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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: TOTAL-SYSTEM PERFORMANCE ASSESSMENT

PRESENTER: DR. FELTON W. BINGHAM

PRESENTER'S TITLE AND ORGANIZATION: SUPERVISOR,
REPOSITORY PERFORMANCE ASSESSMENT DIVISION
SANDIA NATIONAL LABORATORIES

PRESENTER'S TELEPHONE NUMBER: (505) 844-8816

MAY 16-17, 1989

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SCOPE OF PRESENTATION

1. WHAT TOTAL-SYSTEM PERFORMANCE ASSESSMENT IS

   - PREVIOUS CALCULATIONS
   - A BRIEF REVIEW, INTRODUCING MAJOR CONCEPTS AND DEFINITIONS

2. RELIANCE ON CONCEPTS AND MODELS FROM SITE AND ENGINEERED-BARRIER PERFORMANCE ASSESSMENT

3. MAJOR ASPECTS OF TOTAL-SYSTEM ASSESSMENT

   - CUMULATIVE COMPLEMENTARY DISTRIBUTION FUNCTION

   - SCENARIO ANALYSIS

   - TOTAL-SYSTEM MODELING: EXAMPLES FROM A SYSTEM-LEVEL CODE

4. CURRENT AND FUTURE ACTIVITIES

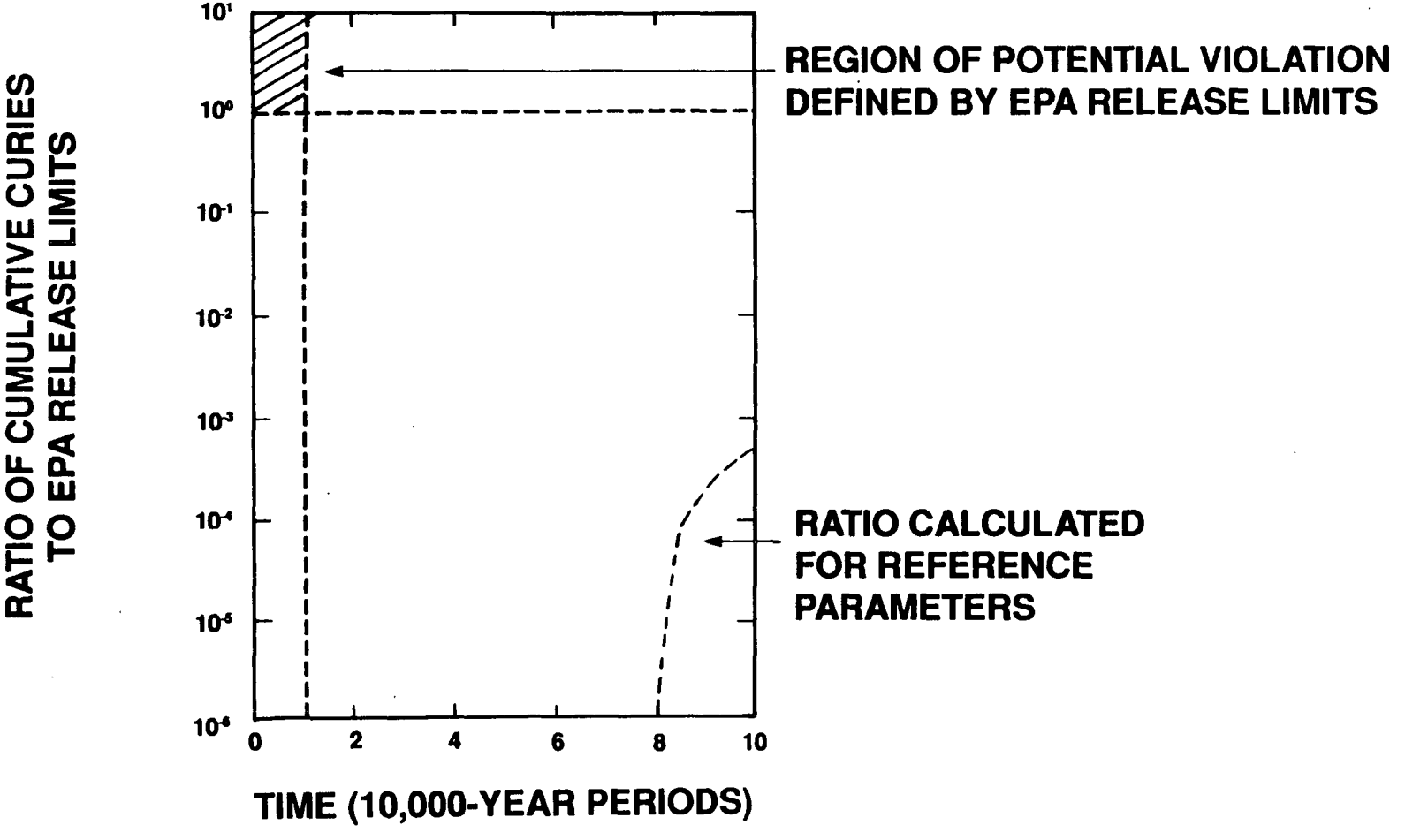
TOTAL-SYSTEM PERFORMANCE ASSESSMENTS DONE IN THE PAST

"PRELIMINARY BOUNDS ON THE EXPECTED POSTCLOSURE PERFORMANCE" (SINNOCK, LIN, AND BRANNEN, 1984)

"PRELIMINARY SYSTEM PERFORMANCE ANALYSIS" IN THE ENVIRONMENTAL ASSESSMENT (1984, 1986)

"POSTCLOSURE ANALYSIS OF NOMINATED SITES" IN DOE COMPARATIVE ANALYSIS (1986)

PRELIMINARY ESTIMATE OF CURIE DISCHARGE TO ACCESSIBLE ENVIRONMENT



WHAT IS TOTAL-SYSTEM PERFORMANCE ASSESSMENT?

