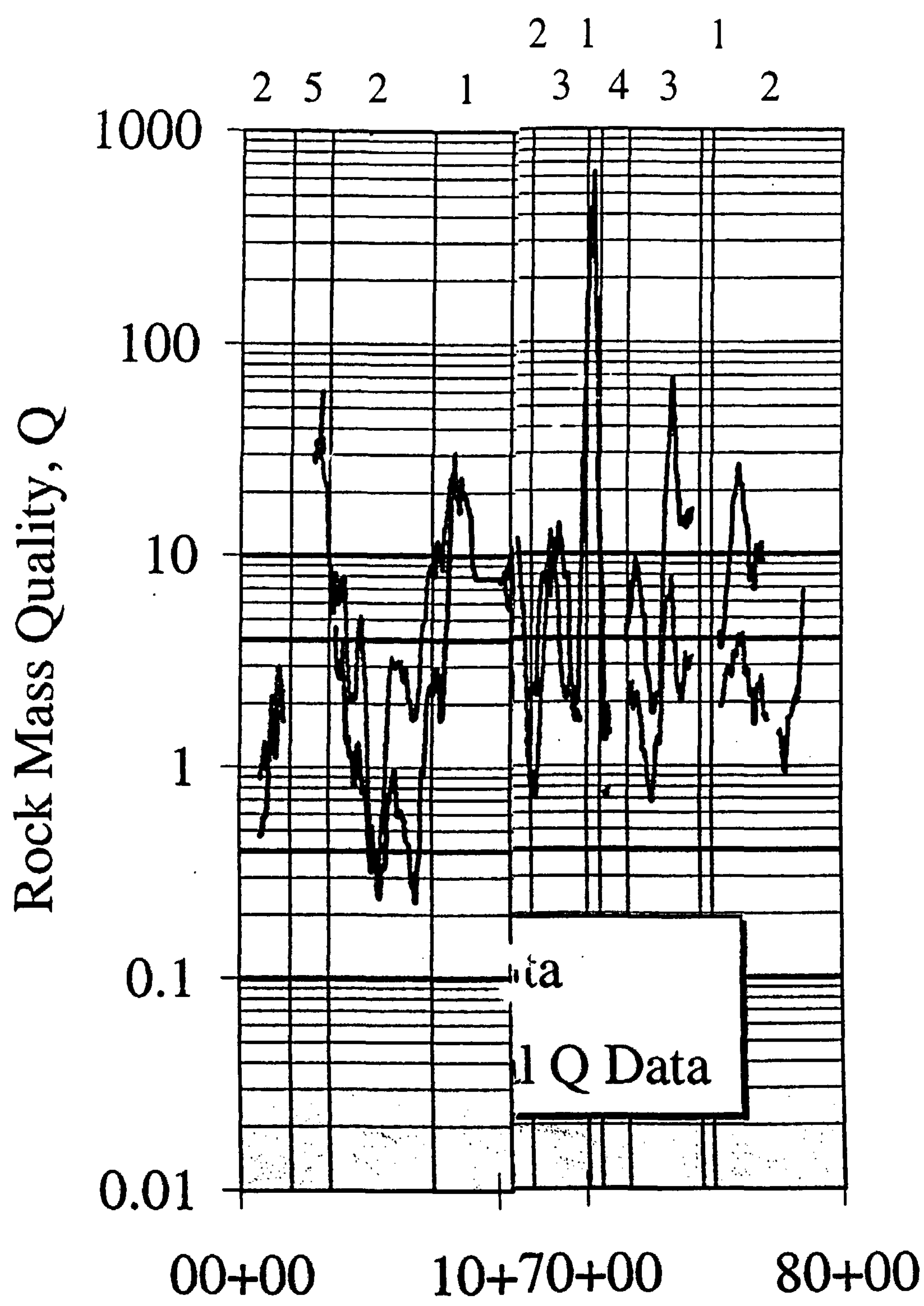
- Joint properties affect block stability

	cohesion (MPa)	friction angle (deg)
TCw	0.11	59
PTn	0.04	36
TSw1	0.07	49
TSw2	0.11	60

- Joint roughness affects block stability
- Failure modes include
  - falling
  - sliding
  - toppling

