8905260416 -
PART 2

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

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

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

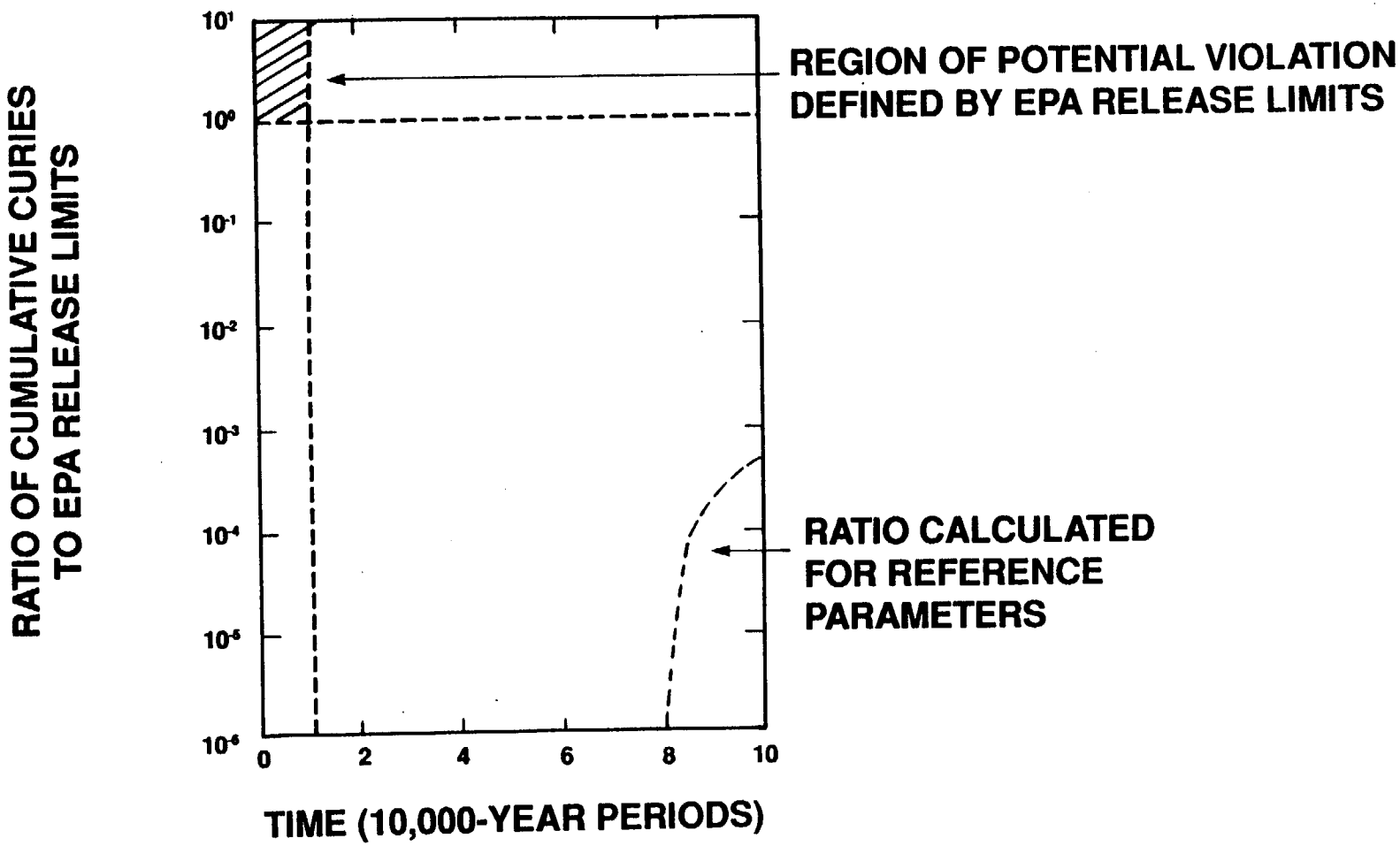
TOTAL-SYSTEM PERFORMANCE ASSESSMENTS DONE IN THE PAST

"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?