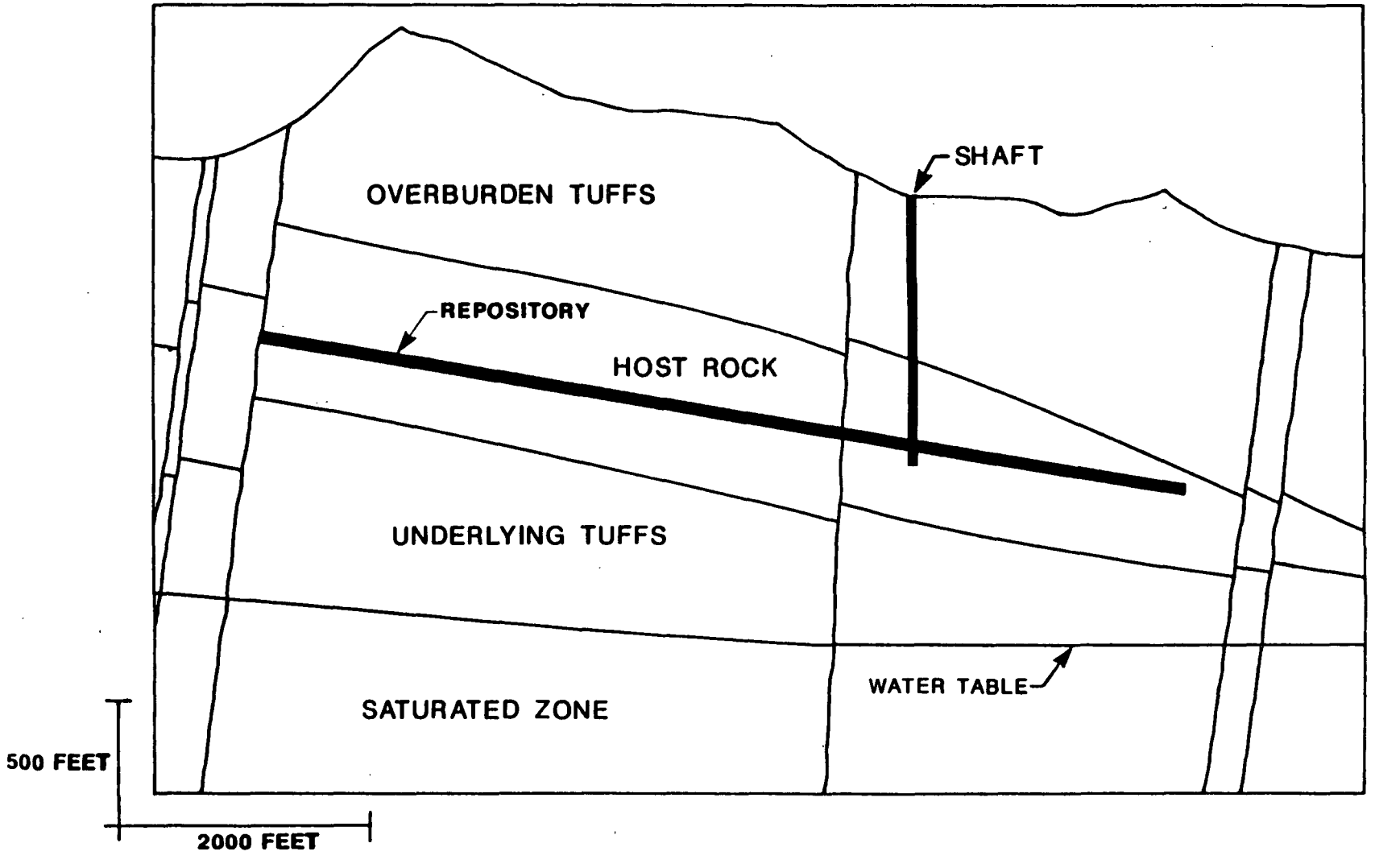
EVALUATING PERFORMANCE OF THE SYSTEM TO MEET REQUIREMENTS

PERFORMANCE: POSTCLOSURE ISOLATION OF RADIOACTIVITY

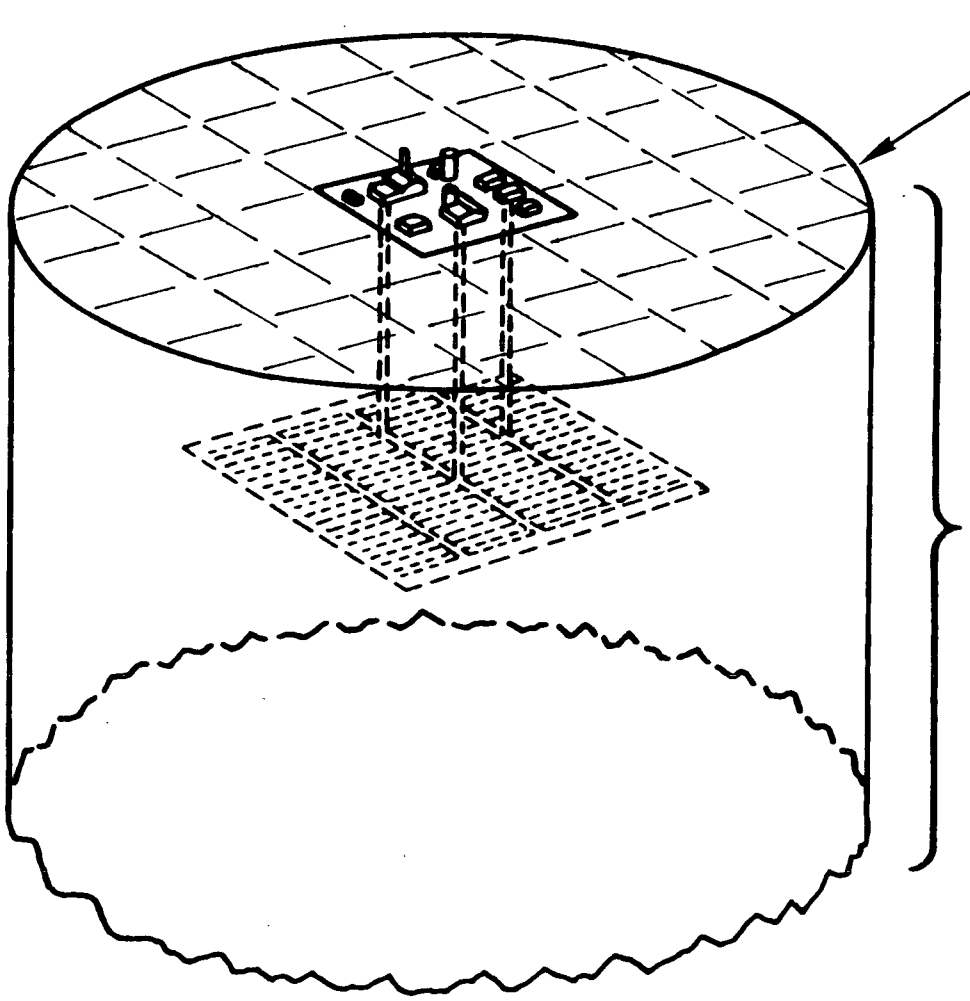
SYSTEM: SITE, REPOSITORY, AND ENGINEERED BARRIERS

REQUIREMENTS: REGULATORY STANDARDS FOR RADIONUCLIDE RELEASE

POSTCLOSURE PERFORMANCE OF SYSTEM



EPA STANDARD FOR RADIOACTIVE RELEASE TO THE ACCESSIBLE ENVIRONMENT



