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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: MULTIPLE-WELL INTERFERENCE AND CONSERVATIVE TRACER TESTING

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REGISTRY HOTEL, DENVER, COLORADO
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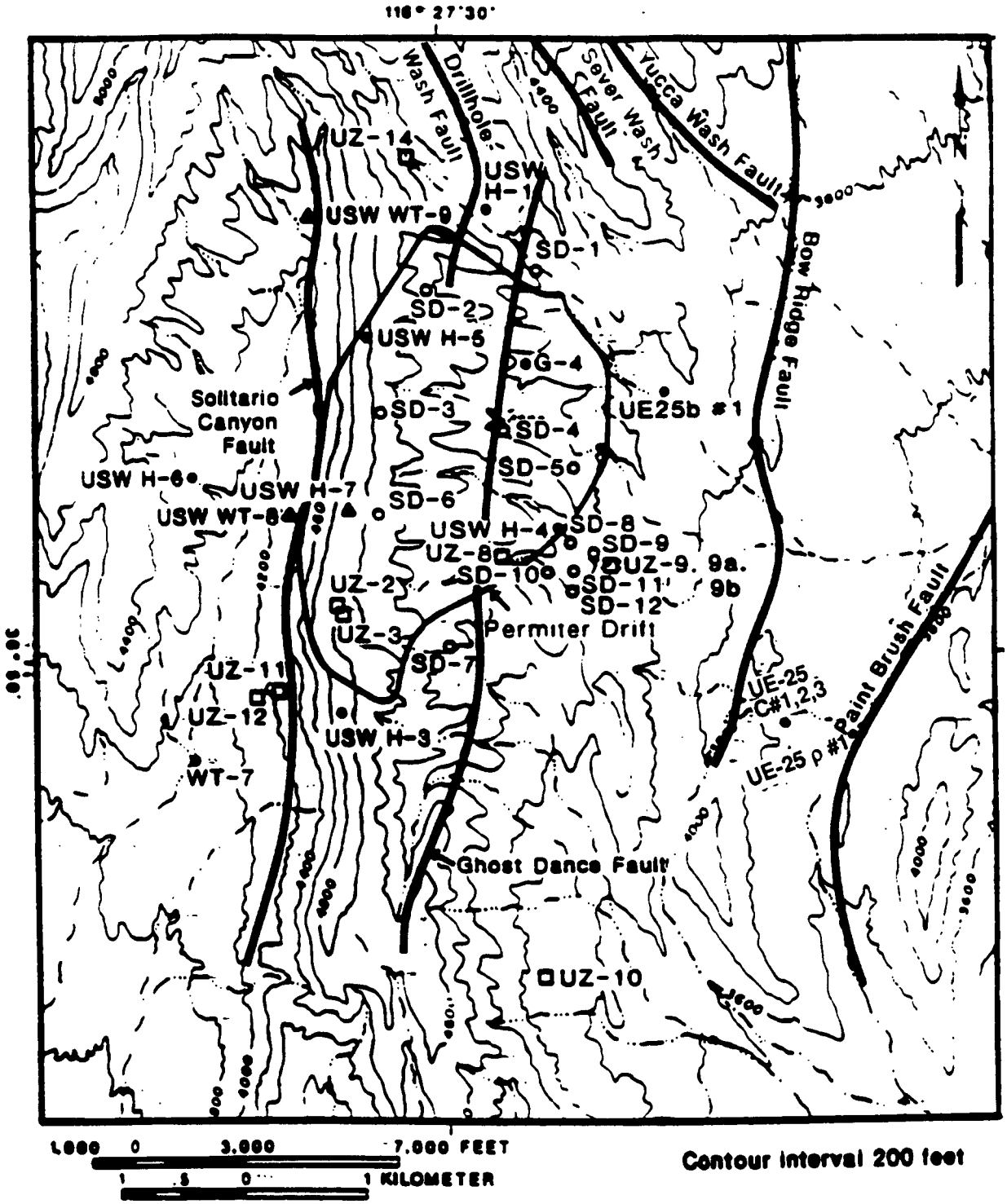
MAP SHOWING LOCATION OF PROPOSED AND SELECTED EXISTING WELLS FOR SITE SATURATED-ZONE SOLITARIO CANYON FAULT CHARACTERIZATION



EXPLANATION:

- ● Existing Well
- ○ Proposed SD Well
- ▲ Proposed Well
- □ Proposed UZ Well

SCOPE OF PRESENTATION

- **MULTIPLE-WELL INTERFERENCE TESTING AT C-HOLES**
  - **CROSS-HOLE TESTS**
  - **LARGE-SCALE PUMPING TEST**
- **TESTING C-HOLE COMPLEX WITH CONSERVATIVE TRACERS**

(NOTE: C-HOLE TESTING IS FOR METHODS DEVELOPMENT)

MULTIPLE-WELL INTERFERENCE TESTING AT C-HOLES

PRIMARY OBJECTIVES:

- DETERMINE HYDRAULIC PROPERTIES (SPATIAL AND DIRECTIONAL VARIATION OF HYDRAULIC CONDUCTIVITY, K; STORAGE COEFFICIENT, S)
- DETERMINE WHETHER ANISOTROPIC POROUS MEDIUM MODEL IS APPROPRIATE
- DETERMINE IF FRACTURE-FLOW MODEL IS APPROPRIATE
- EXAMINE SCALE DEPENDENCY OF FLOW PARAMETERS AT C-HOLES
- DESCRIBE HYDRAULIC CONNECTION BETWEEN FRACTURES AND BETWEEN STRATIGRAPHIC UNITS