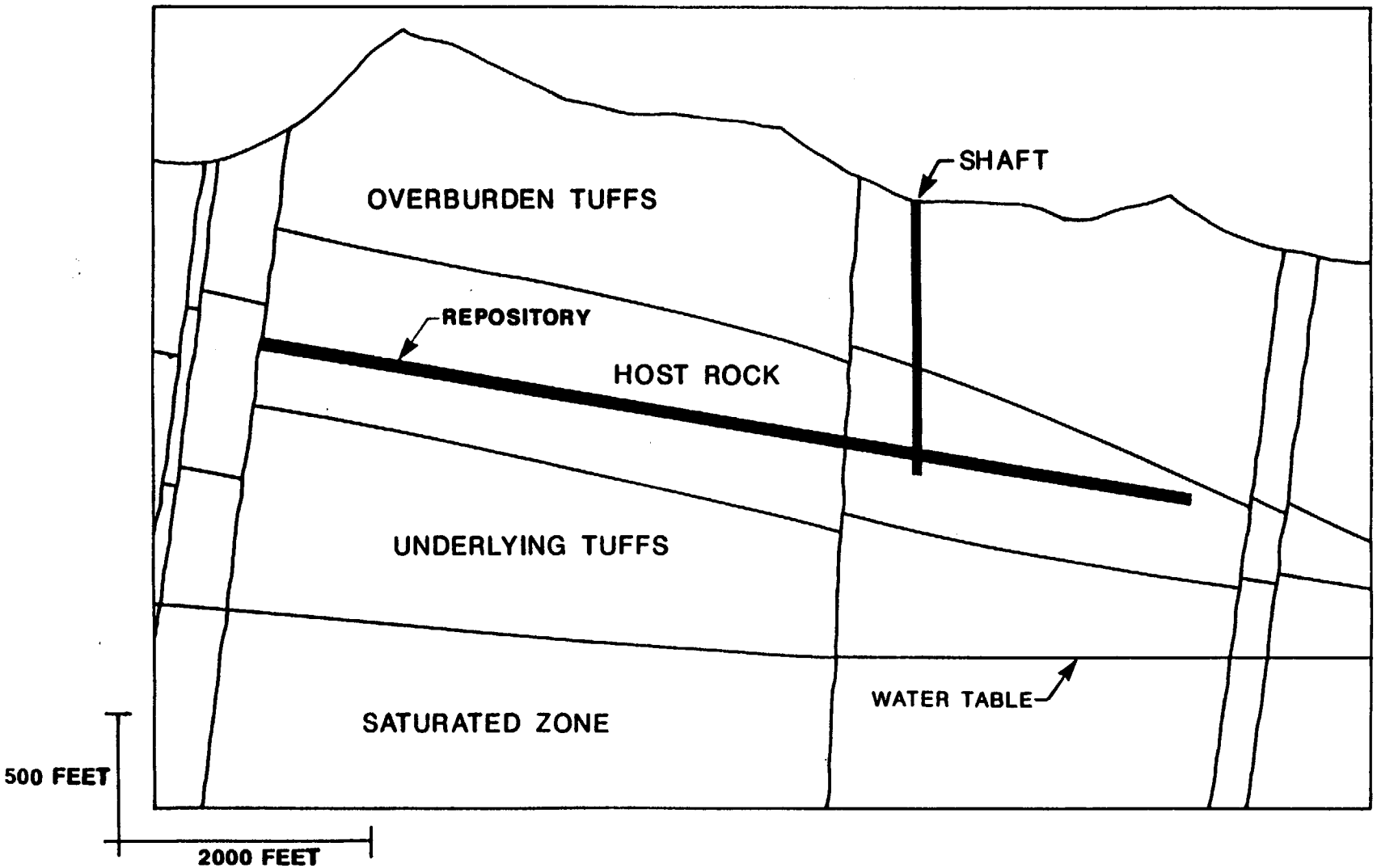
EVALUATING PERFORMANCE OF THE SYSTEM TO MEET REQUIREMENTS

PERFORMANCE: POSTCLOSURE ISOLATION OF RADIOACTIVITY

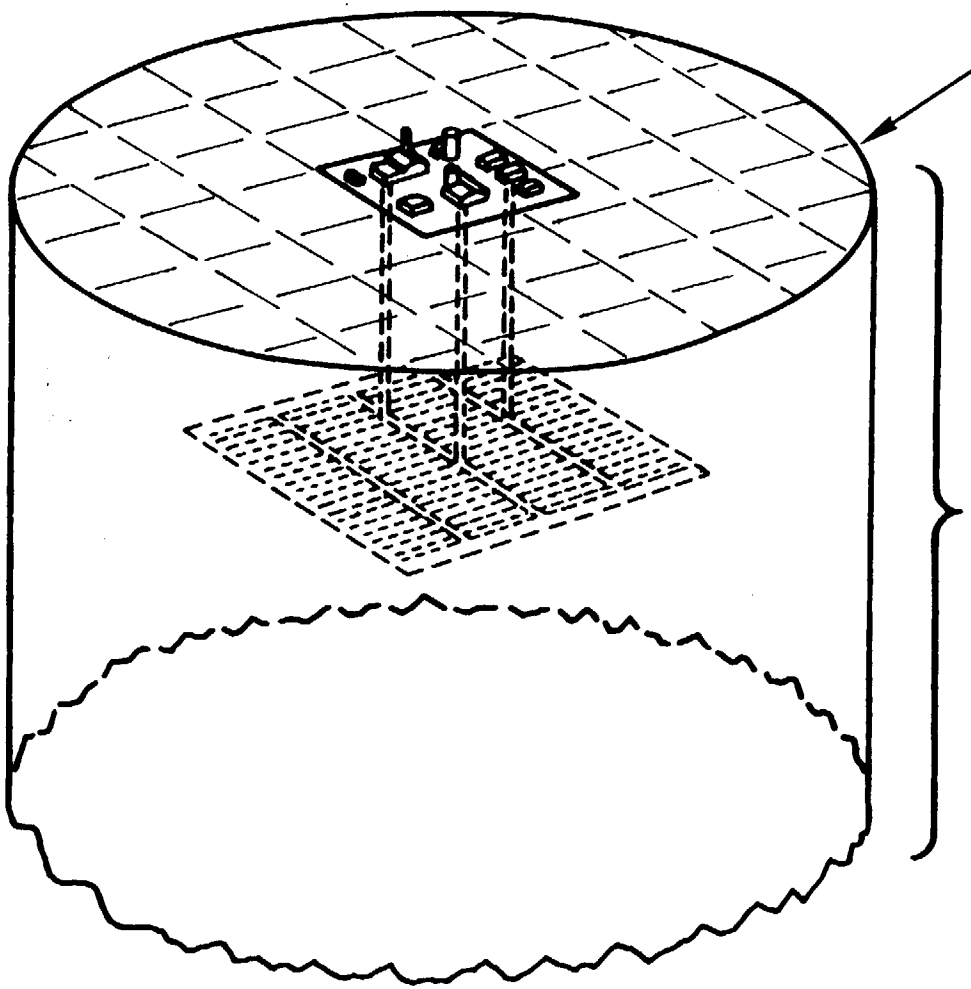
SYSTEM: SITE, REPOSITORY, AND ENGINEERED BARRIERS

REQUIREMENTS: REGULATORY STANDARDS FOR RADIONUCLIDE RELEASE