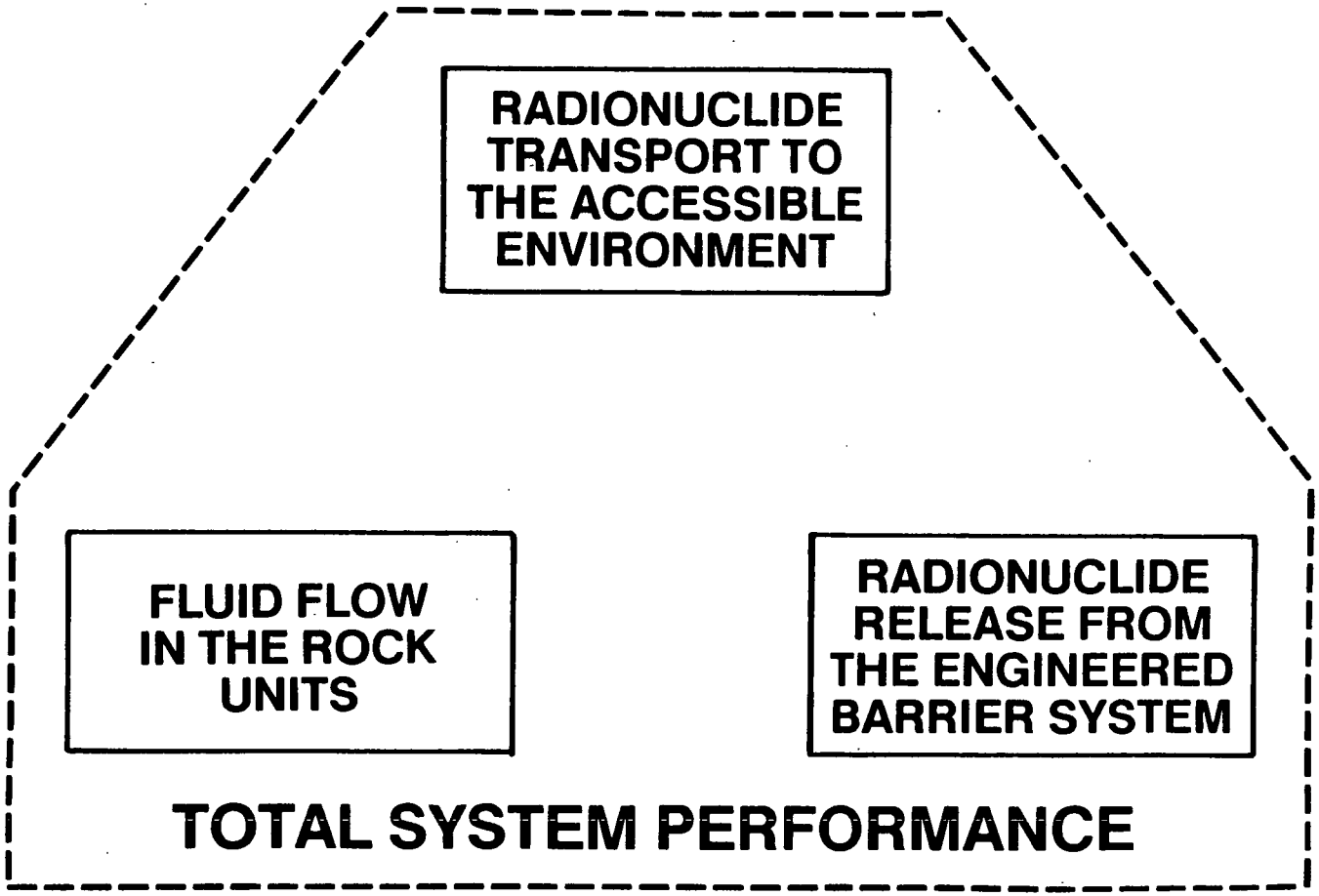
RADIOACTIVE RELEASE

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

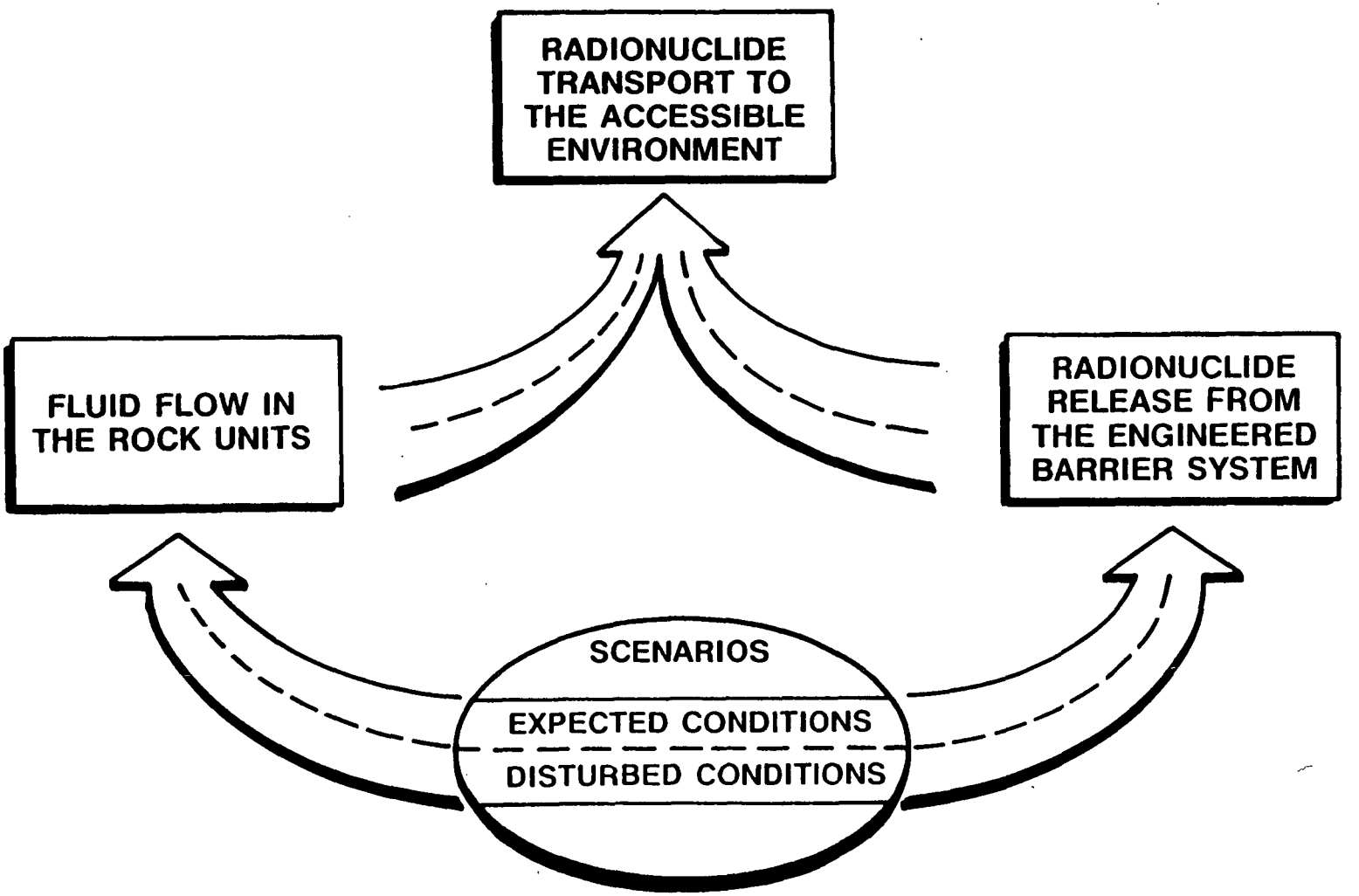
MUST MEET SPECIFIED LIMITS

RADIONUCLIDE	CI/1000 MTHM

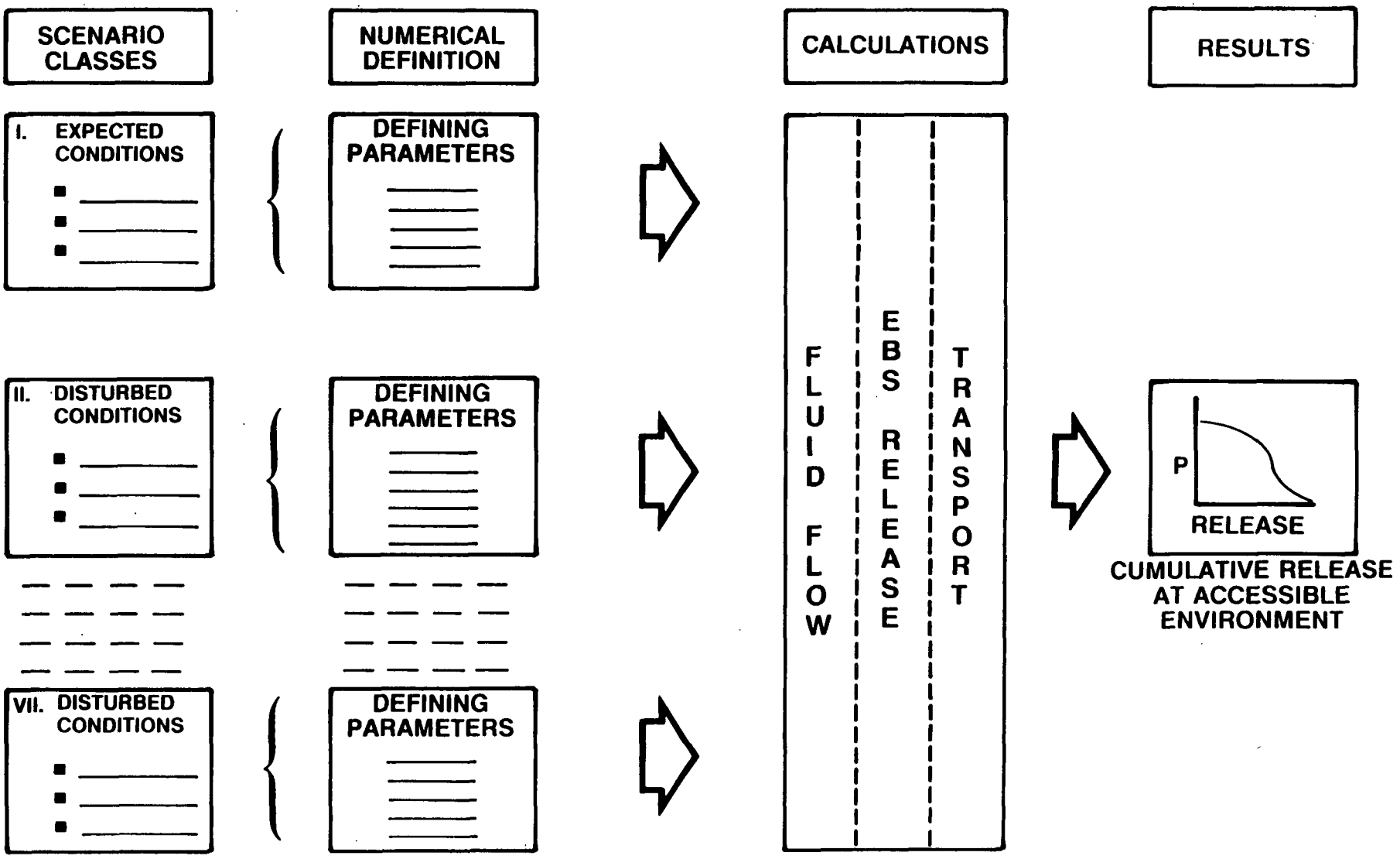
TOTAL SYSTEM PERFORMANCE INCLUDES THREE PRIMARY COMPONENTS



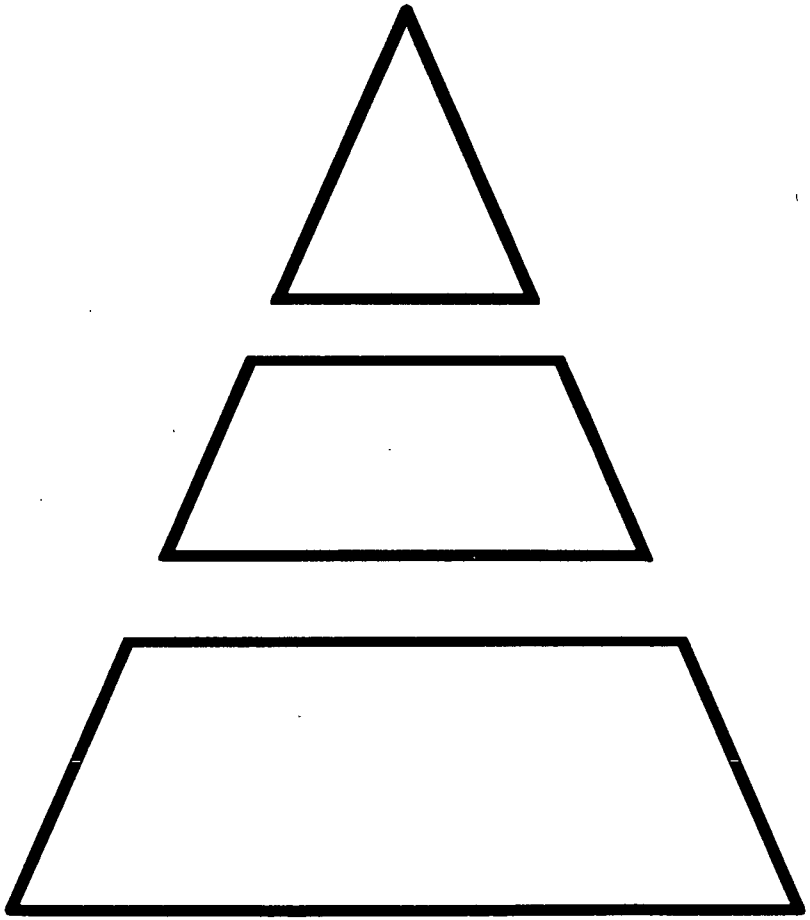
METHODS FOR PERFORMANCE ASSESSMENT MUST ACCOMMODATE EXPECTED AND DISTURBED SITE CONDITIONS