Use of Fracture Data in ESF Design

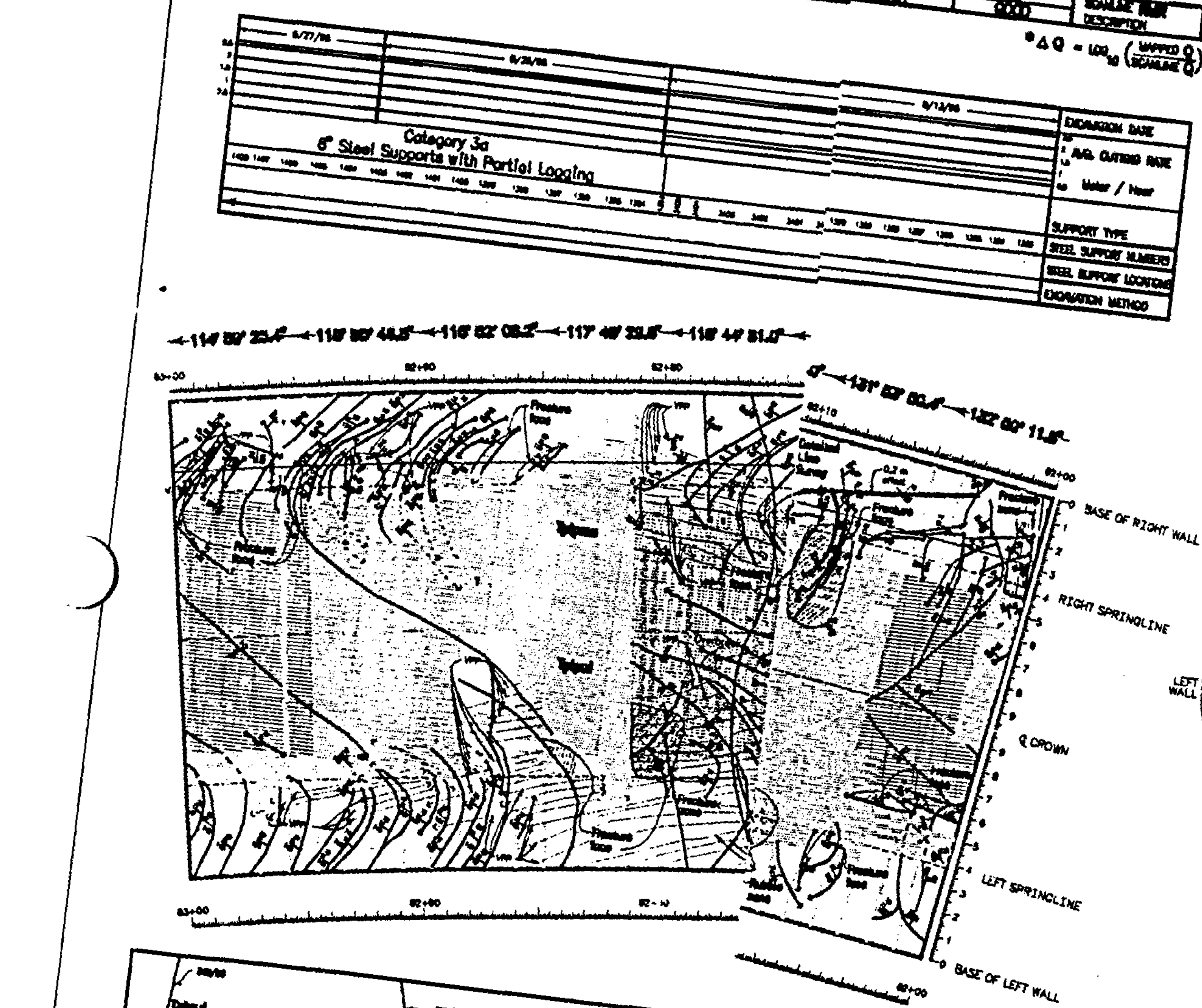
- Posters (attached)
  - ESF Rock Mass Quality
  - Full-Peripheral Geologic Map of the ESF (Station 62+00 to 63+00)
  - Correlation of 3.01X Areas with Off-Normal Conditions
  - Determination of Primary Joint Sets
  - Discontinuity Orientations and Frequencies
  - Fracture Orientations of the ESF
  - Distribution of Block Size in the ESF Main Loop
  - Example of Key Block Size versus Tunnel Orientation
  - Example of Key Block Ground Support

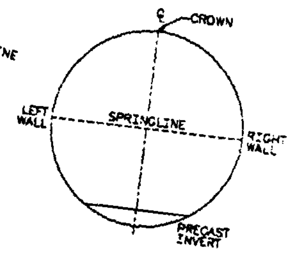


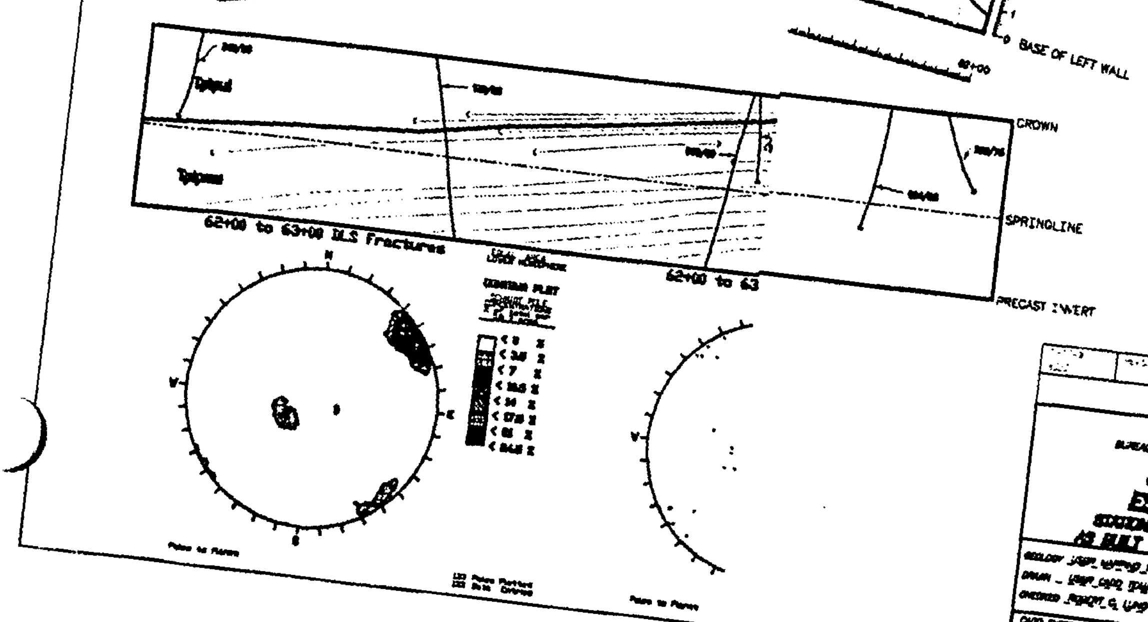
Rock Mass Quality, Q
1000
100
10
1
0.1
0.01
2 5 2 1 2 1 3 4 3 1 2
ta
l Q Data
00+00
10+70+00
80+00

74%	66%	56%	53%	[illegible]	71%	[illegible]	R.Q.D.
[illegible]	0.57	[illegible]	0.71	1.0	[illegible]	0.87	SCANLINE Q
[illegible]	[illegible]	[illegible]	1.2	[illegible]	[illegible]	[illegible]	MAPPED Q
0.5	[illegible]	0.5	0.2	-0.2	0.5	-0.02	ΔQ *
POOR	VERY POOR	POOR	POOR	VERY POOR	VERY POOR	VERY POOR	DESCRIPTION
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	SCANLINE RMR
GOOD	FAIR	FAIR	GOOD	FAIR	FAIR	GOOD	DESCRIPTION

$* \Delta Q = \log_{10}\left(\frac{\text{MAPPED Q}}{\text{SCANLINE Q}}\right)$







Notes

For General Geologic Explanation and Notes, see Drawing OA-46-263.