POSTCLOSURE PERFORMANCE OF SYSTEM



EPA STANDARD FOR RADIOACTIVE RELEASE TO THE ACCESSIBLE ENVIRONMENT



ACCESSIBLE ENVIRONMENT

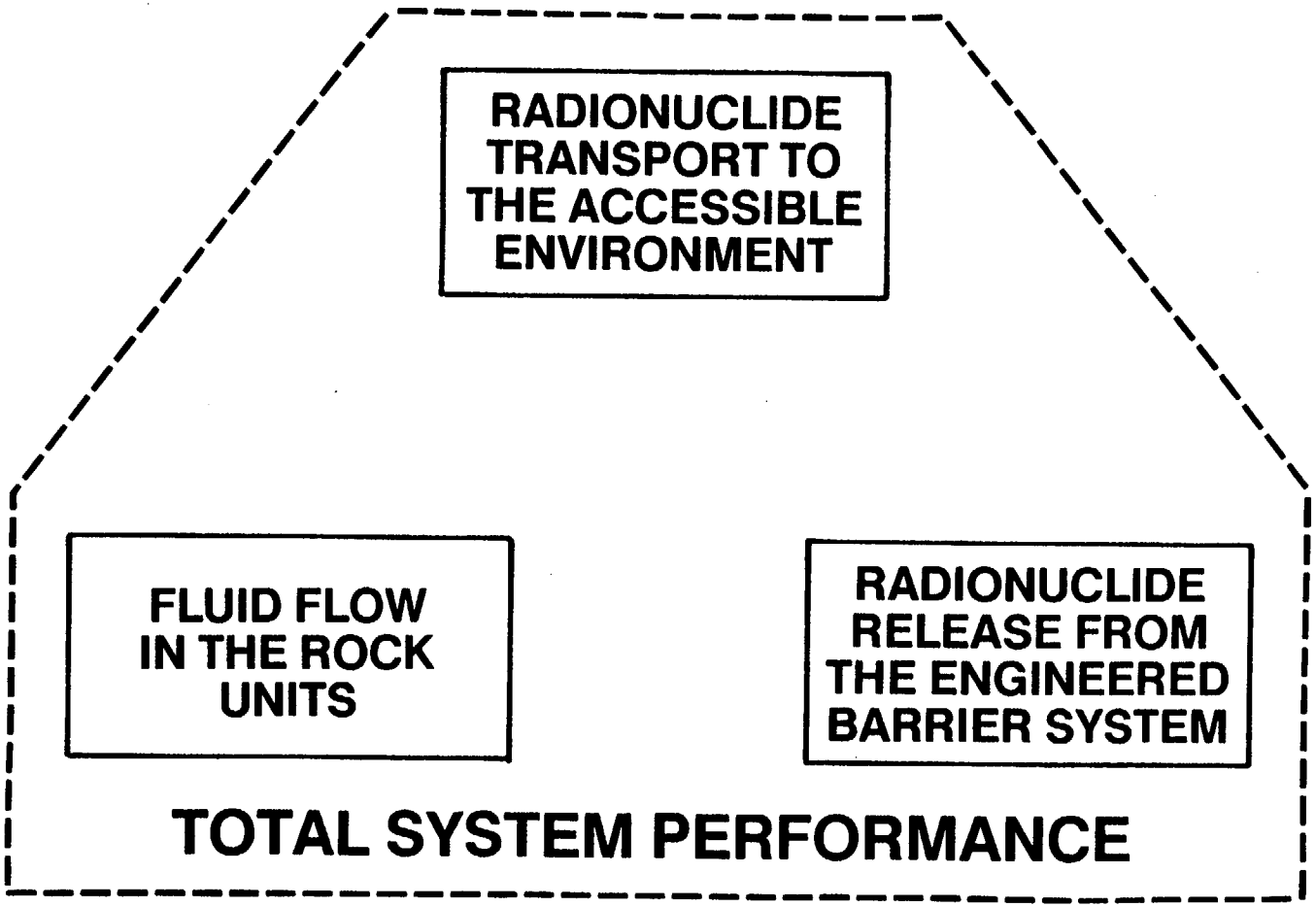
RADIOACTIVE RELEASE

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

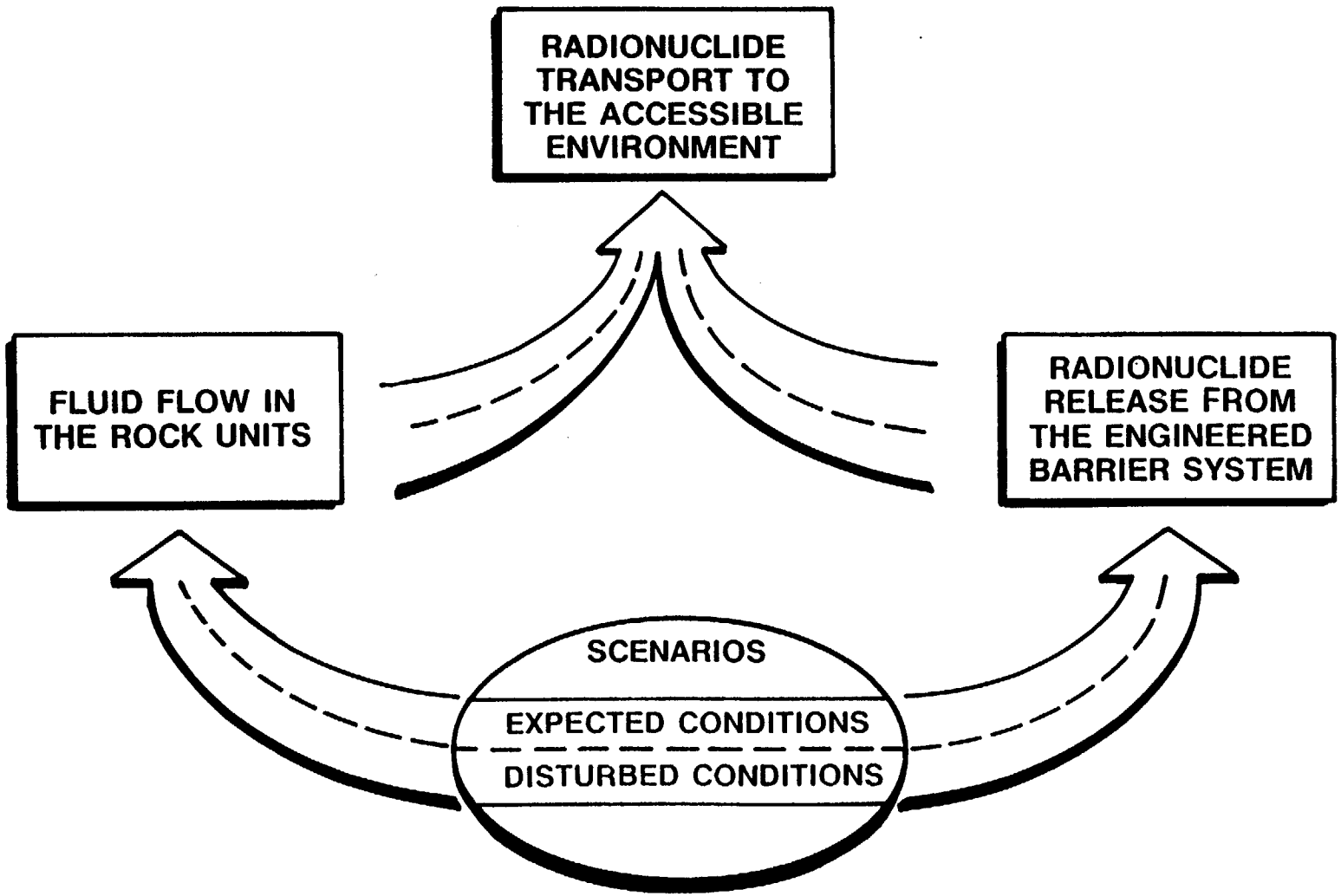