PROBABILISTIC ESTIMATES OF RELEASES WILL INCORPORATE MULTIPLE SCENARIO CLASSES



EACH COMPONENT CAN INCLUDE A HIERARCHY OF METHODS TO PREDICT PERFORMANCE



LEAST COMPLEX

TYPICAL USES: COMBINED -SCENARIO TREATMENT
MULTIPLE CALCULATIONS FOR PDFs
BOUNDING ANALYSIS OF SYSTEM

LESS COMPLEX

TYPICAL USES: INDIVIDUAL-SCENARIO TREATMENT
BOUNDING ANALYSES OF SUB-SYSTEMS

MOST COMPLEX

TYPICAL USES: DETAILS OF SPECIFIC PHENOMENON COUPLED INTERACTIONS

APPLICATIONS FOR TOTAL-SYSTEM PERFORMANCE ASSESSMENT

- DEFINING THE SITE-CHARACTERIZATION PROGRAM
- EVALUATING THE IMPACT OF SITE-CHARACTERIZATION ACTIVITIES ON SITE INTEGRITY
- INTERPRETING INFORMATION FROM SITE CHARACTERIZATION
- EVALUATING ALTERNATIVE DESIGN CONFIGURATIONS
- PREDICTING LONG-TERM ENVIRONMENTAL IMPACTS
- DETERMINING COMPLIANCE WITH REGULATORY STANDARDS

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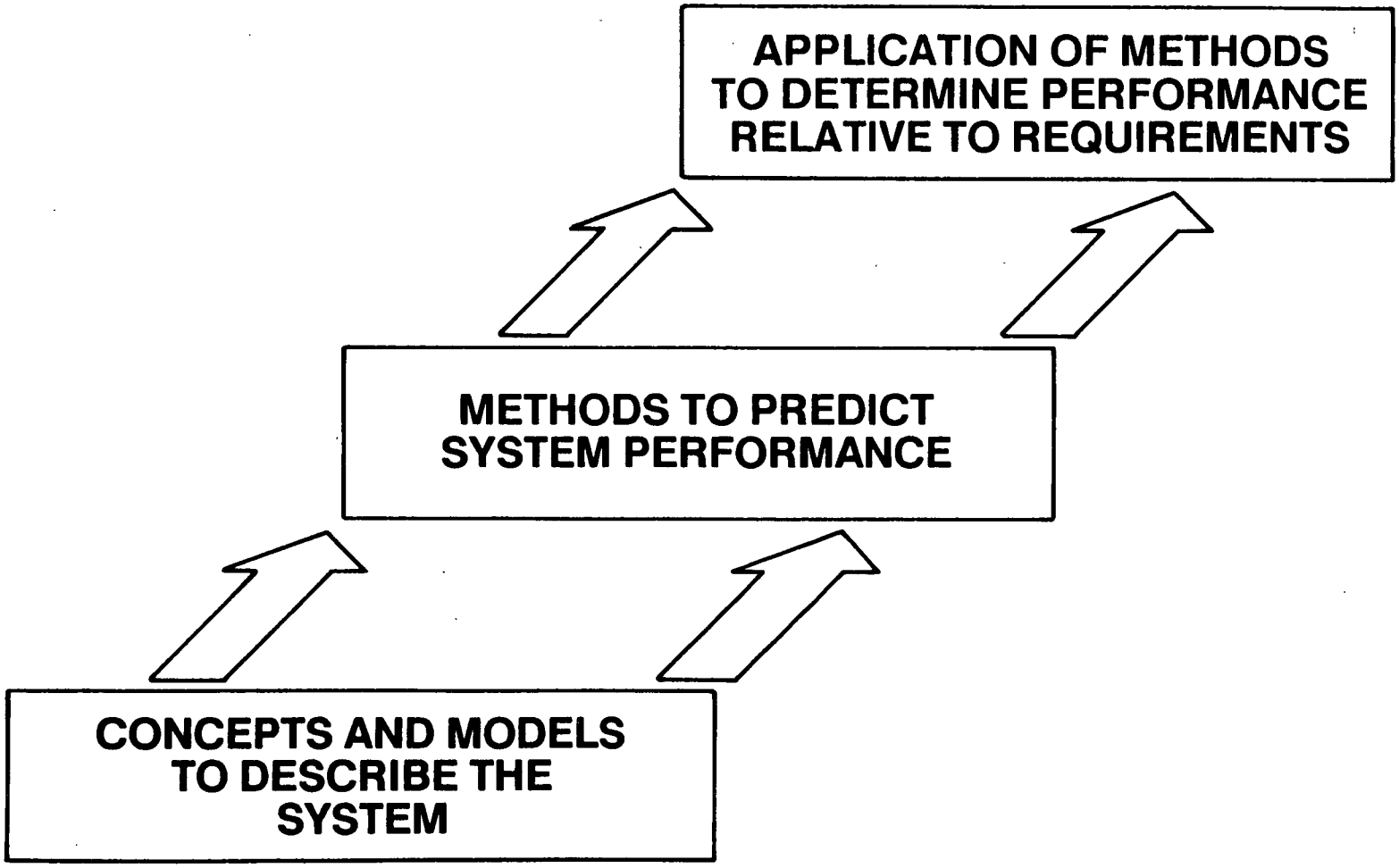
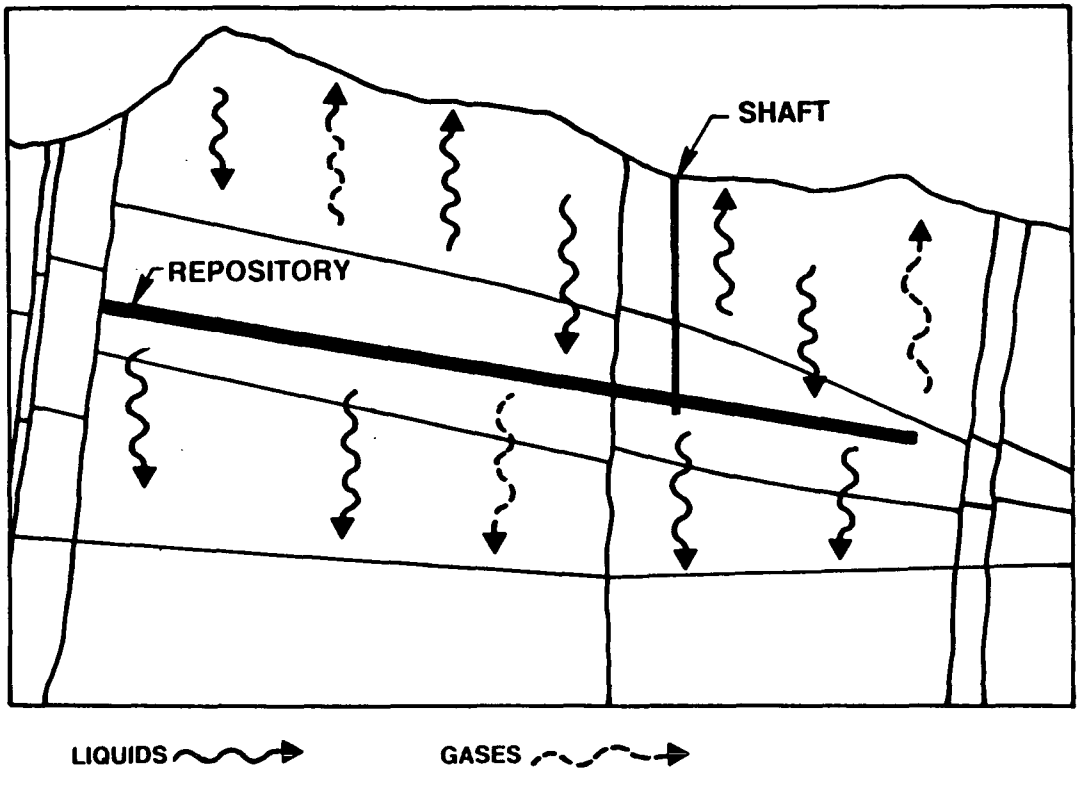
APPROACH TO TOTAL SYSTEM PERFORMANCE ASSESSMENT