MULTIPLE-WELL INTERFERENCE TESTING AT C-HOLES

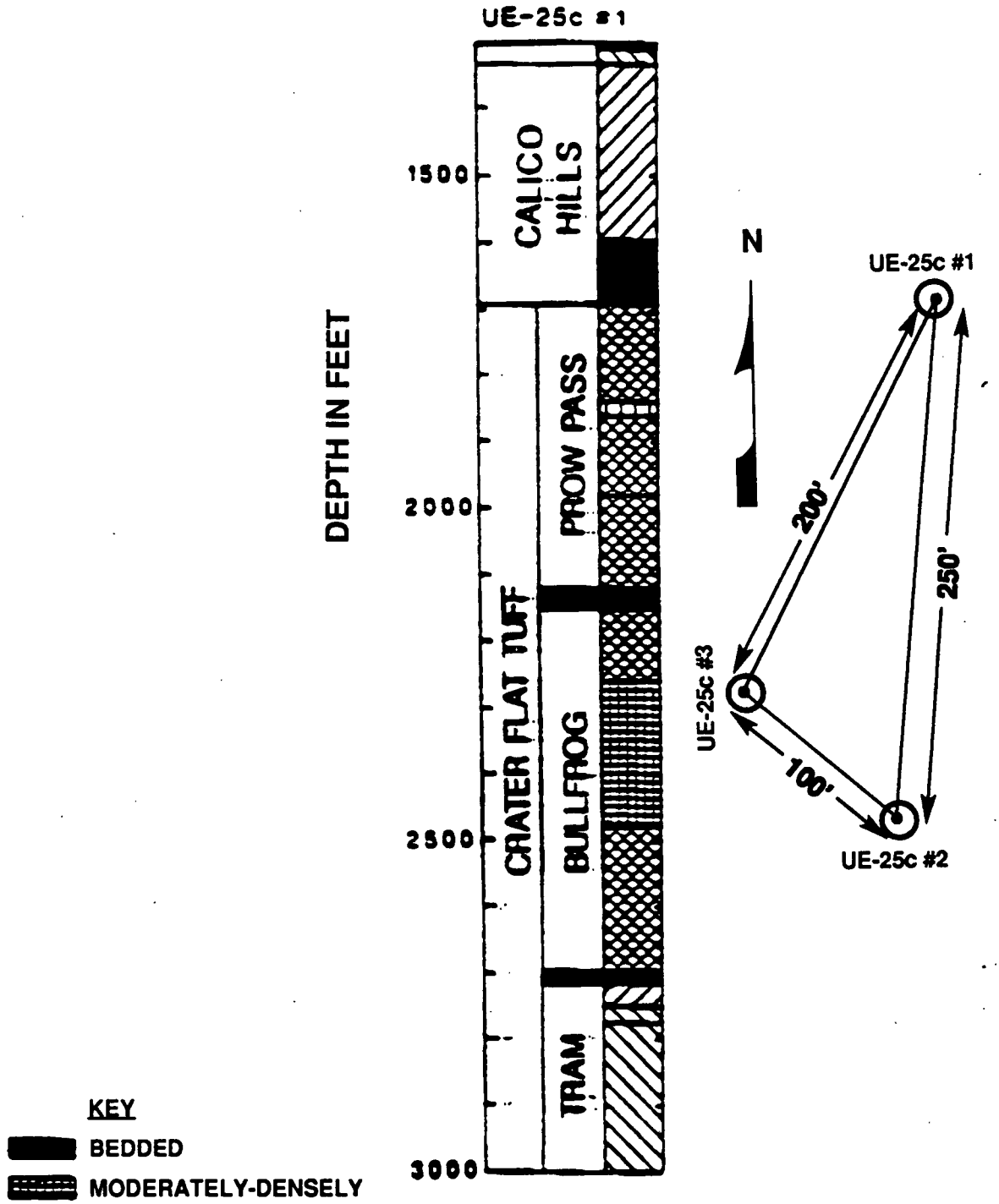
(CONTINUED)

CROSS-HOLE TESTS:

- **PUMP FROM TEST ZONE OF ONE WELL, MONITOR HYDRAULIC RESPONSE IN 5 TEST ZONES OF ALL WELLS (ALSO OBSERVE RECOVERY)**

- **VARY:**
  - PUMPING WELL
  - PUMPING INTERVAL
  - MONITORING INTERVAL
  - PUMPING RATE
  - HYDRAULIC CONDUCTANCE OF PUMPING AND MONITORING INTERVALS