MUST MEET SPECIFIED LIMITS

RADIONUCLIDE	CI/1000 MTHM

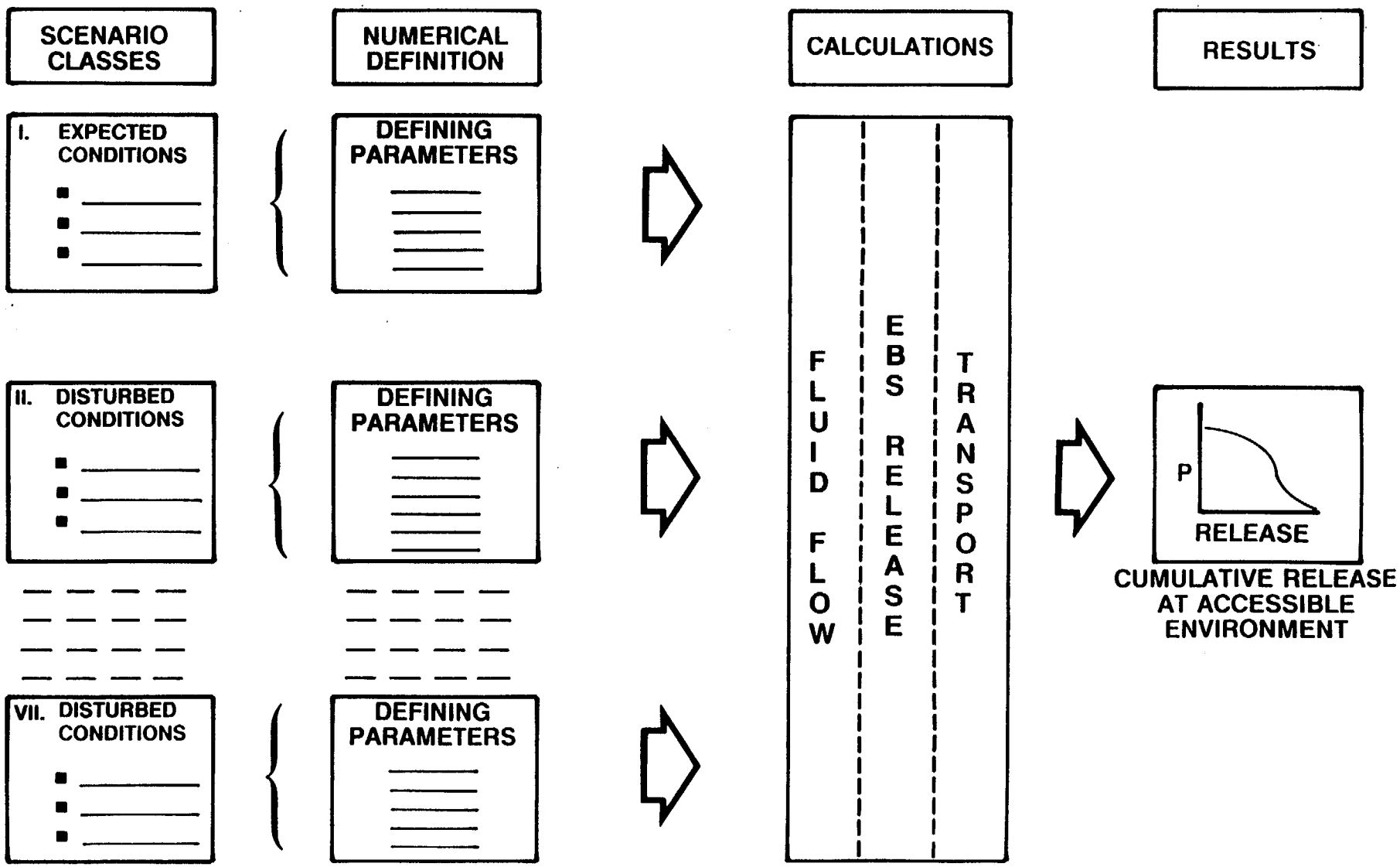
TOTAL SYSTEM PERFORMANCE INCLUDES THREE PRIMARY COMPONENTS



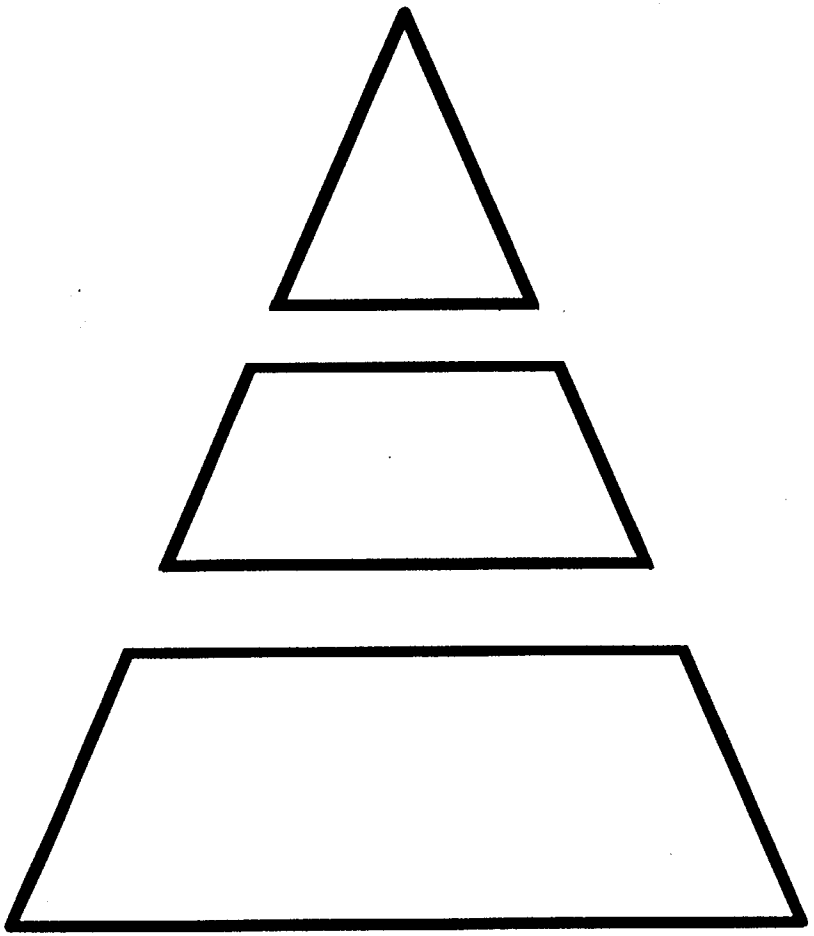
METHODS FOR PERFORMANCE ASSESSMENT MUST ACCOMMODATE EXPECTED AND DISTURBED SITE CONDITIONS