Fracture data for stereo plots taken exclusively from detailed line surveys along right wall.

Unless otherwise noted, the Detailed Line Survey is 0.8 m below right rib springline.

1:125 (METERS)

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION / U.S. GEOLOGICAL SURVEY
YUCCA MOUNTAIN PROJECT
GEOLOGIC MAPPING OF THE ESF

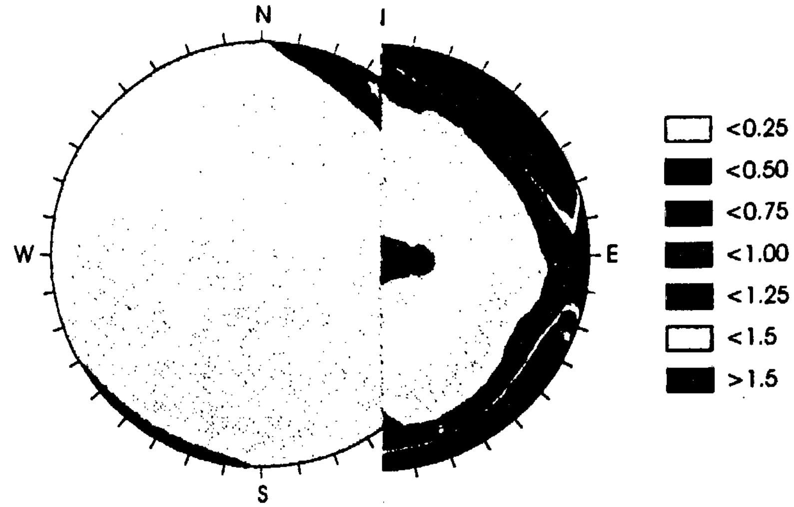
ESF - SOUTH RAMP
STATION 62+00.00 TO STATION 63+00.00
AS BUILT GEOLOGY AND GEOTECHNICAL DATA

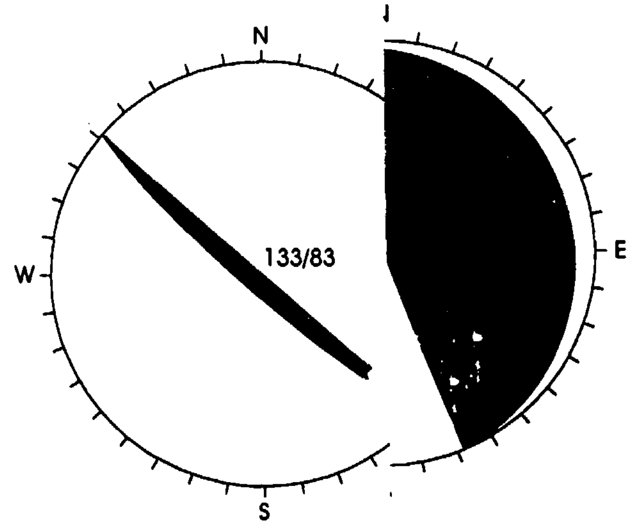
GEOLOGY USGS MAPPING TEAM — PEER REVIEW [illegible]
DRAWN USBR CADD TEAM — PRINCIPAL INVESTIGATOR [illegible]
CHECKED [illegible] — [illegible]
CADD SYSTEM AutoCad 12.0 — CADD FILENAME [illegible]
MERCURY, NEVADA — SCP [illegible]