CONCEPTS AND MODELS FOR FLUID FLOW IN THE ROCK UNITS



FLOW MECHANISMS

- ROCK HYDROLOGIC PROPERTIES
- MATRIX/FRACTURE FLOW
- DRIVING POTENTIALS
- GAS-FLOW CHARACTERISTICS

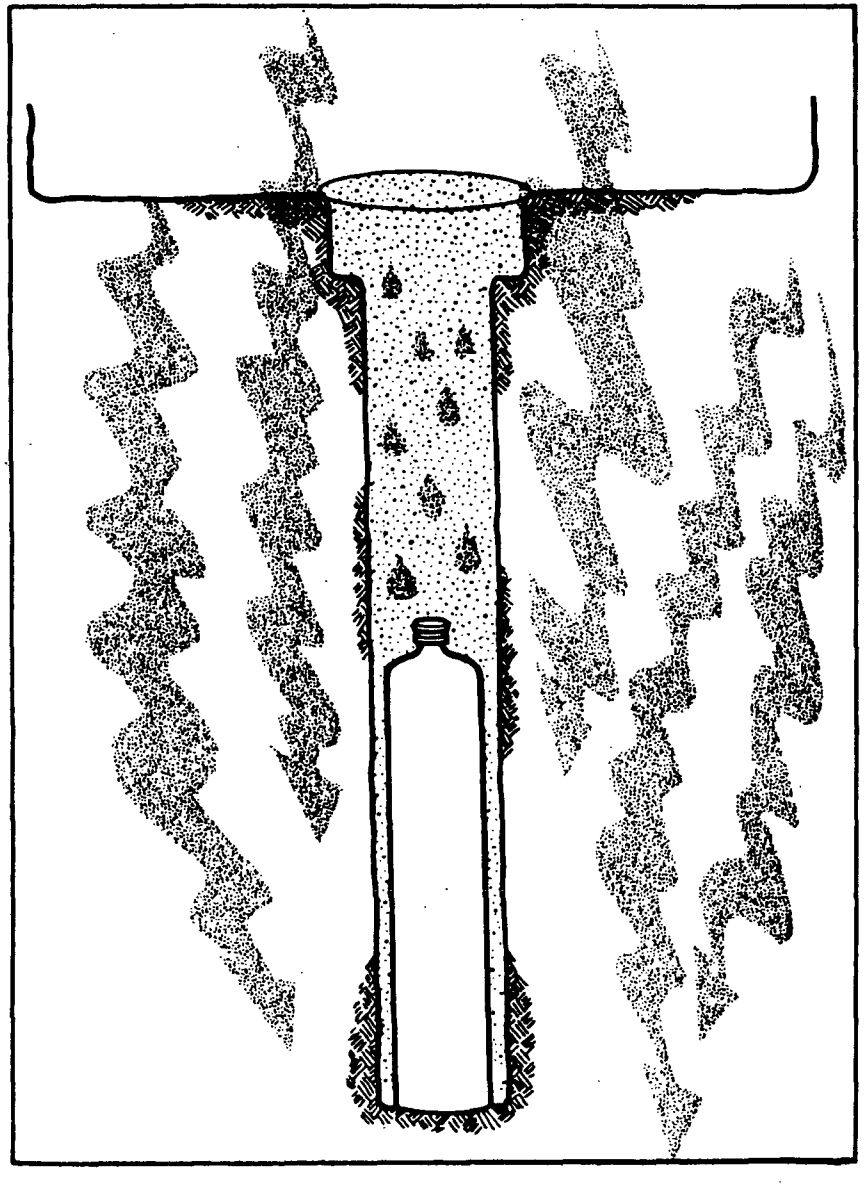
FLUX IN THE UNSATURATED ZONE

- CLIMATIC CONDITIONS
- INFILTRATION
- PERCOLATION

PRIMARY RESULTS

FLUID VELOCITY DISTRIBUTIONS AND SATURATION CONDITIONS

CONCEPTS AND MODELS FOR RADIONUCLIDE RELEASE FROM THE ENGINEERED BARRIER SYSTEM



WASTE PACKAGE LIFETIME

- LOCAL ENVIRONMENT
- DEGRADATION MODES AND RATES

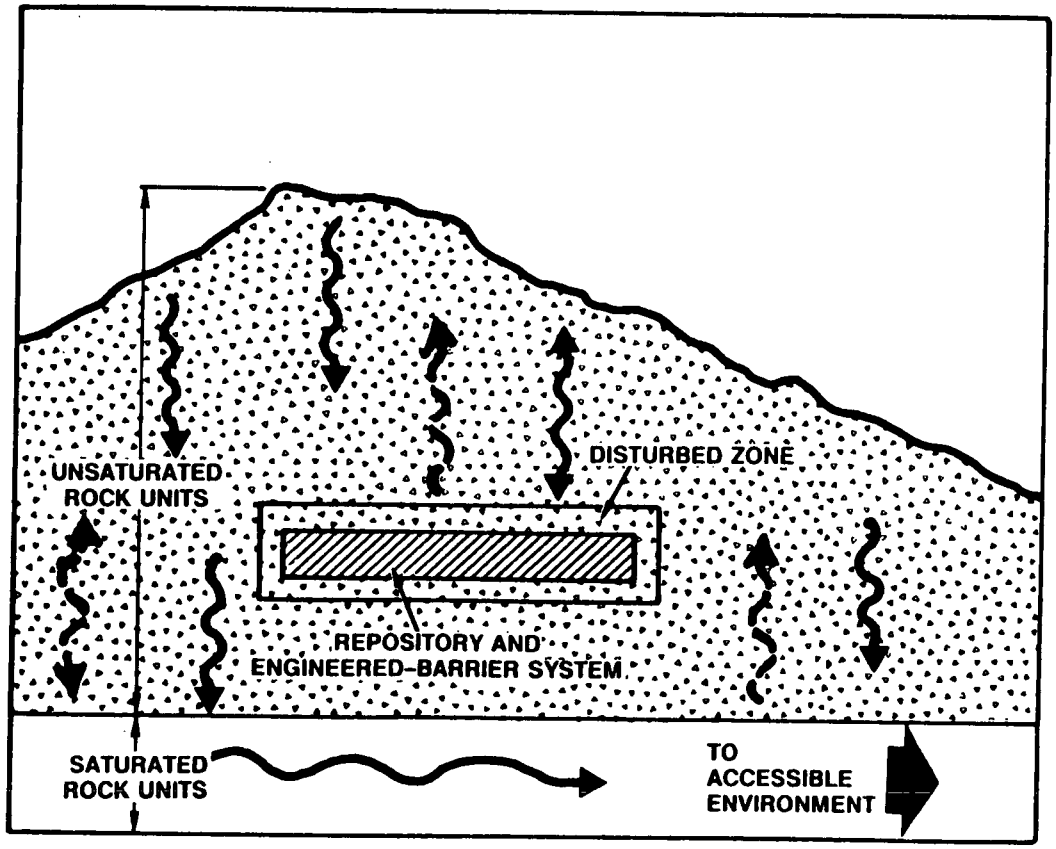
RADIONUCLIDE RELEASE RATE

- FORM OF NUCLIDES
- AVAILABLE INVENTORY
- SOLUBILITY
- REACTION RATES

PRIMARY RESULTS

TEMPORAL AND SPATIAL DISTRIBUTIONS OF RADIONUCLIDE INJECTION INTO FLUID FLOW (SOURCE TERM DISTRIBUTION)

CONCEPTS AND MODELS FOR RADIONUCLIDE TRANSPORT TO THE ACCESSIBLE ENVIRONMENT



VELOCITY DISTRIBUTIONS

SOURCE TERM DISTRIBUTION

REPOSITORY IMPACTS

- ROCK DEFORMATION
- SEALS
- THERMAL EFFECTS

TRANSPORT PHENOMENA

- CHEMICAL RETARDATION
- MATRIX–FRACTURE COUPLING

PRIMARY RESULTS

RADIONUCLIDE CONCENTRATIONS AT THE ACCESSIBLE ENVIRONMENT AS A FUNCTION OF TIME

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PERFORMANCE MEASURE FOR OVERALL SYSTEM