C-HOLE CONFIGURATION AND TYPICAL LITHOLOGY



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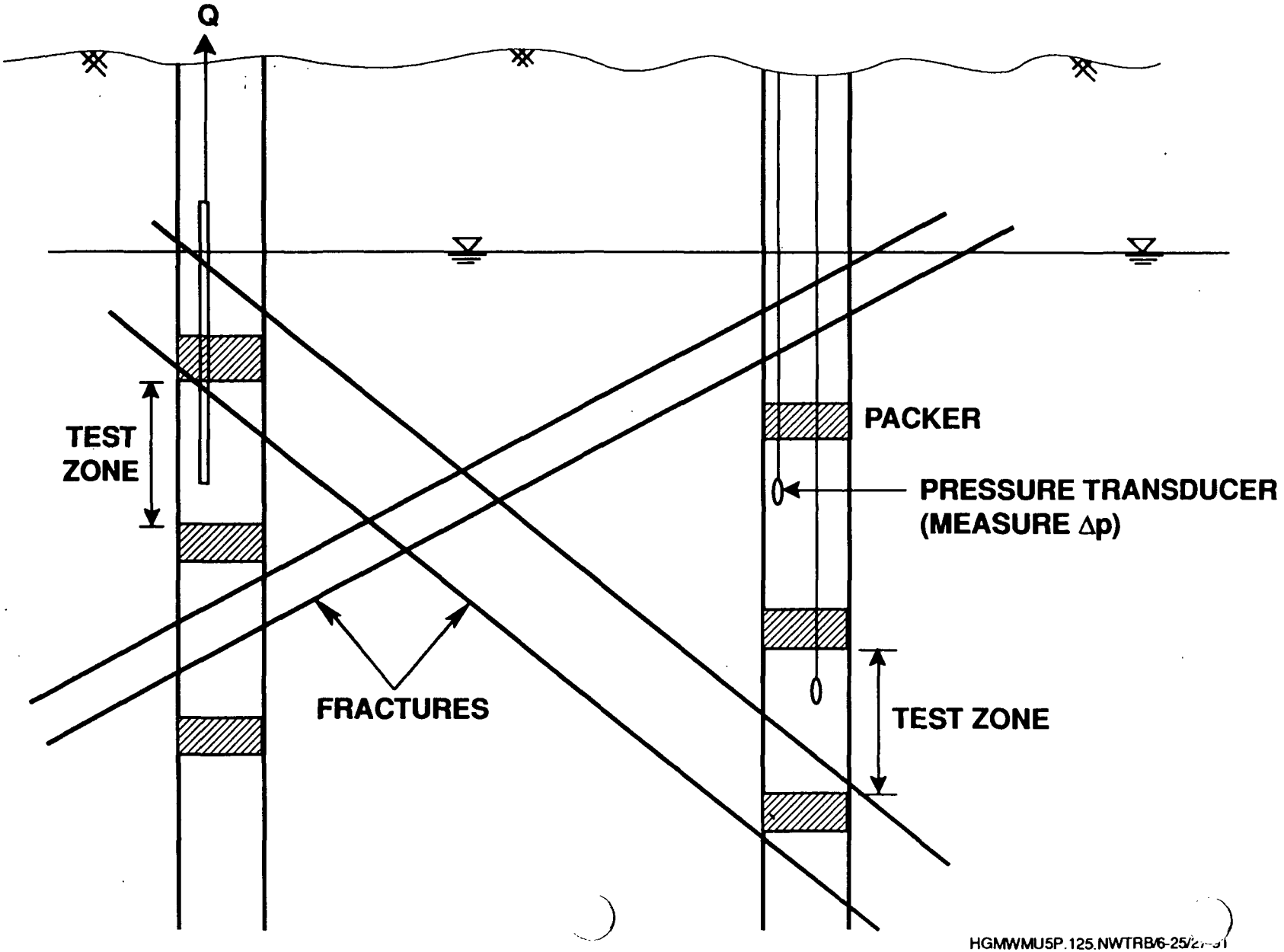
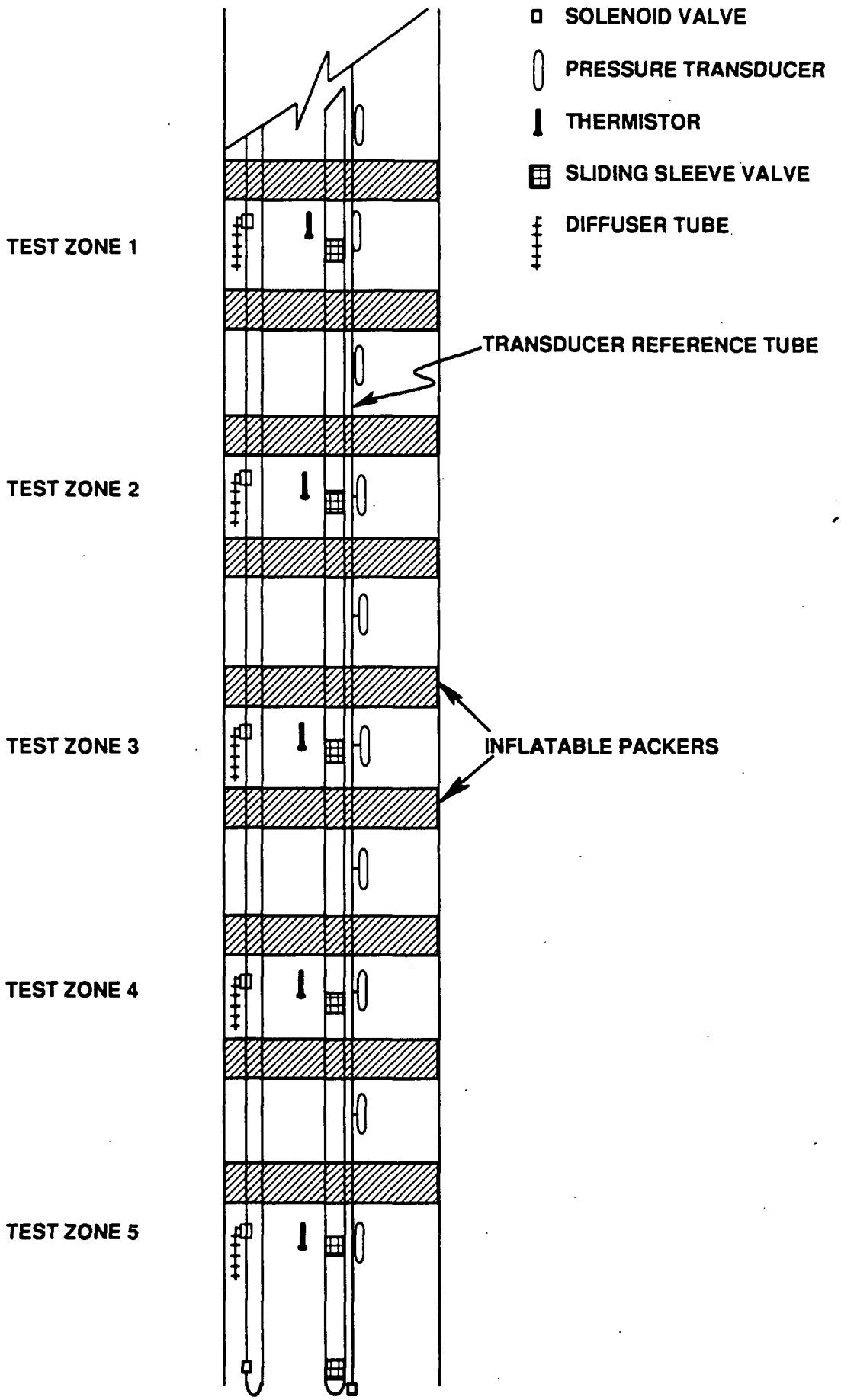
HYPOTHETICAL CROSS-SECTION