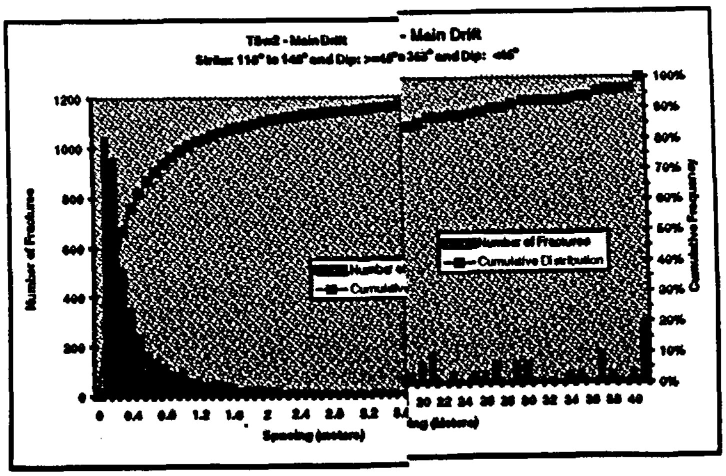
OA-46-286

3.01X Areas						RMR			
Case	Thermo-mechanical Unit	ESF Tunnel Station From	ESF Tunnel Station To	ESF Tunnel Station Midpoint	Interval Length (m)	rval oint unnel on)	Litho-stratigraphic Unit	Length of 3.01X Area That Either Has a Q Value with a Less Than 5% Probability of Occurrence Or Contains Faults (m)	Percent Rated 3.01X Area for Each Thermo-mechanical Unit That Either Has a Q Value with a Less Than 5% Probability of Occurrence Or Contains Faults
1	B.R. Fault	01+99.50	02+02.00	02+00.75	2.50	:d		—	—
1	TCw	01+87.87	01+99.50	01+93.69	11.63	:d			
2	TCw	05+20.87	05+25.00	05+22.94	4.13	2.50	Tpcpul	4.13	
		05+25.00	05+30.00	05+27.50	5.00	7.50	Tpcpul	5.00	
		05+30.00	05+35.00	05+32.50	5.00	2.50	Tpcpul		
		05+35.00	05+40.00	05+37.50	5.00	7.50	Tpcpul		
		05+40.00	05+45.00	05+42.50	5.00	2.50	Tpcpul	5.00	
		05+45.00	05+50.00	05+47.50	5.00	7.50	Tpcpmn	5.00	
		05+50.00	05+55.00	05+52.50	5.00	2.50	Tpcpmn	5.00	
		05+55.00	05+60.00	05+57.50	5.00	7.50	Tpcpmn		
		05+60.00	05+65.00	05+62.50	5.00	2.50	Tpcpmn		
		05+65.00	05+70.00	05+67.50	5.00	7.50	Tpcpmn		
		05+70.00	05+75.00	05+72.50	5.00	2.50	Tpcpmn	5.00	
		05+75.00	05+80.00	05+77.50	5.00	7.50	Tpcpmn		
		05+80.00	05+85.00	05+82.50	5.00	2.50	Tpcpmn		
		05+85.00	05+90.00	05+87.50	5.00	7.50	Tpcpll		
		05+90.00	05+95.00	05+92.50	5.00	2.50	Tpcpll		
		05+95.00	06+00.00	05+97.50	5.00	7.50	Tpcpll		
		06+00.00	06+05.00	06+02.50	5.00	2.50	Tpcpll		
		06+05.00	06+10.00	06+07.50	5.00	7.50	Tpcpll		
		06+10.00	06+15.00	06+12.50	5.00	2.50	Tpcpll	5.00	
		06+15.00	06+20.00	06+17.50	5.00	7.50	Tpcpln		
		06+20.00	06+25.00	06+22.50	5.00	2.50	Tpcpln		
		06+25.00	06+30.00	06+27.50	5.00	7.50	Tpcpln		
		06+30.00	06+35.00	06+32.50	5.00	2.50	Tpcpln		
		06+35.00	06+40.00	06+37.50	5.00	7.50	Tpcpln	5.00	
		06+40.00	06+45.00	06+42.50	5.00	2.50	Tpcpln		
		06+45.00	06+50.00	06+47.50	5.00	7.50	Tpcpln		
		06+50.00	06+55.00	06+52.50	5.00	2.50	Tpcpln		
		06+55.00	06+60.00	06+57.50	5.00	7.50	Tpcpln		
		06+60.00	06+65.00	06+62.50	5.00	2.50	Tpcpln	5.00	
		06+65.00	06+70.00	06+67.50	5.00	7.50	Tpcpln		
		06+70.00	06+75.00	06+72.50	5.00	2.50	Tpcpln		
		06+75.00	06+80.00	06+77.50	5.00	7.50	Tpcpln		
		06+80.00	06+85.00	06+82.50	5.00	2.50	Tpcpln	5.00	
		06+85.00	06+90.00	06+87.50	5.00	7.50	Tpcpln	5.00	
		06+90.00	06+95.00	06+92.50	5.00	2.50	Tpcpln		
		06+95.00	07+00.00	06+97.50	5.00	7.50	Tpcpln		
		07+00.00	07+04.50	07+02.25	4.50	2.50	Tpcpln	4.50	
7	TCw	75+20.68	75+25.00	75+22.84	4.32	2.50	Tpcpln		
		75+25.00	75+28.00	75+26.50	3.00	7.50	Tpcpln		
8	TCw	76+62.87	76+65.00	76+63.94	2.13	2.50	Tpcpmn	2.13	
		76+65.00	76+70.00	76+67.50	5.00	7.50	Tpcpmn	5.00	
		76+70.00	76+75.00	76+72.50	5.00	2.50	Tpcpmn	5.00	
		76+75.00	76+80.00	76+77.50	5.00	7.50	Tpcpmn	5.00	
		76+80.00	76+85.00	76+82.50	5.00	2.50	Tpcpmn	5.00	
		76+85.00	76+90.00	76+87.50	5.00	7.50	Tpcpmn	5.00	
		76+90.00	76+95.00	76+92.50	5.00	2.50	Tpcpmn	5.00	

Case	Thermo-mechanical Unit	3.01X Areas ESF Tunnel Station From	To	Midpoint	Interval Length (m)	MR ...val ...oint ...nnel ...m)	Litho-stratigraphic Unit	Length of 3.01X Area That Either Has a Q Value with a Less Than 5% Probability of Occurrence Or Contains Faults (m)	Percent Rated 3.01X Area for Each Thermo-mechanical Unit That Either Has a Q Value with a Less Than 5% Probability of Occurrence Or Contains Faults
8	TCw	76+95.00	77-00.00	76-97.50	5.00	.50	Tpcpmn	5.00	
		77+00.00	77-05.00	77-02.50	5.00	.50	Tpcpmn	5.00	
		77+05.00	77-10.00	77-07.50	5.00	.50	Tpcpmn	5.00	
		77+10.00	77-15.00	77-12.50	5.00	.50	Tpcpmn	5.00	
		77+15.00	77-40.00	77-27.50	25.00	j			
		77+40.00	[illegible]-41.00	77-40.50	1.00	.50	Tpcpmn	1.00	
	Total for TCw Unit				*280.71*			*111.76*	*46%*
3	TSw1	11+01.00	11+05.00	11+03.00	4.00	.50	Tptrvl	4.00	
		11+05.00	11+10.00	11-07.50	5.00	.50	Tptrvl		
		11+10.00	11+15.00	11+12.50	5.00	.50	Tptrvl	5.00	
		11+15.00	11+20.00	11+17.50	5.00	.50	Tptrvl	5.00	
		11+20.00	11+25.00	11-22.50	5.00	.50	Tptrvl	5.00	
		11+25.00	11+30.00	11-27.50	5.00	.50	Tptrvl	5.00	
		11+30.00	11-35.00	11+32.50	5.00	.50	Tptrvl	5.00	
		11+35.00	11+40.00	11+37.50	5.00	.50	Tptrvl	5.00	
		11+40.00	11+45.00	11-42.50	5.00	.50	Tptrvl	5.00	
		11+45.00	11+50.00	11+47.50	5.00	.50	Tptrvl	5.00	
		11+50.00	11+55.00	11+52.50	5.00	.50	Tptrvl	5.00	
		11+55.00	11+60.00	11+57.50	5.00	.50	Tptrvl	5.00	
		11+60.00	11+65.00	11+62.50	5.00	.50	Tptrvl	5.00	
		11+65.00	11+70.00	11+67.50	5.00	.50	Tptrvl	5.00	
		11+70.00	11+75.00	11+72.50	5.00	.50	Tptrvl	5.00	
		11+75.00	11+80.00	11+77.50	5.00	.50	Tptrvl	5.00	
		11+80.00	11+82.00	11+81.00	2.00	.50	Tptrvl		
	Total for TSw1 Unit				*81.00*			*74.00*	*91%*
4	TSw2	60+16.11	60+20.00	60+18.06	3.89	.50	Tptpmn	3.89	
		60+20.00	60+25.00	60+22.50	5.00	.50	Tptpmn	5.00	
		60+25.00	60+30.00	60+27.50	5.00	.50	Tptpmn		
		60+30.00	60+35.00	60+32.50	5.00	.50	Tptpmn		
		60+35.00	60+40.00	60+37.50	5.00	.50	Tptpmn		
		60+40.00	60+45.00	60+42.50	5.00	.50	Tptpmn		
		60+45.00	60+49.88	60+47.44	4.88	.50	Tptpmn		
5	TSw2	62+04.23	62+10.00	62+07.12	5.77	.50	Tptpmn	5.77	
		62+10.00	62+15.00	62+12.50	5.00	.50	Tptpmn	5.00	
		62+15.00	62+20.00	62+17.50	5.00	.50	Tptpmn	5.00	
		62+20.00	62+25.00	62+22.50	5.00	.50	Tptpmn	5.00	
		62+25.00	62+30.00	62+27.50	5.00	.50	Tptpmn	5.00	
		62+30.00	62+32.00	62+31.00	2.00	.50	Tptpmn		
6	TSw2	71+07.25	71+10.00	71+08.63	2.75	.50	Tptpmn		
		71+10.00	71+15.00	71+12.50	5.00	.50	Tptpmn	5.00	
		71+15.00	71+40.00	71+27.50	25.00	d			
		71+40.00	71+44.39	71+42.20	4.39	.50	Tptpmn	4.39	
	Total for TSw2 Unit				*98.68*			*44.05*	*60%*
1	UO	02+02.00	02+72.44	02+37.22	70.44	d			
	Total for UO Unit				*70.44*			—	—