$$M = \sum_i \frac{Q_i}{L_i}$$

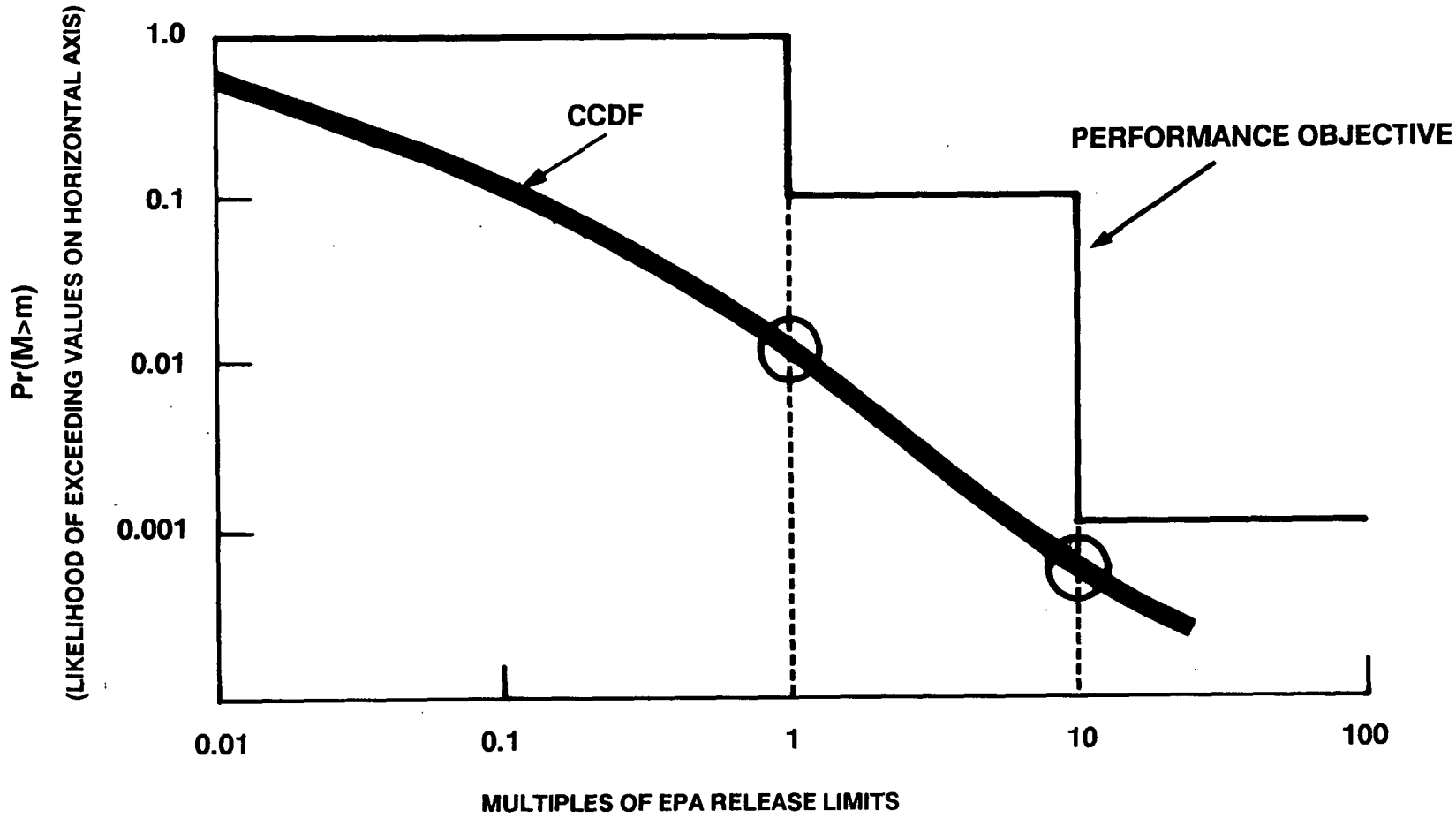
M = NORMALIZED RELEASE FROM TOTAL SYSTEM

Q_i = CUMULATIVE RADIOACTIVITY OF THE i^{TH} RADIONUCLIDE RELEASED TO ACCESSIBLE ENVIRONMENT IN THE 10,000-YR PERIOD AFTER CLOSURE (C_i)

L_i = RELEASE LIMIT FOR THE i^{TH} NUCLIDE AS SPECIFIED IN REGULATIONS (C_i)

CCDF

OVERALL COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION (CCDF)



DEFINITION OF THE CCDF

$$\Pr(M>m) = \int_{V_1} dv_1 \int_{V_2} dv_2 \ldots \int_{V_n} dv_n \, U\,[M(v_1, v_2, \ldots, v_n) - m]\, f(v_1, v_2, \ldots, v_n)$$

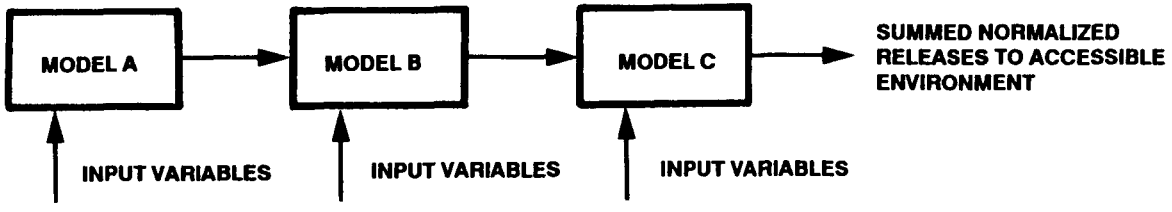
v_i = VARIABLES OF THE SYSTEM IMPORTANT TO WASTE ISOLATION

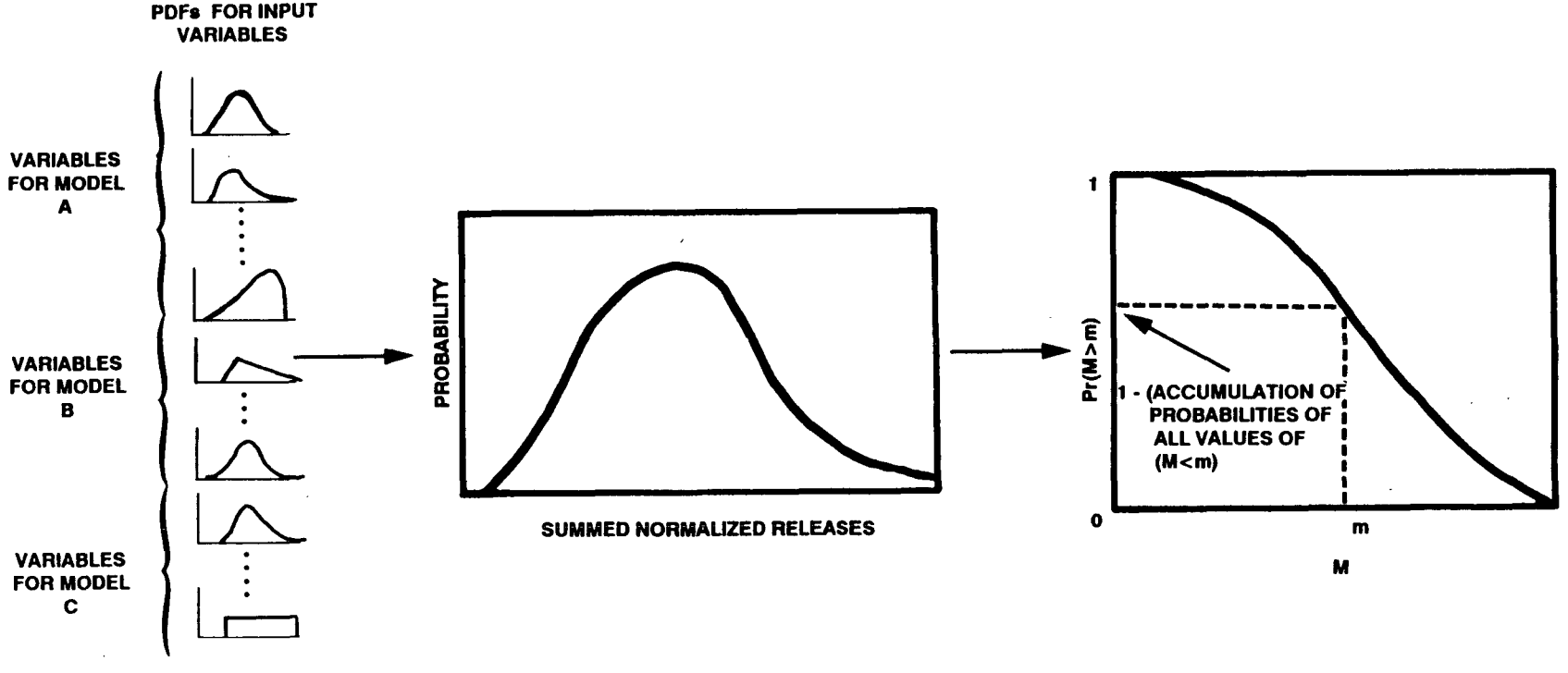
$f(v)$ = JOINT PROBABILITY DENSITY FUNCTION FOR THE VARIABLES OF THE SYSTEM

$u(x)$ = STEP FUNCTION

$u(x) = 1$ for $x>0$
$= 0$ for $x<0$

CONSTRUCTION OF THE COMPLEMTARY CUMULATIVE DISTRIBUTION FUNCTION (CCDF)





SCENARIO SELECTION

USES OF SCENARIOS

1. RESTRICTION OF CCDF INTEGRATION

   - CCDF MAY BE EXPANDED INTO INTEGRATION OVER SCENARIOS

2. AS A SHORTCUT TO DECIDING WHICH STATE VARIABLES WILL CONTRIBUTE SIGNIFICANTLY TO THE CCDF

   - THIS USE IS IMPORTANT TO THE GUIDING OF SITE CHARACTERIZATION

   - IT FURTHERS COMMUNICATION BETWEEN WORKERS IN PERFORMANCE ASSESSMENT AND IN FIELD INVESTIGATIONS

PURPOSE OF SCENARIO SELECTION DONE SO FAR

TO GUIDE SITE CHARACTERIZATION

- GOVERNING PRINCIPLE IN PLANNING: TO OBTAIN THE DATA THAT ARE NEEDED
- SCENARIO SELECTION IS AN EARLY STEP IN PERFORMANCE ALLOCATION