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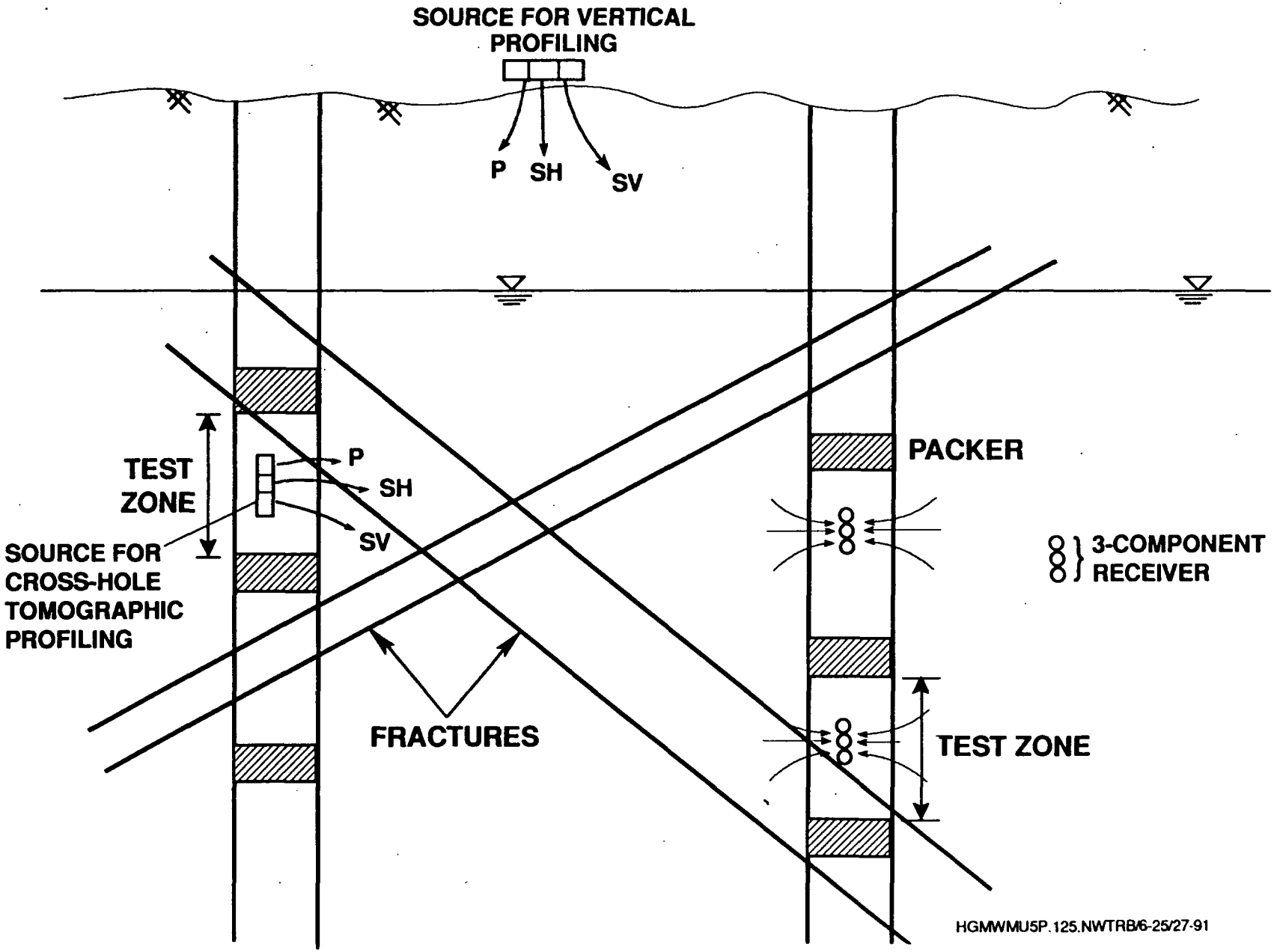
MULTIPLE-WELL INTERFERENCE TESTING AT C-HOLES

(CONTINUED)

CROSS-HOLE TESTS:

- **SELECT TEST INTERVALS BASED ON**
  - CROSS-HOLE SEISMIC SURVEYS
  - TEMPERATURE LOGS } INTRABOREHOLE FLOW INDICATORS
  - TRACEJECTOR SURVEYS
  - ANALYSIS OF COMPLETED HYDRAULIC STRESS TESTS
  - FRACTURE DISTRIBUTION FROM ACOUSTIC TELEVIEWER AND TV CAMERA LOGS

HYPOTHETICAL CROSS-SECTION:
CROSS-HOLE SEISMIC SURVEYS



SELECTION OF TEST INTERVAL COMBINATIONS

CROSS-HOLE SEISMIC SURVEYS:

- CONSTRUCT FENCE DIAGRAM OF SEISMIC PROPERTIES TO ESTIMATE
  - FRACTURE LOCATION
  - FRACTURE DENSITY
  - FRACTURE ORIENTATION