N
W
E
S
<0.25
<0.50
<0.75
<1.00
<1.25
<1.5
>1.5

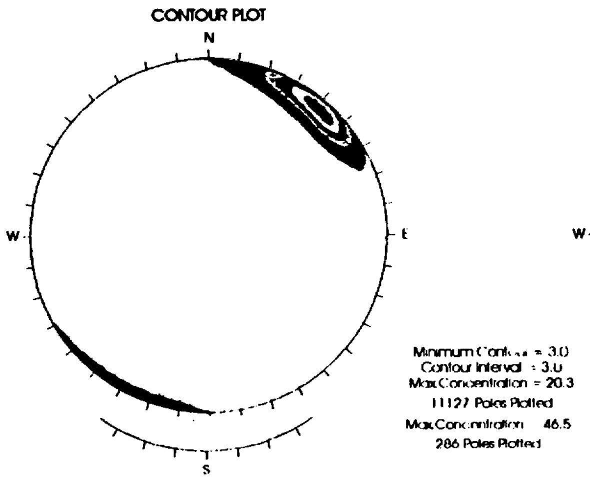

N
W
E
S
133/83

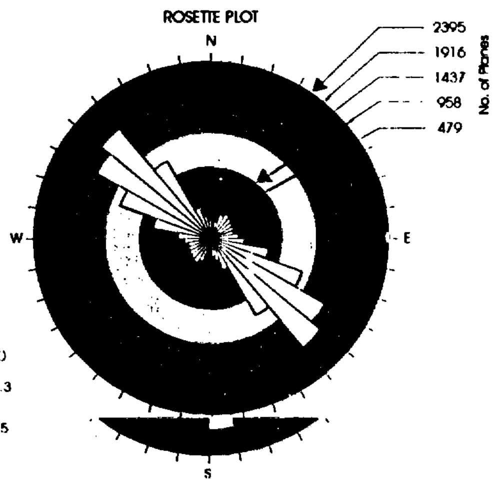

- Main Drift
Number of Fractures
Cumulative Distribution
1200
1000
800
600
400
200
0
100%
0%

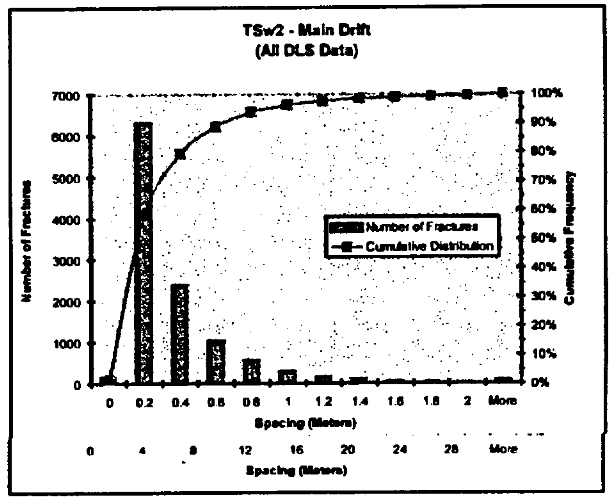
DISCONTINUITY ORIENTATIONS AND FREQUENCIES