IMPLICATION: THE SELECTION DONE SO FAR IS NOT THE SELECTION THAT WILL APPEAR IN THE LICENSE APPLICATION

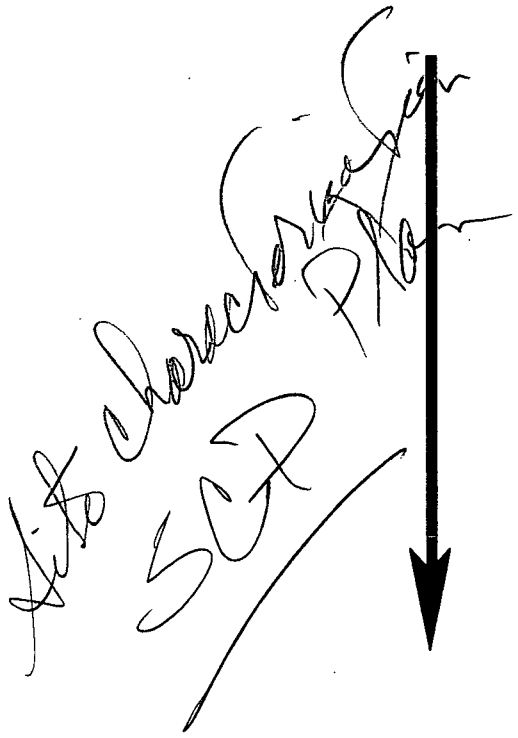
GENERAL PRINCIPLES FOR SCENARIO SELECTION DONE FOR SITE CHARACTERIZATION

- TAKE INTO ACCOUNT ALL SUFFICIENTLY CREDIBLE NATURAL PROCESSES AND EVENTS
  - GENERALLY OMIT CATEGORIES WITH LIKELIHOOD LESS THAN 10^{-4} IN 10,000 YEARS
  - OMIT THOSE THAT CONTRIBUTE INSIGNIFICANTLY TO CCDF
- DEVELOP SCENARIOS INITIATED BY HUMAN ACTIVITIES
- DEVELOP "NOMINAL" AND "DISRUPTIVE" SCENARIO CLASSES
- BE CONSERVATIVE: ENSURE THAT ALL NECESSARY DATA ARE COLLECTED
- BE RESPONSIBLE: DON'T WASTE RESOURCES ON INSIGNIFICANT SCENARIOS

EXAMPLES FROM ROSS STUDY

(INITIATING EVENT) — **CLIMATE CHANGE**

(SEQUENCES)



1. **CLIMATE CHANGE --►INCREASED INFILTRATION --►INCREASED FLUX AT REPOSITORY**
2. **CLIMATE CHANGE --►WATER-TABLE RISE ABOVE CALICO HILLS UNIT**

-
-
-

6. **CLIMATE CHANGE --►PERCHED WATER --► DRAINING BY FRACTURE FLOW**

GROUPED SCENARIO CLASSES FOR GUIDING SITE CHARACTERIZATION

- DIRECT RELEASES (MAGMA, HUMAN INTRUSION)
- PARTIAL FAILURE OF ENGINEERED BARRIERS
- PARTIAL FAILURE OF UNSATURATED-ZONE BARRIERS (INCREASED FLUX, WATER-TABLE RISE, CHANGES IN HYDRAULIC OR GEOCHEMICAL PROPERTIES)
- PARTIAL FAILURE OF SATURATED-ZONE BARRIERS (FORESHORTENING OF ZONE, CHANGED PROPERTIES OF ZONE)
- UNDISTURBED PERFORMANCE OF ALL BARRIERS

SOME EXAMPLES OF TOTAL-SYSTEM MODELING

TOSPAC MODULES

HYDROLOGIC MODULES
(STEADY-STATE OR TRANSIENT FLOW)

INPUT

ROCK PROPERTIES FOR MATRIX AND FRACTURES

$[n_m, n_f, S_m, S_f, K_m(\psi, z), K_f(\psi, z)]$

INITIAL CONDITIONS

$[\psi(z, t=0) \text{ or } S_m(z, t=0)]$

BOUNDARY CONDITIONS

[WATER TABLE LOCATION, q_{tot}]

WATER CONSERVATION EQ.

(DARCY'S LAW OR RICHARD'S EQ.)

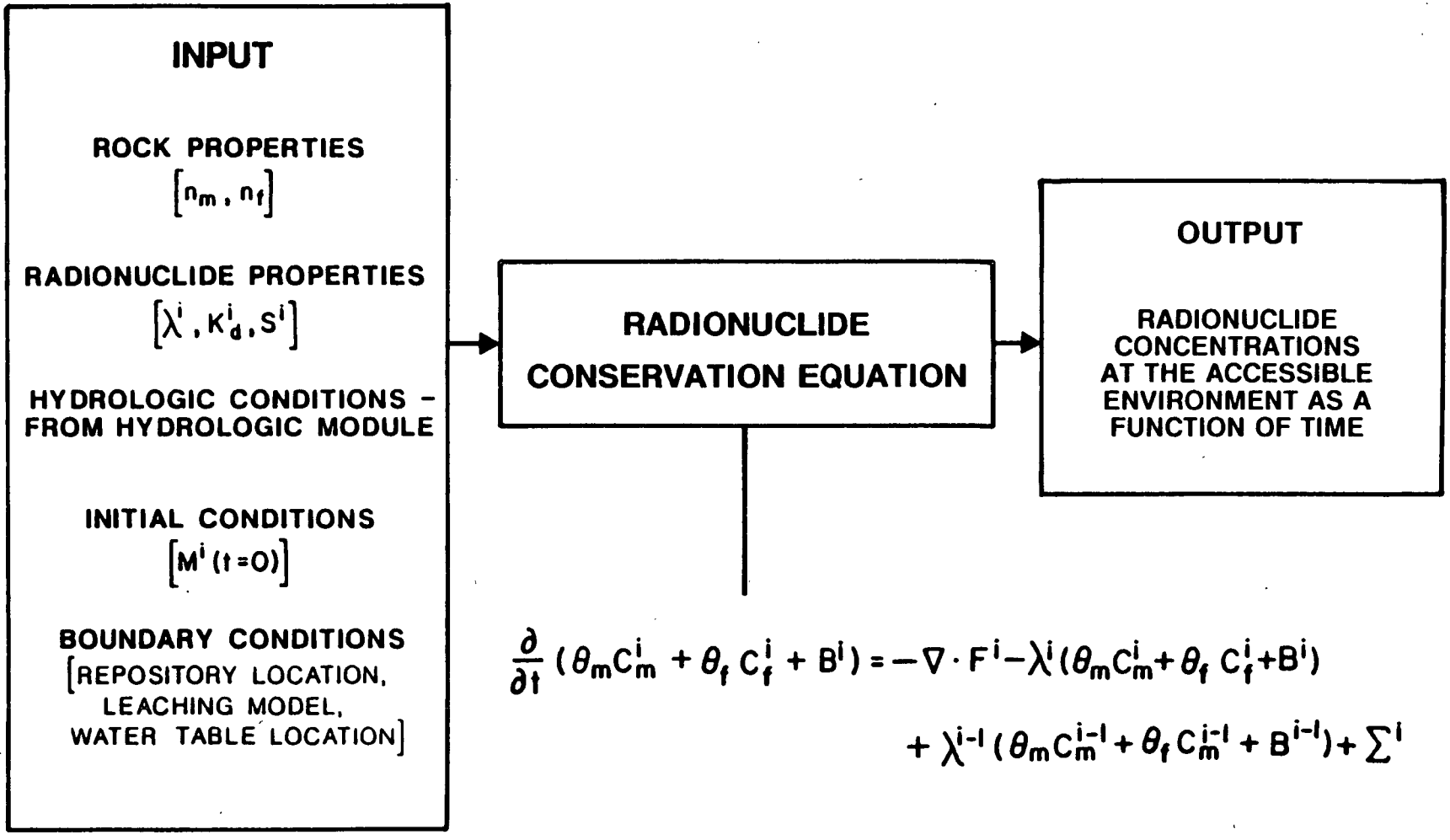
$$C\frac{\partial \psi}{\partial t} = K\frac{\partial^2 \psi}{\partial z^2} + \left(\frac{\partial K}{\partial z} + \beta_w' K \frac{\partial \psi}{\partial z}\right)\left(\frac{\partial \psi}{\partial z} + 1\right)$$