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

SCOPE OF PRESENTATION

1. WHAT TOTAL-SYSTEM PERFORMANCE ASSESSMENT IS

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

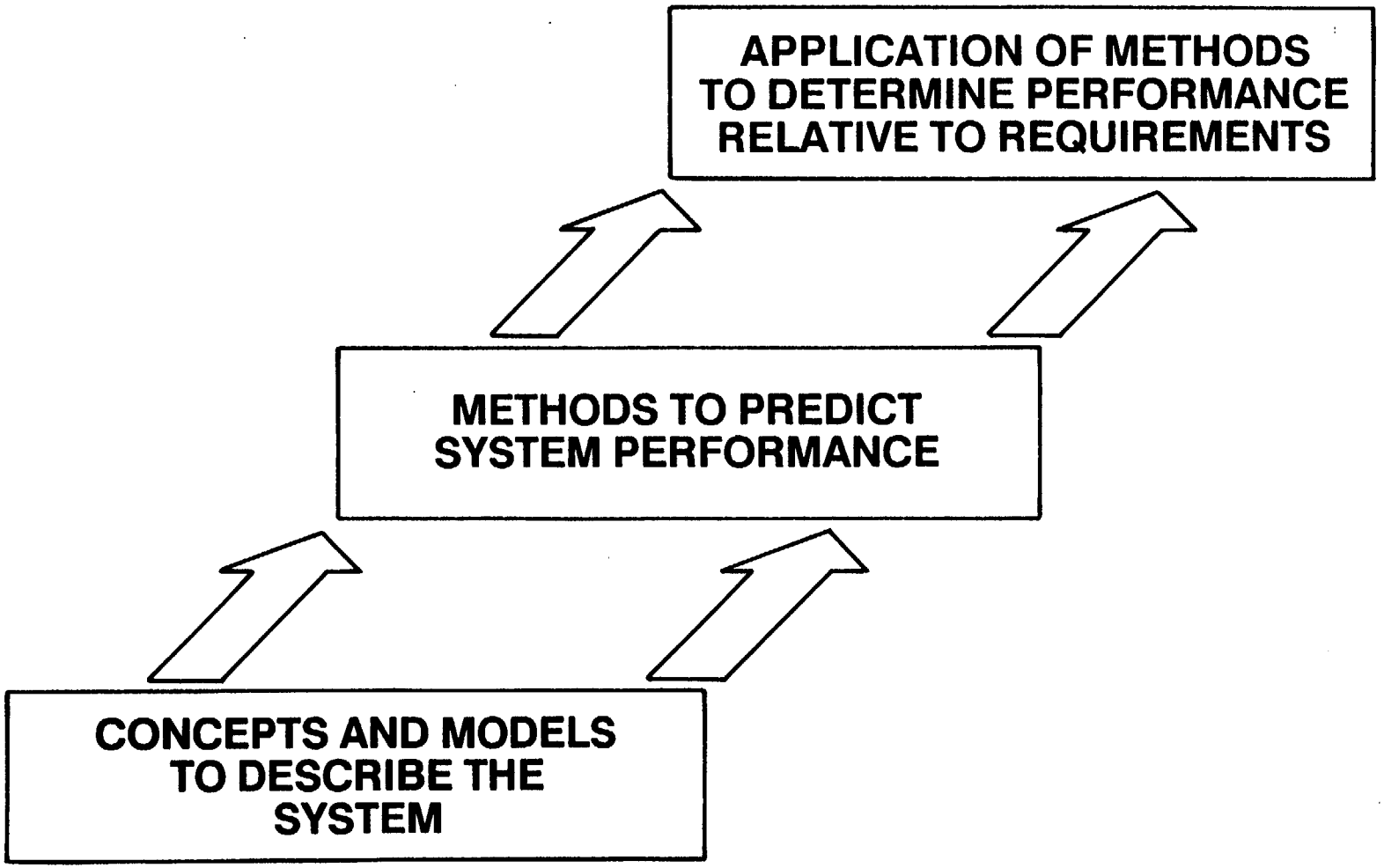
2. RELIANCE ON CONCEPTS AND MODELS FROM SITE AND ENGINEERED-BARRIER PERFORMANCE ASSESSMENT

3. MAJOR ASPECTS OF TOTAL-SYSTEM ASSESSMENT

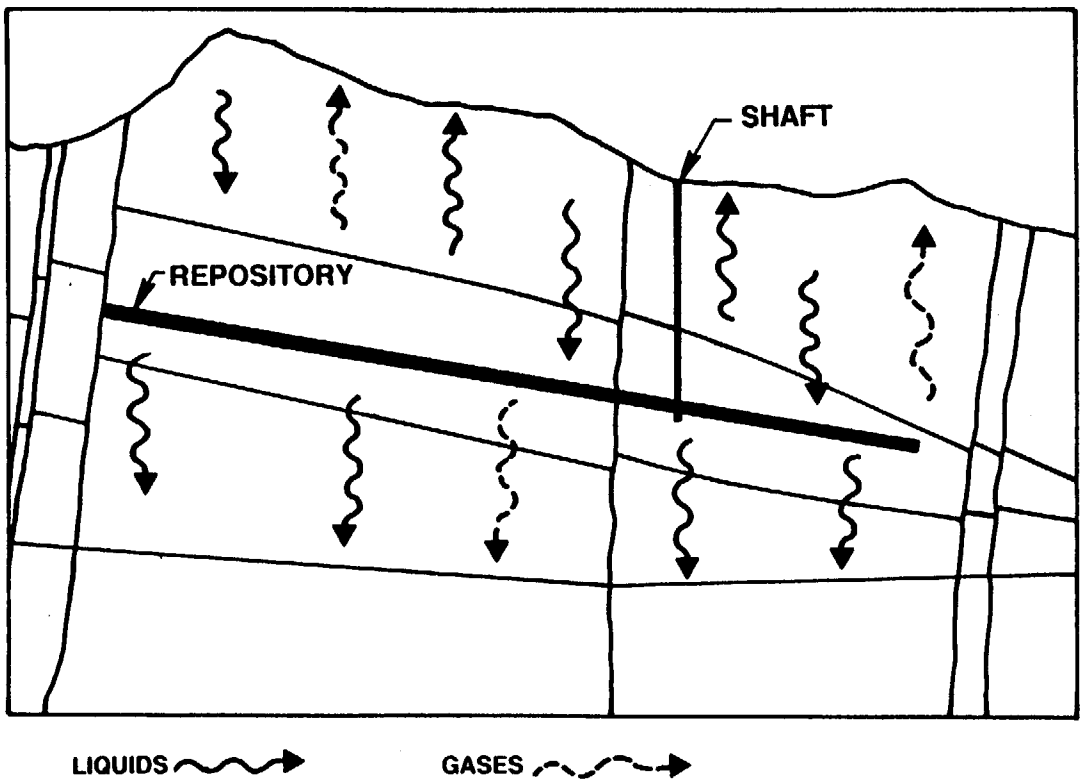
   - CUMULATIVE COMPLEMENTARY DISTRIBUTION FUNCTION
   - SCENARIO ANALYSIS
   - TOTAL-SYSTEM MODELING: EXAMPLES FROM A SYSTEM-LEVEL CODE