TSw2 - ESF Main Drift - DLS Data

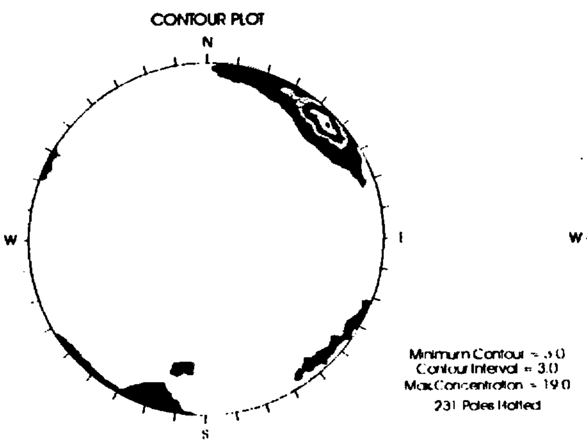
Complete DLS Data Set

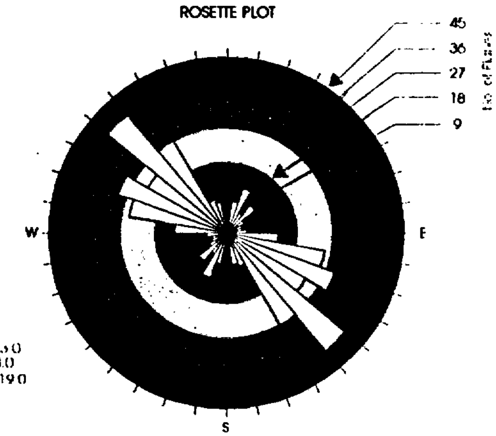


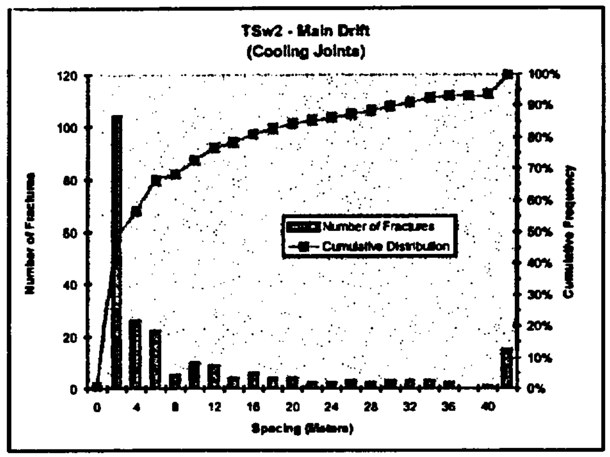




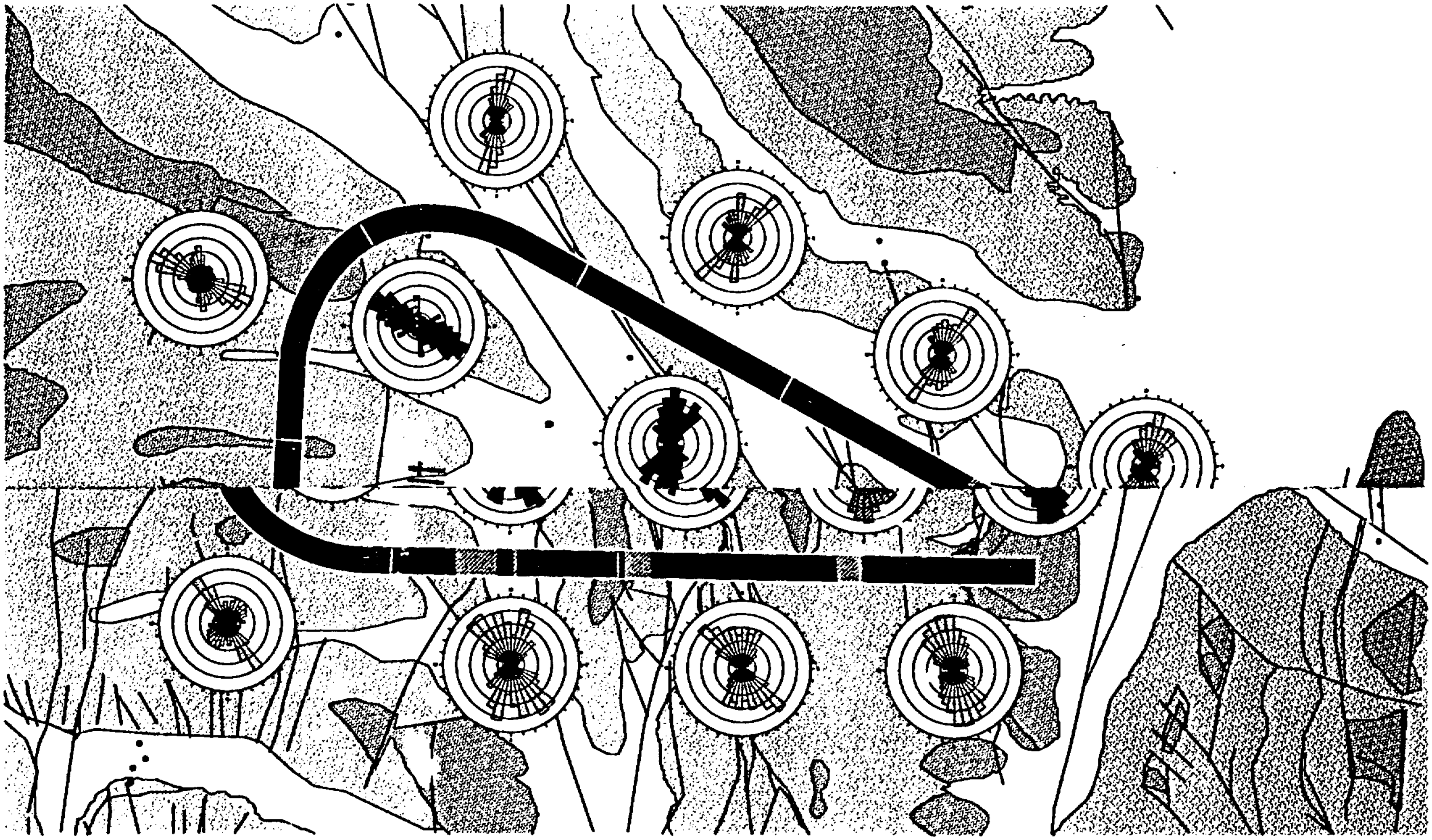
DLS Cooling Joints







FRACTURE ORIENTATIONS OF THE EXPLORATORY STUDIES FACILITY YUCCA MOUNTAIN, NEVADA

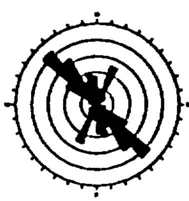


Thermal Mechanical Units of the ESF

- UO - Undifferentiated Overburden
- TCw - Tiva Canyon welded
- PTn - Paintbrush nonwelded
- TSw1 - Topopah Spring welded lithophysal rich
- TSw2 - Topopah Spring welded lithophysal poor