OUTPUT

PROFILES OF PRESSURE HEAD, SATURATION, AND WATER VELOCITY

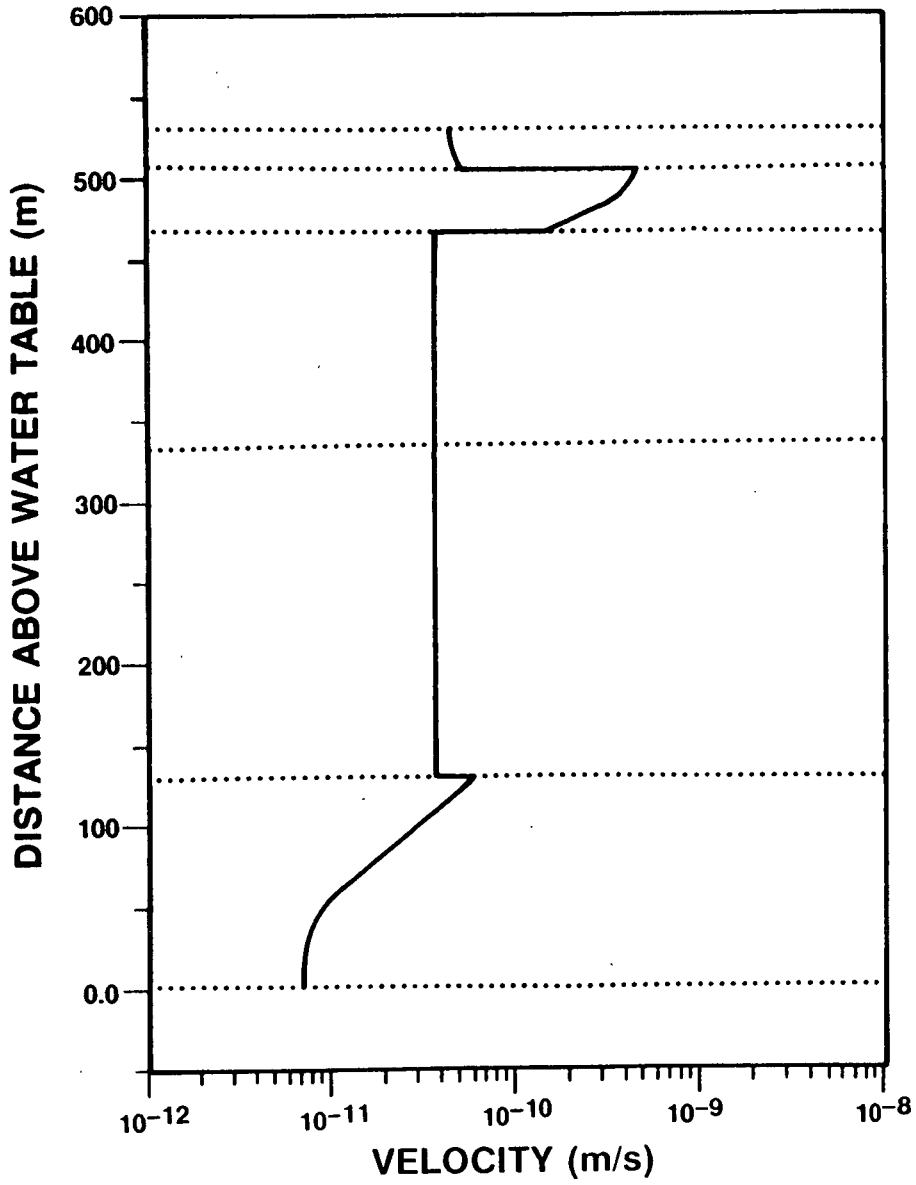
TOSPAC MODULES

TRANSPORT MODULE



$$\frac{\partial}{\partial t}(\theta_m C_m^i + \theta_f C_f^i + B^i) = -\nabla \cdot F^i - \lambda^i(\theta_m C_m^i + \theta_f C_f^i + B^i) + \lambda^{i-1}(\theta_m C_m^{i-1} + \theta_f C_m^{i-1} + B^{i-1}) + \sum^i$$

TOSPAC CALCULATION OF AVERAGE WATER VELOCITY



ROCK UNITS

TCw

PTn

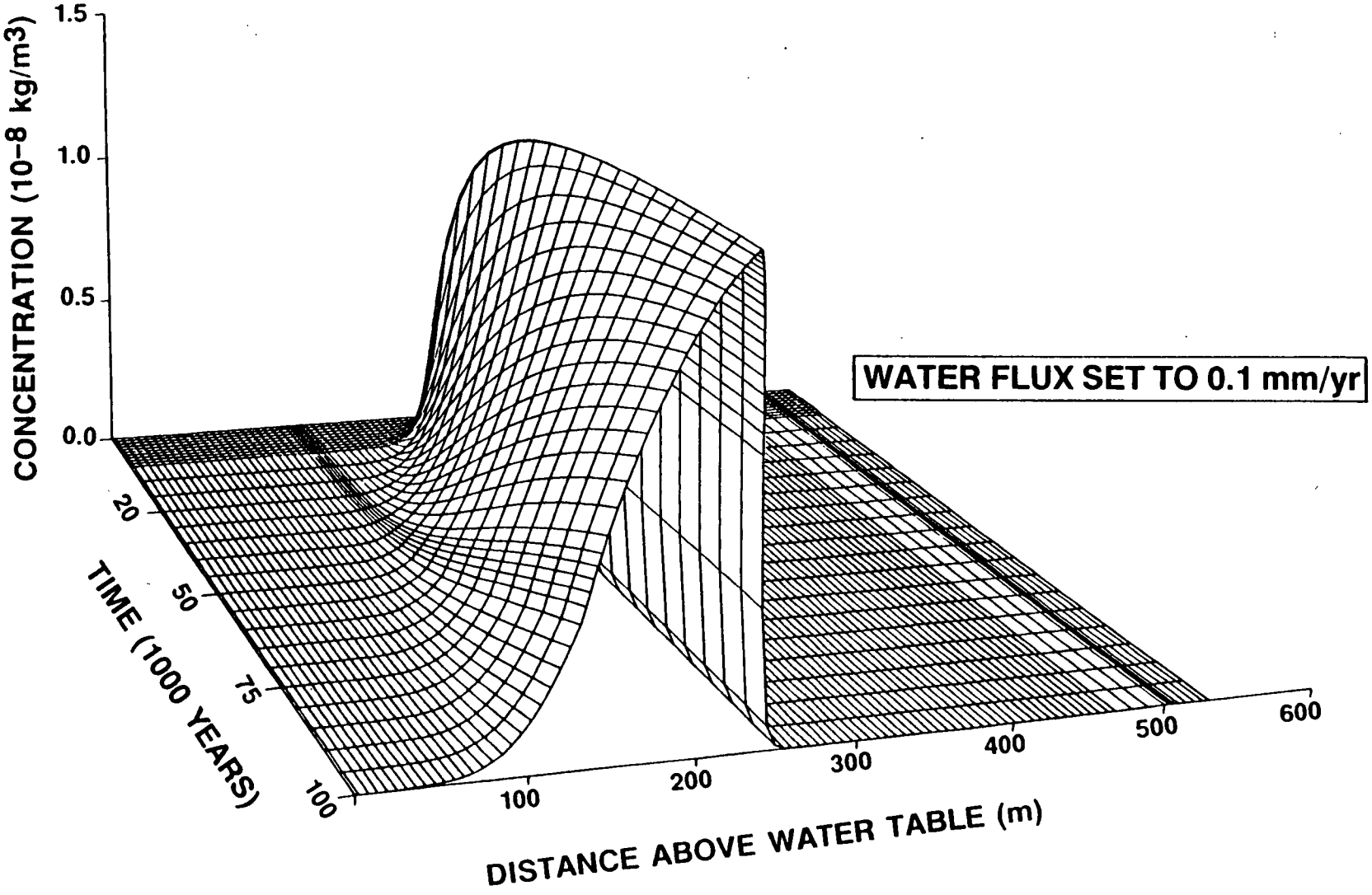
TSw1

TSw2-3

CHnv

WATER FLUX SET TO 0.1 mm/yr

TOSPAC CALCULATION OF I-129 CONCENTRATION IN THE MATRIX



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FUTURE SCENARIO SELECTION

- SELECTION WILL BEGIN FROM RESULTS ALREADY REPORTED
- EMPHASIS WILL SHIFT TO USE IN CONSTRUCTING CCDF
- INCREASED RELIANCE CAN BE MADE ON DATA
  - SITE CHARACTERIZATION HAS BEEN PARTLY DESIGNED TO HELP SCENARIO SELECTION
- FINAL SELECTIONS MUST REST ON JUDGMENT
  - INFORMED JUDGMENT
  - JUDGMENT FROM MANY SOURCES
  - JUDGMENT CONTROLLED BY FORMAL PROCEDURES

SOME NEAR-TERM ACTIVITIES IN TOTAL-SYSTEM MODELING

PARTICIPATION IN "TEST PROBLEM" EXERCISE

REFINEMENTS OF TOTAL-SYSTEM MODELS

- TO FOLLOW ADVANCES IN TRANSPORT MODELING
- TO ALLOW MORE-COMPLEX SOURCE TERMS

CONSTRUCTION OF TOTAL-SYSTEM SIMULATOR

BENCHMARKING OF CODES

DETAILED SUPPORT FOR DESIGN OF EXPLORATORY-SHAFT FACILITY