4. CURRENT AND FUTURE ACTIVITIES

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

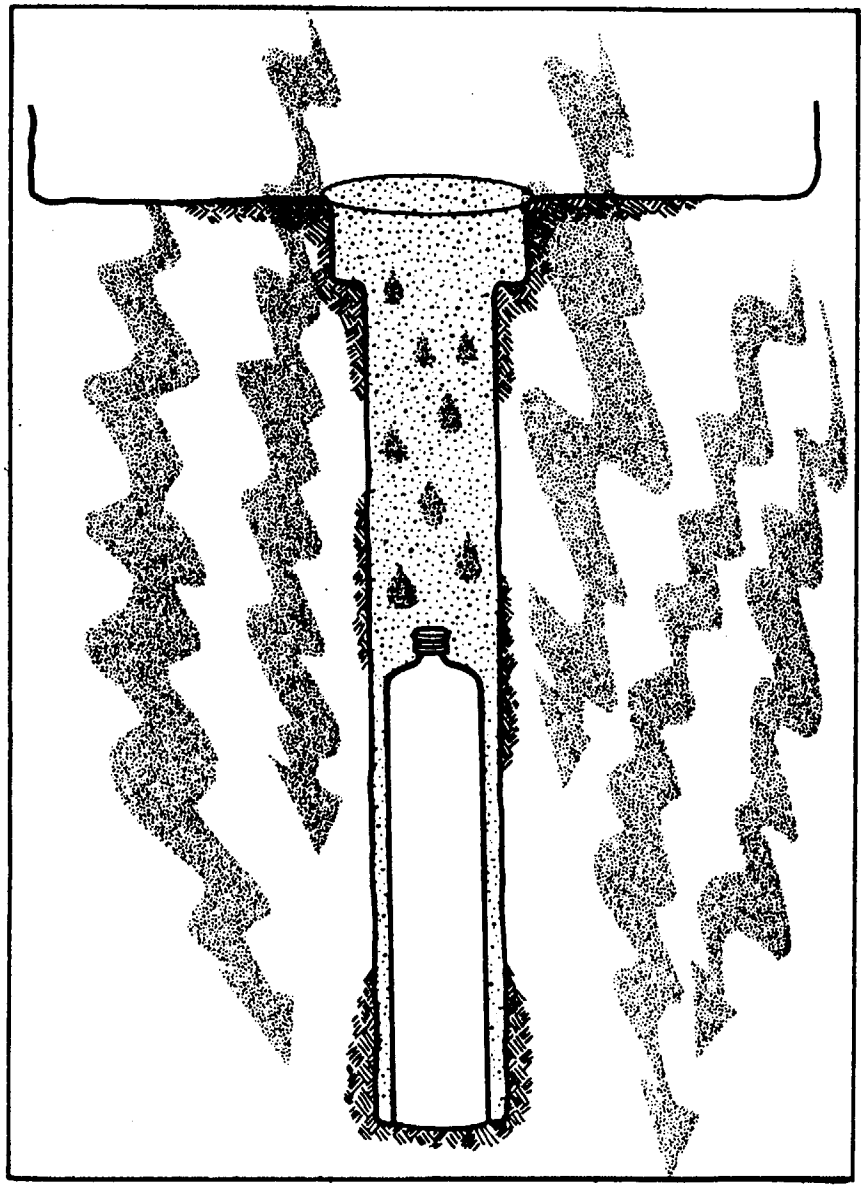
FLUX IN THE UNSATURATED ZONE

- 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

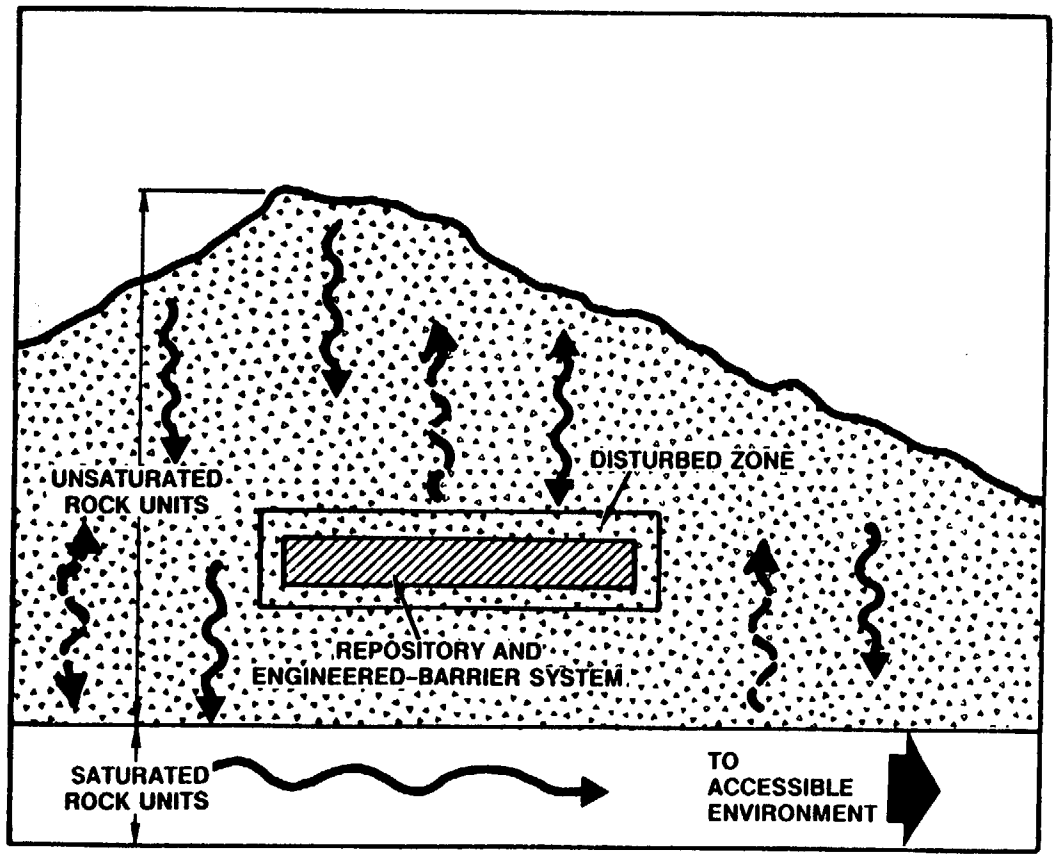
RADIONUCLIDE RELEASE RATE

- 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

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