Surface Geology of the ESF Area

- Alluvium & Colluvium
- Rainier Mesa Tuff
- Tiva Canyon Crystal - rich member
- Tiva Canyon Crystal - poor member

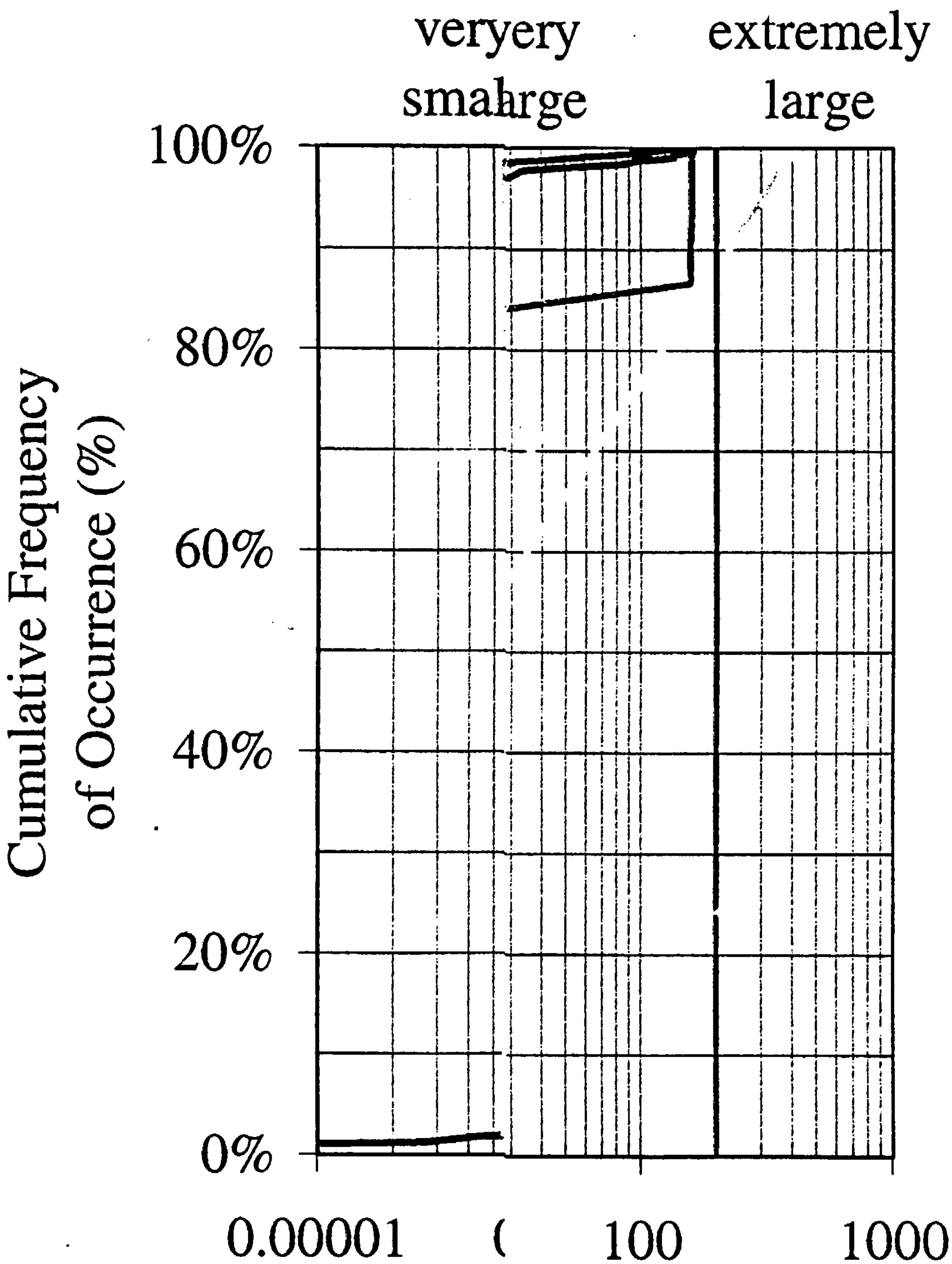


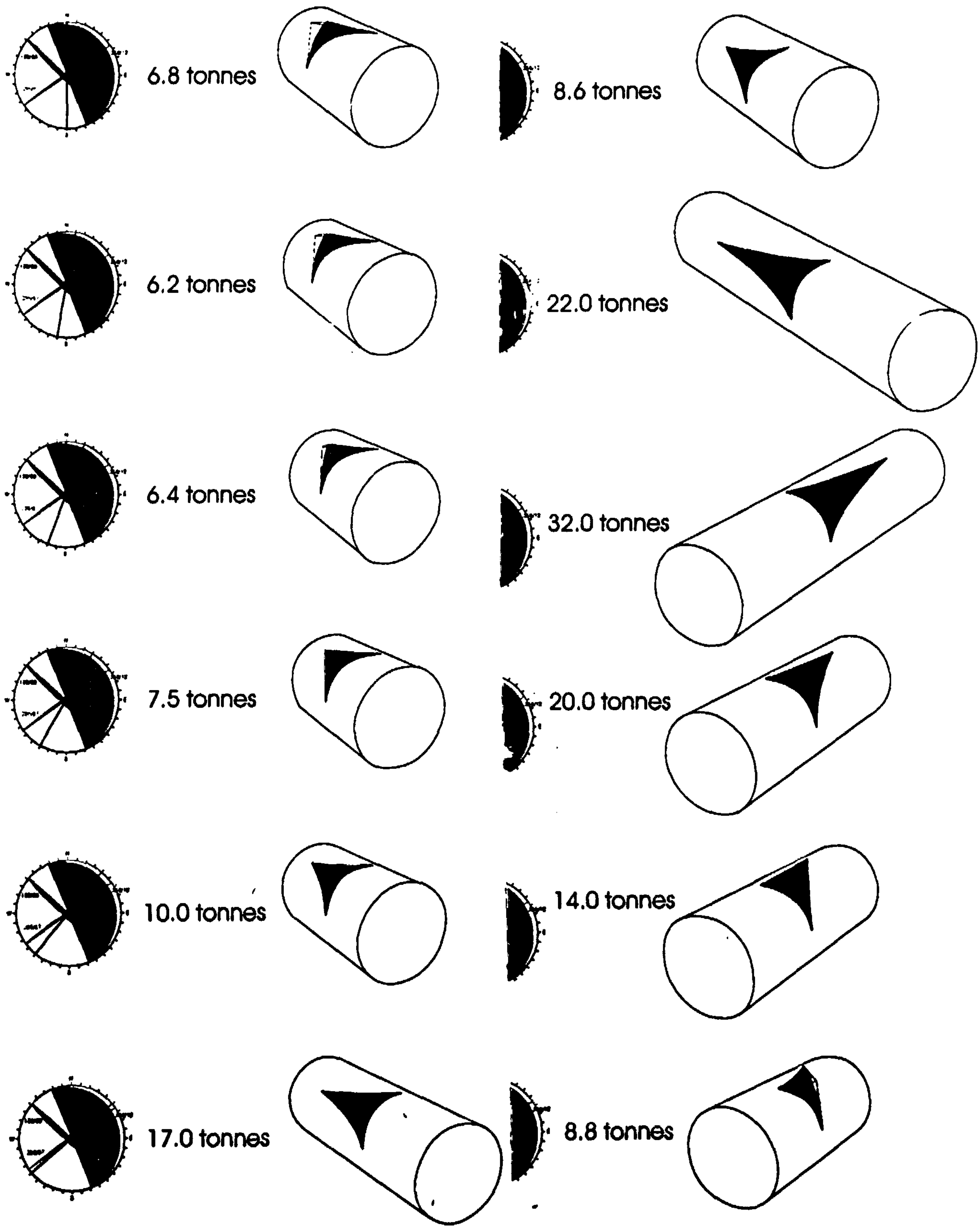
Strike Direction Rose of DLS Fractures
- Outer ring spaced at 500 m intervals
- Inner ring based on T/M unit (color coded)

Scale (m)

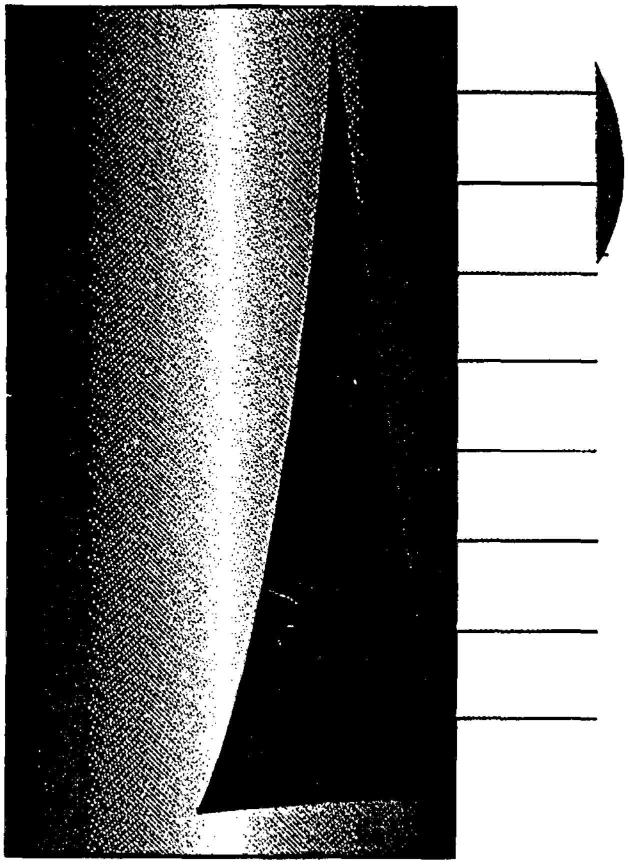
0 500

DP

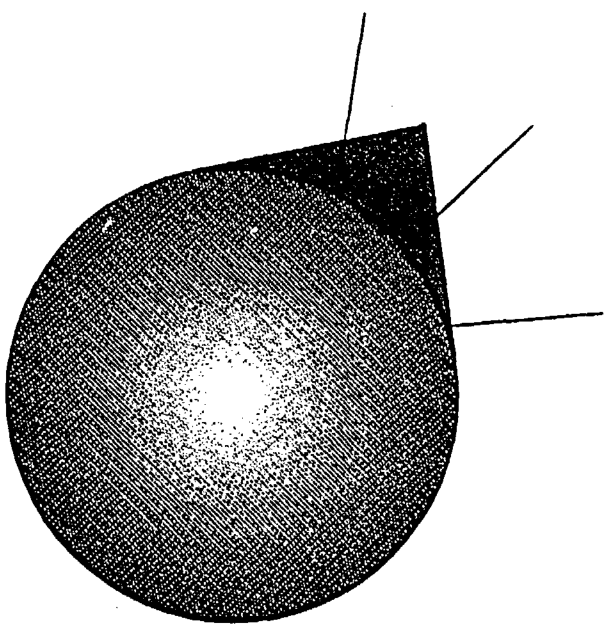

veryery
smalarge
extremely
large
100%
80%
60%
40%
20%
0%
Cumulative Frequency
of Occurrence (%)
0.00001
100
1000


6.8 tonnes
8.6 tonnes
6.2 tonnes
22.0 tonnes
6.4 tonnes
32.0 tonnes
7.5 tonnes
20.0 tonnes
10.0 tonnes
14.0 tonnes
17.0 tonnes
8.8 tonnes

TOP VIEW



FRONT VIEW



WEDGE: 32 TONNES

BOLT PATTERN
SPACING: 1.5 m X 1.5 m
LENGTH: 3.00 m

SHOTCRETE
THICKNESS: 5 cm
SHEAR STRENGTH: 200 t/m^2

FACTORS OF SAFETY
BOLTS: 5.08
SHOTCRETE AND BOLTS: 13.85