  ESTIMATED IN VERTICAL PLANES BETWEEN WELLS

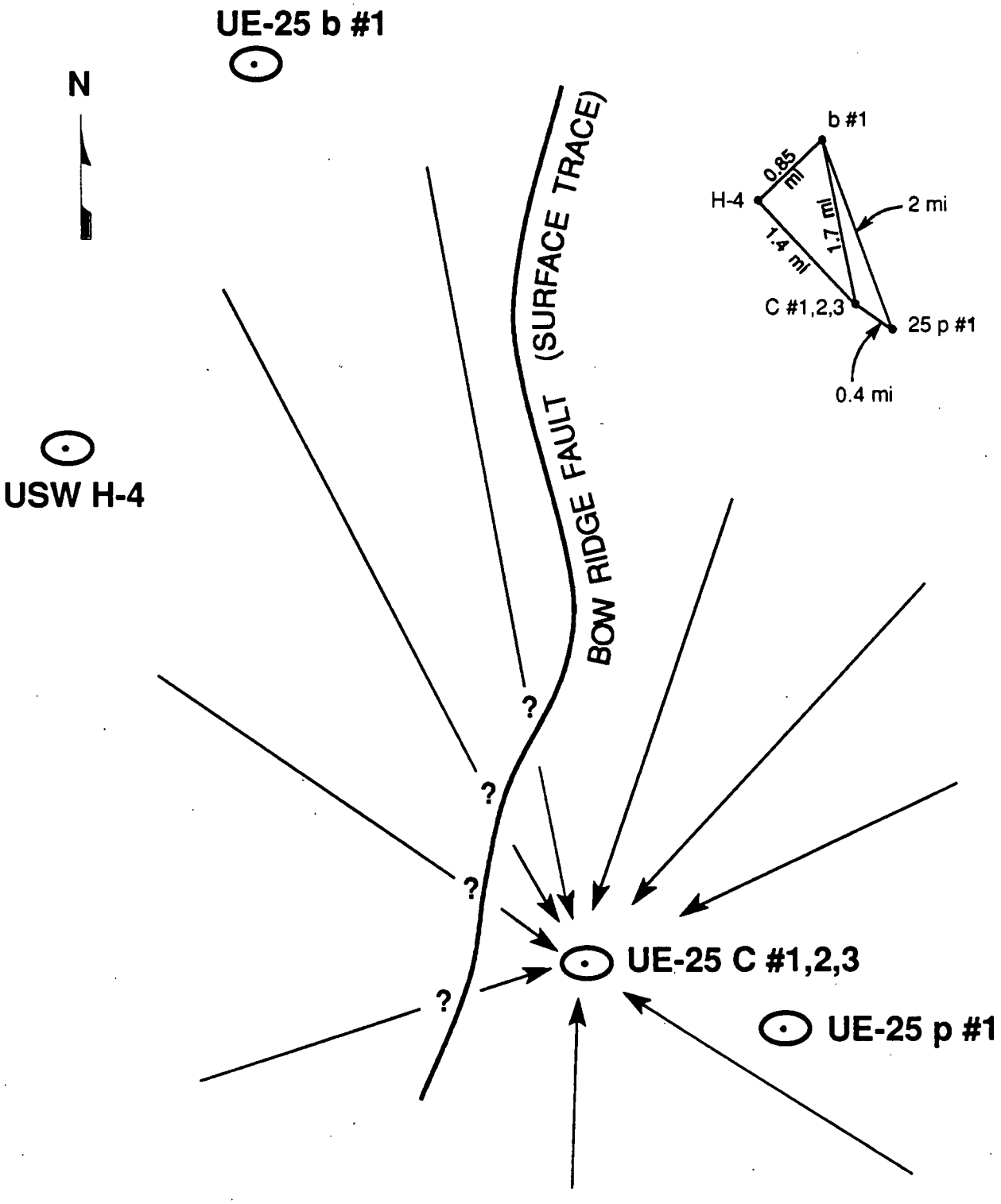
- DIFFERENT FRACTURE CHARACTERISTICS AFFECT SEISMIC WAVE SPEED

MULTIPLE-WELL INTERFERENCE TESTING AT C-HOLES

LARGE-SCALE PUMPING TEST:

- PUMP ONE OF C-WELLS FOR APPROXIMATELY 30 DAYS
- MONITOR ALL 3 C-HOLES AND WELLS USW H-4, UE-25b#1, UE-25p#1 (AND OTHER NETWORK WELLS)
- STOP PUMPING AND MONITOR RECOVERY IN ALL WELLS FOR APPROXIMATELY 30 DAYS

LARGE-SCALE PUMPING TEST



ANALYSIS OF MULTIPLE-WELL INTERFERENCE TESTS

TRY PROGRESSIVELY MORE COMPLEX CONCEPTUAL MODELS:

- POROUS MEDIUM (ANISOTROPIC; HOMOGENEOUS OR NON-HOMOGENEOUS) ASSUMPTION
- DUAL POROSITY MEDIUM (HOMOGENEOUS OR NON-HOMOGENEOUS) ASSUMPTION
- COMPOSITE POROUS MEDIUM ASSUMPTION
- FRACTURE NETWORK MODELS

ANALYSIS OF MULTIPLE-WELL INTERFERENCE TESTS

(CONTINUED)

DUAL POROSITY MEDIUM ASSUMPTION:

- ROCK MATRIX: SMALL K, LARGE S
- FRACTURE SYSTEM: LARGE K, SMALL S

COMPOSITE POROUS MEDIUM ASSUMPTION:

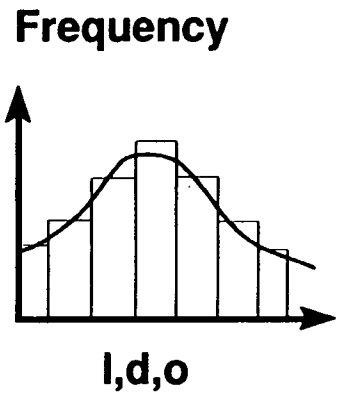
- INNER REGION NEAR PUMPING WELL: DOMINATED BY FEW FRACTURES
- OUTER REGION: EXTENSIVELY FRACTURED
- INNER AND OUTER FRACTURE SYSTEMS CONNECTED
- HYDRAULIC CHARACTERISTICS OF INNER REGION SIGNIFICANTLY DIFFERENT FROM AVERAGE CHARACTERISTICS OF FLOW SYSTEM

INTERFERENCE TESTS

(CONTINUED)

FRACTURE NETWORK MODELS:

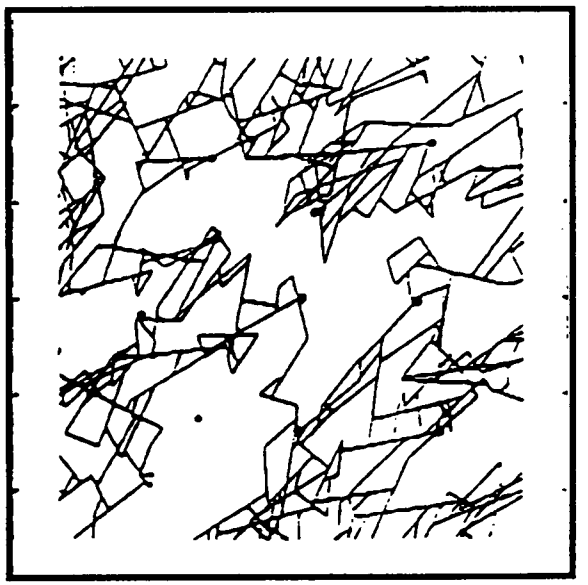
- **FRACTURE NETWORK**
  - FRACTURE LENGTH: l=l (x,y,z)
  - FRACTURE DENSITY: d=d(x,y,z)
  - FRACTURE ORIENTATION: o=o(x,y,z)
  - A SPECIFIC NETWORK: n=(l,d,o)



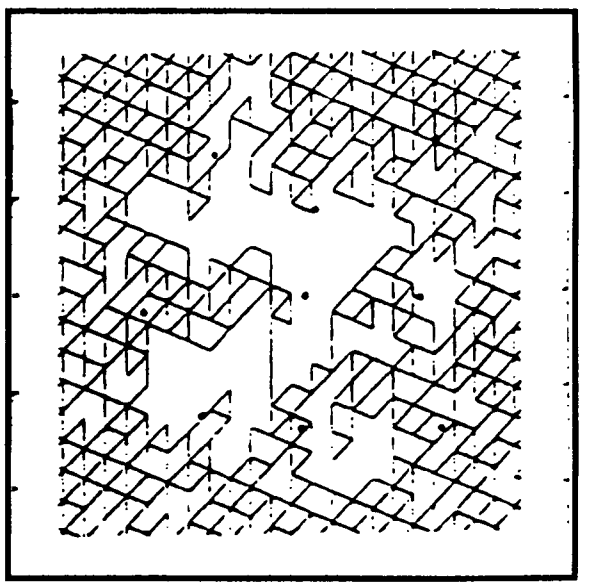
ANALYSIS OF MULTIPLE-WELL INTERFERENCE TESTS