PERFORMANCE MEASURE FOR OVERALL SYSTEM

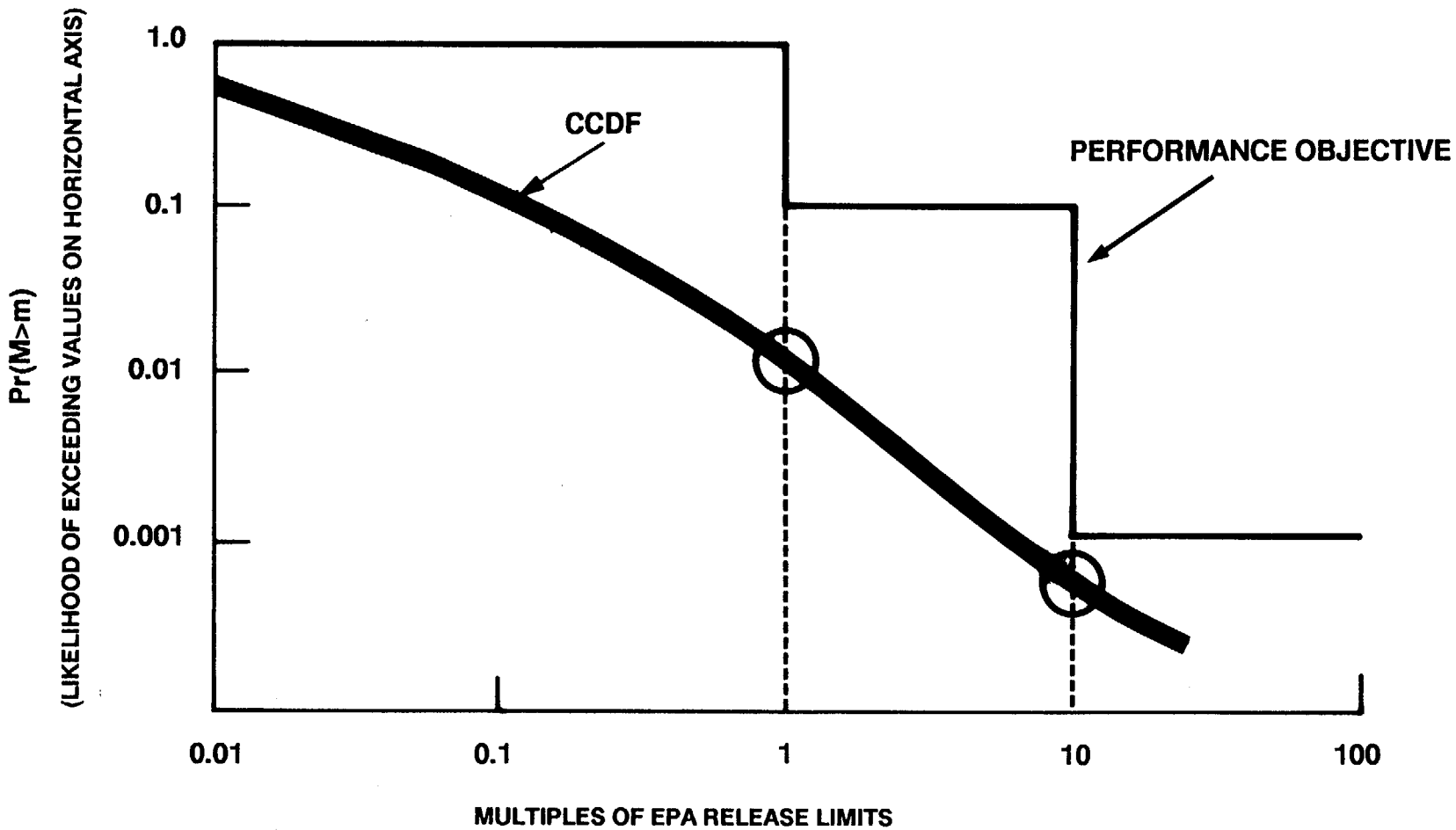
$$M = \sum_i \frac{Q_i}{L_i}$$

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)

OVERALL COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION (CCDF)



DEFINITION OF THE CCDF

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

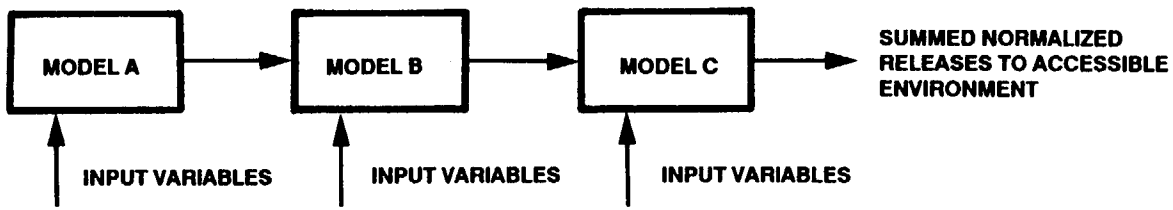
v_i = VARIABLES OF THE SYSTEM IMPORTANT TO WASTE ISOLATION