(CONTINUED)

FRACTURE NETWORK MODELS



a) "REAL" FRACTURE NETWORK



b) ITS EQUIVALENT DISCONTINUUM MODEL: LBL

ANALYSIS OF MULTIPLE-WELL INTERFERENCE TESTS

(CONTINUED)

FRACTURE NETWORK MODELS

- TRY DIFFERENT FRACTURE NETWORKS
  - NETWORKS TO BRACKET RANGE OF UNCERTAINTY: $n_1(l_1,d_1,o_1)$, $n_2(l_2,d_2,o_2)$, ...
  - DIFFERENT HYPOTHESES FOR FRACTURE DISTRIBUTION BENEATH YUCCA MOUNTAIN
    - * STRATIGRAPHICALLY CONTROLLED
    - * INDEPENDENT FROM STRATIGRAPHY
  - NETWORK PATTERNS SUGGESTED BY: CROSS-HOLE SEISMIC PROFILING, OUTCROP STUDIES, BOREHOLE GEOPHYSICS (TV CAMERA LOGS)

ANALYSIS OF MULTIPLE-WELL INTERFERENCE TESTS

(CONTINUED)

- COMPARISON OF MULTIPLE-WELL TESTS (CROSS-HOLE AND LARGE-SCALE) WITH SINGLE-WELL TESTS:
  - MULTIPLE-WELL TESTS CONSIDERED MORE RELIABLE
  - DETERMINE APPLICABILITY OF SINGLE-WELL TEST THROUGHOUT AREA

TESTING OF C-HOLE COMPLEX WITH CONSERVATIVE TRACERS

PRIMARY OBJECTIVES

- **DETERMINE:**
  - EFFECTIVE POROSITY (θ)
  - LONGITUDINAL DISPERSIVITY (α_L)
  - AVERAGE LINEAR VELOCITY (υ)
  - POSSIBLY, MATRIX DIFFUSION (D_m) FOR QUANTITATIVE EVALUATION OF RADIONUCLIDE TRANSPORT

- **DETERMINE WHAT CONCEPTUAL MODEL FOR SOLUTE TRANSPORT BEST SIMULATES TRACER TEST RESULTS**

TESTING OF C-HOLE COMPLEX WITH CONSERVATIVE TRACERS

(CONTINUED)

PARAMETER REQUIREMENTS:

$Q_c = Q_c(\upsilon, D, R) \longleftrightarrow C = C(x,y,z,t)$

- Q_c: FLUX OF CONSTITUENT (RADIONUCLIDE)
- υ: FLOW VELOCITY (ADVECTION)
  $\upsilon = \upsilon(K,S,\theta,n)$ [θ: EFFECTIVE POROSITY]
- D: HYDRODYNAMIC DISPERSION, $D = D(\upsilon, \alpha_L, \alpha_T, D_m)$

  α_L, α_T: DISPERSIVITIES [$K \xrightarrow{\text{GEO-STATISTICS}} \alpha_L$]

  D_m: MOLECULAR DIFFUSION

- R: REACTION OF SOLUTE (RADIONUCLIDE)
  - WITH OTHER RADIONUCLIDES
  - WITH ROCK MATRIX
  - WITH OTHER SOLUTES

TESTING OF C-HOLE COMPLEX WITH CONSERVATIVE TRACERS

(CONTINUED)

TRACERS TO BE USED:

- DUE TO OVERLAPPING TESTS, MULTIPLE TRACERS ARE USED
- THE INITIAL TESTS WILL USE THE ORGANIC ANION TRIFLUOROMETHYL-BENZOATE
- UNLV WILL IDENTIFY SUITABLE ORGANIC TRACERS

TESTING OF C-HOLE COMPLEX WITH CONSERVATIVE TRACERS

(CONTINUED)

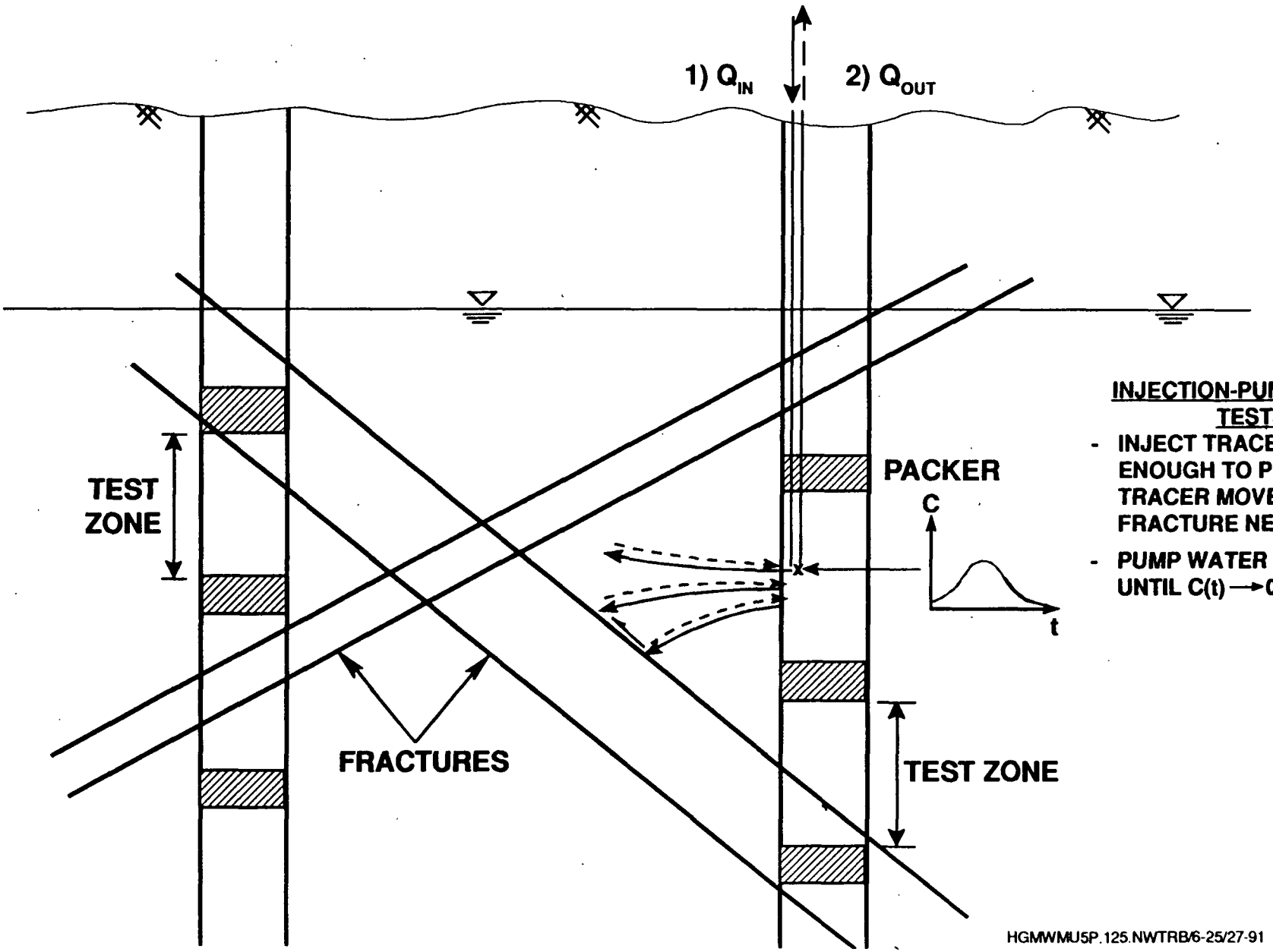
TESTS TO BE PERFORMED:

- INJECTION-PUMPBACK TESTS
- TWO-WELL RECIRCULATION TESTS
- MULTIPLE-WELL CONVERGENT TESTS

FOR ALL TESTS:

- DONE IN TEST INTERVALS WITH HIGH K

HYPOTHETICAL CROSS-SECTION:
TESTING OF C-HOLE COMPLEX WITH CONSERVATIVE TRACERS



INJECTION-PUMPBACK TESTS

- INJECT TRACER LONG ENOUGH TO PERMIT TRACER MOVEMENT IN FRACTURE NETWORK
- PUMP WATER BACK UNTIL C(t) → 0

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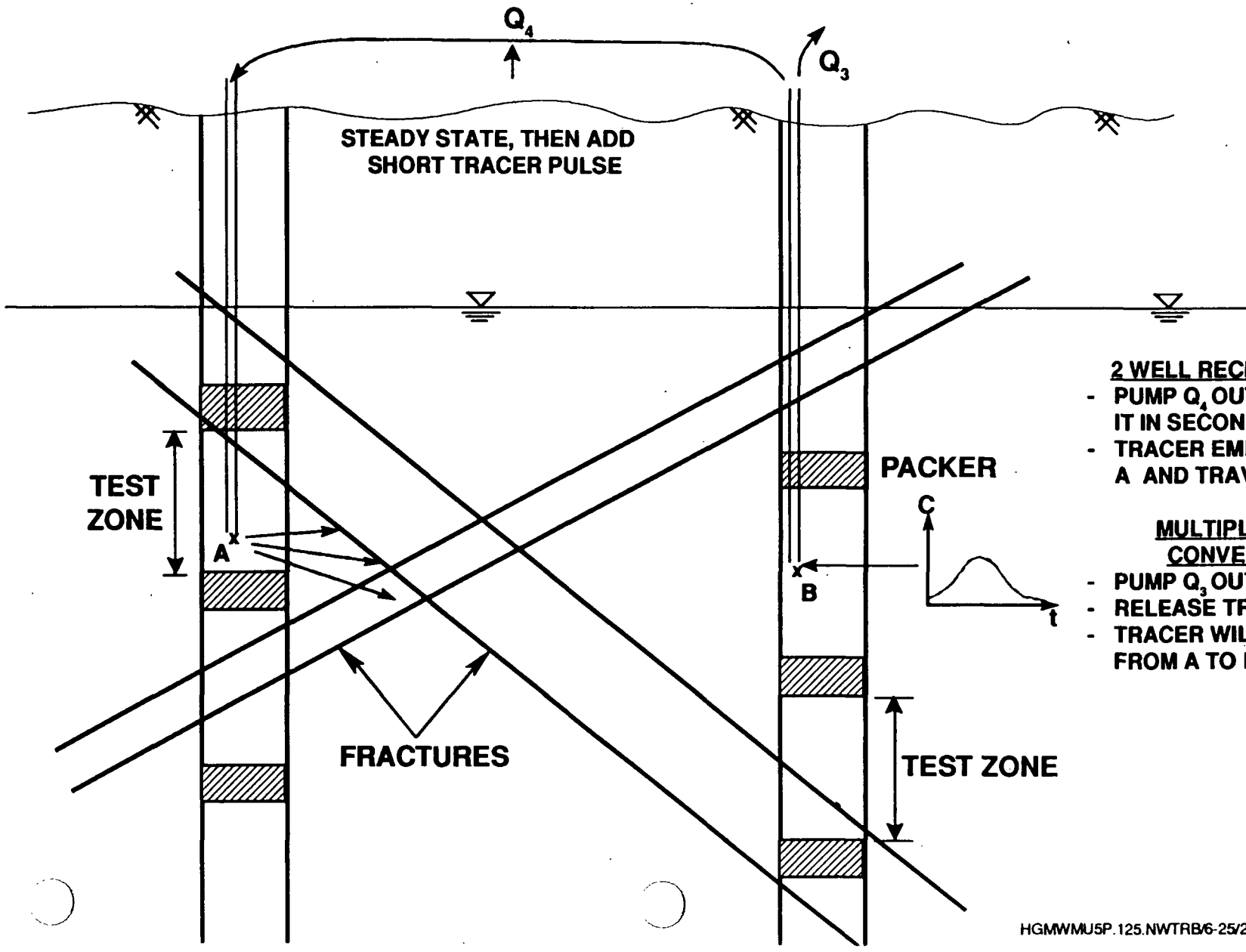
HYPOTHETICAL CROSS-SECTION:
TESTING OF C-HOLE COMPLEX WITH CONSERVATIVE TRACERS

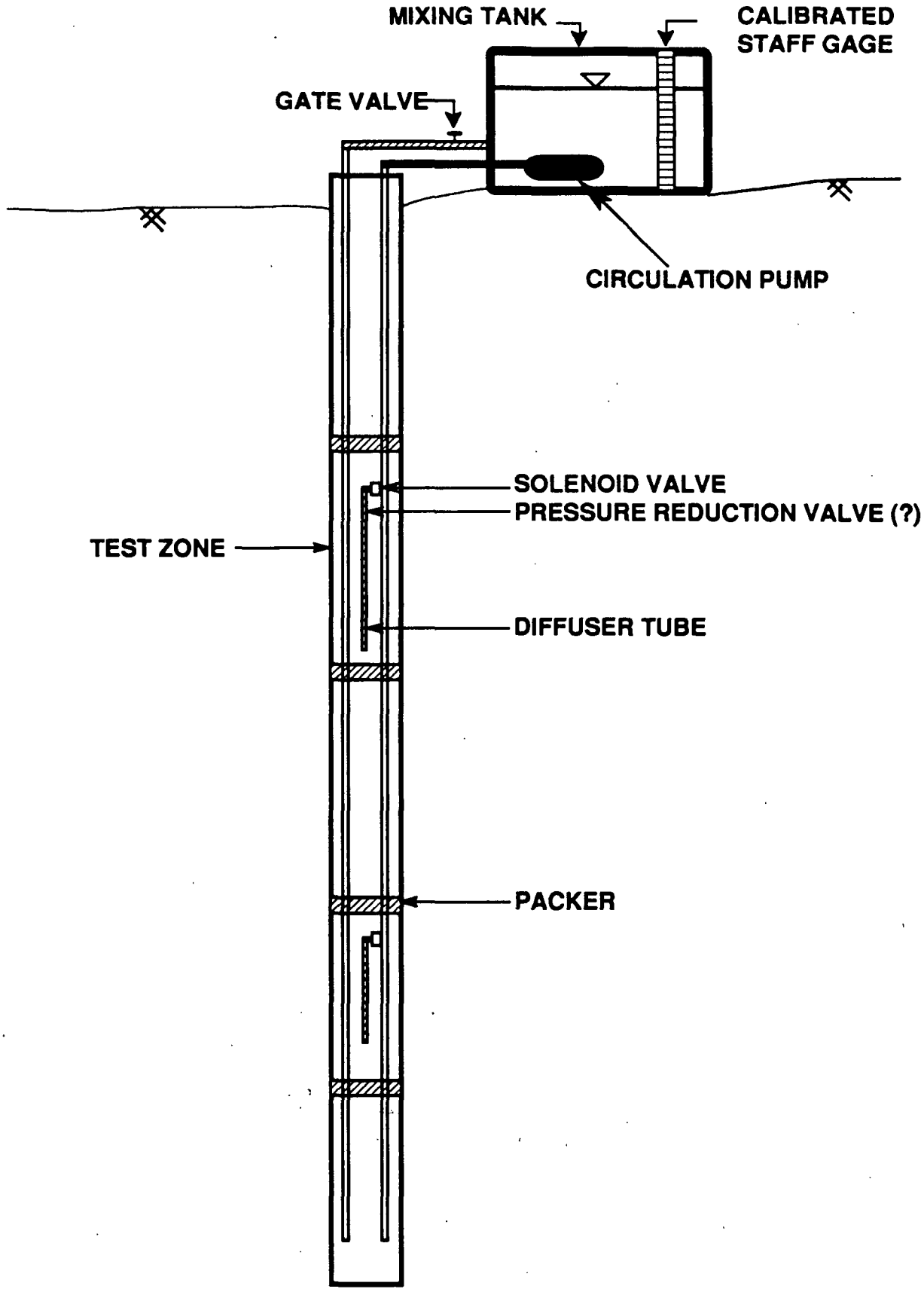


2 WELL RECIRCULATION

- PUMP Q_4 OUT AND INJECT IT IN SECOND WELL
- TRACER EMERGES FROM A AND TRAVELS TO B

MULTIPLE-WELL CONVERGENT

- PUMP Q_3 OUT
- RELEASE TRACER AT A
- TRACER WILL TRAVEL FROM A TO B



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ANALYSIS OF CONSERVATIVE TRACER TESTS

POROUS MEDIUM ASSUMPTION:

- HOMOGENEOUS ⟶ ANALYTICAL C=C(r,t)
- HETEROGENEOUS ⟶ NUMERICAL MODELS
  - 2-D MODELS C=C(x,y,t)
  - 3-D MODELS C=C(x,y,z,t)

DUAL POROSITY SOLUTE TRANSPORT MODELS:

- IF EVIDENCE OF TRANSPORT IN BOTH FRACTURES AND MATRIX

COMPOSITE POROUS MEDIUM:

- ADAPT NUMERICAL MODELS (FEW ANALYTICAL PROCEDURES AVAILABLE)

FRACTURE-NETWORK MODELS:

- LBL'S DISCONTINUUM MODEL IS MAIN ONE
- USE MODEL TO IDENTIFY FRACTURE NETWORK THAT BEST SIMULATES BOTH HYDRAULIC AND TRACER TESTS

ANALYSIS OF CONSERVATIVE TRACER TESTS

(CONTINUED)

1.) $Q_c = Q_c(\upsilon, D, \overset{\circ}{R}) \longrightarrow C = C(x,y,z,t)$

2.) $\upsilon = \upsilon(K,S,\theta,n)$

3.) $D = D(\upsilon, \alpha_L, D_m)$

USE INVERSE TECHNIQUES TO OBTAIN PARAMETERS,

$$C(x,y,z,t) \quad C(r,t) \qquad \underline{\text{INVERSION TECHNIQUES}} \rightarrow \theta, \alpha_L, D_m, n$$

$$+ 1), 2), 3)$$

WHAT CHOICE OF θ, α_L, D_m, n ALONG WITH 1), 2), AND 3) MAKES DIFFERENCE BETWEEN COMPUTED AND MEASURED C(r,t) AS SMALL AS POSSIBLE?

ANALYSIS OF CONSERVATIVE TRACER TESTS

(CONTINUED)

MATRIX DIFFUSION (D_m):

- ADDRESSED BY EXPERIMENTS USING POLYSTYRENE MICROSPHERES
  - EXPERIMENTS DONE UNDER SCP REACTIVE TRACER ACTIVITY (PERFORMED BY LANL)