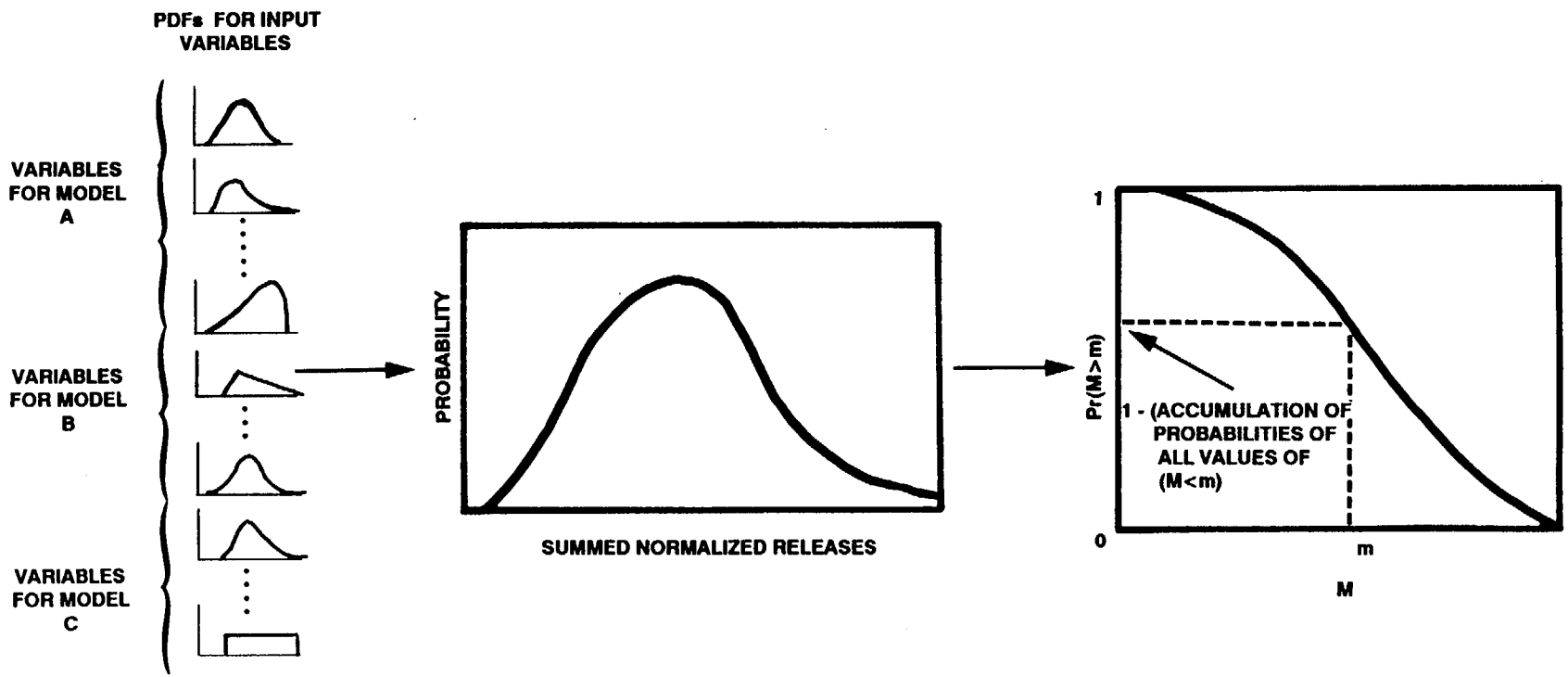
$f(v)$ = JOINT PROBABILITY DENSITY FUNCTION FOR THE VARIABLES OF THE SYSTEM

$u(x)$ = STEP FUNCTION

$$u(x) = 1 \text{ for } x>0$$
$$= 0 \text{ for } x<0$$

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

INPUT

ROCK PROPERTIES
$[n_m, n_f]$

RADIONUCLIDE PROPERTIES
$[\lambda^i, K_d^i, S^i]$

HYDROLOGIC CONDITIONS - FROM HYDROLOGIC MODULE

INITIAL CONDITIONS
$[M^i(t=0)]$

BOUNDARY CONDITIONS
[REPOSITORY LOCATION, LEACHING MODEL, WATER TABLE LOCATION]

→

RADIONUCLIDE CONSERVATION EQUATION

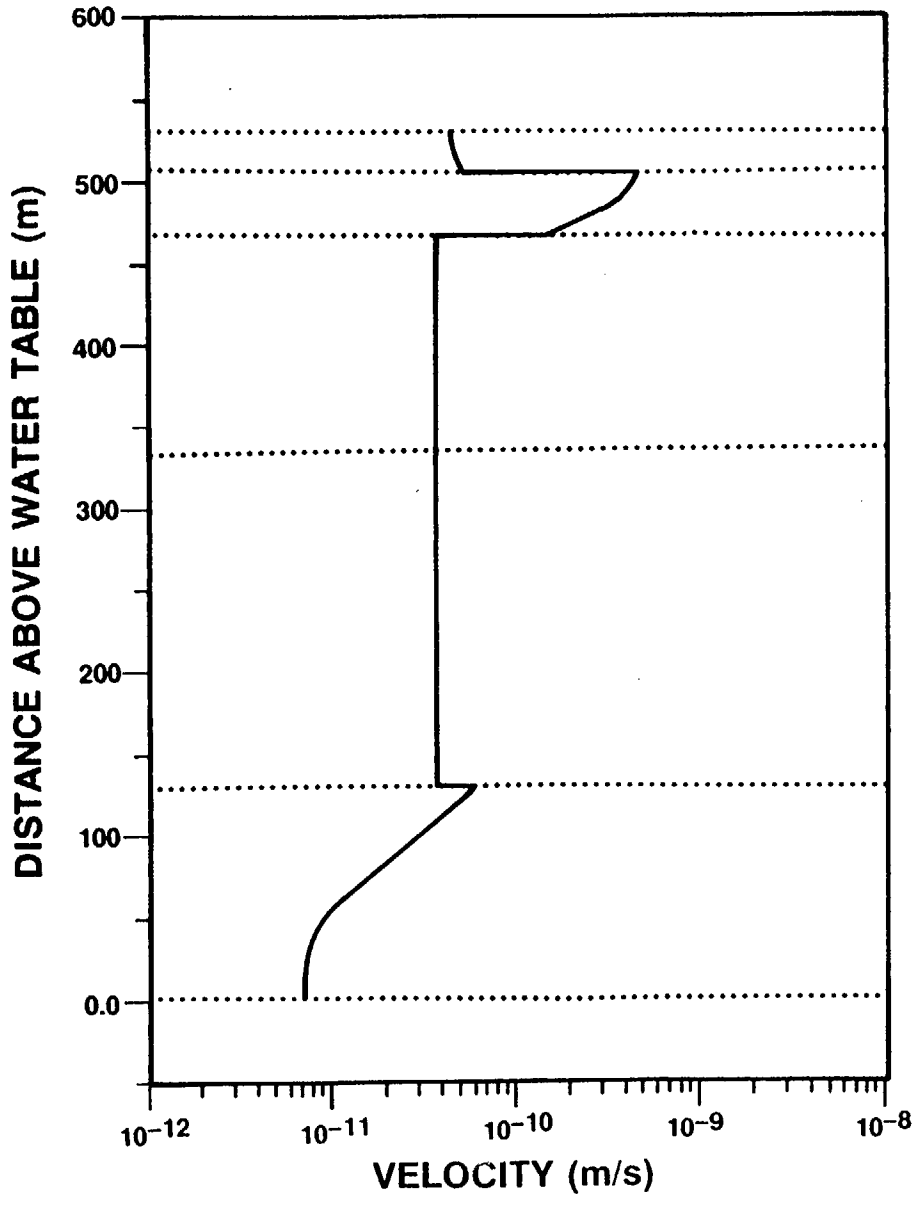
→

OUTPUT

RADIONUCLIDE CONCENTRATIONS AT THE ACCESSIBLE ENVIRONMENT AS A FUNCTION OF TIME

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

TOSPAC CALCULATION OF AVERAGE WATER VELOCITY



ROCK UNITS

TCw

PTn

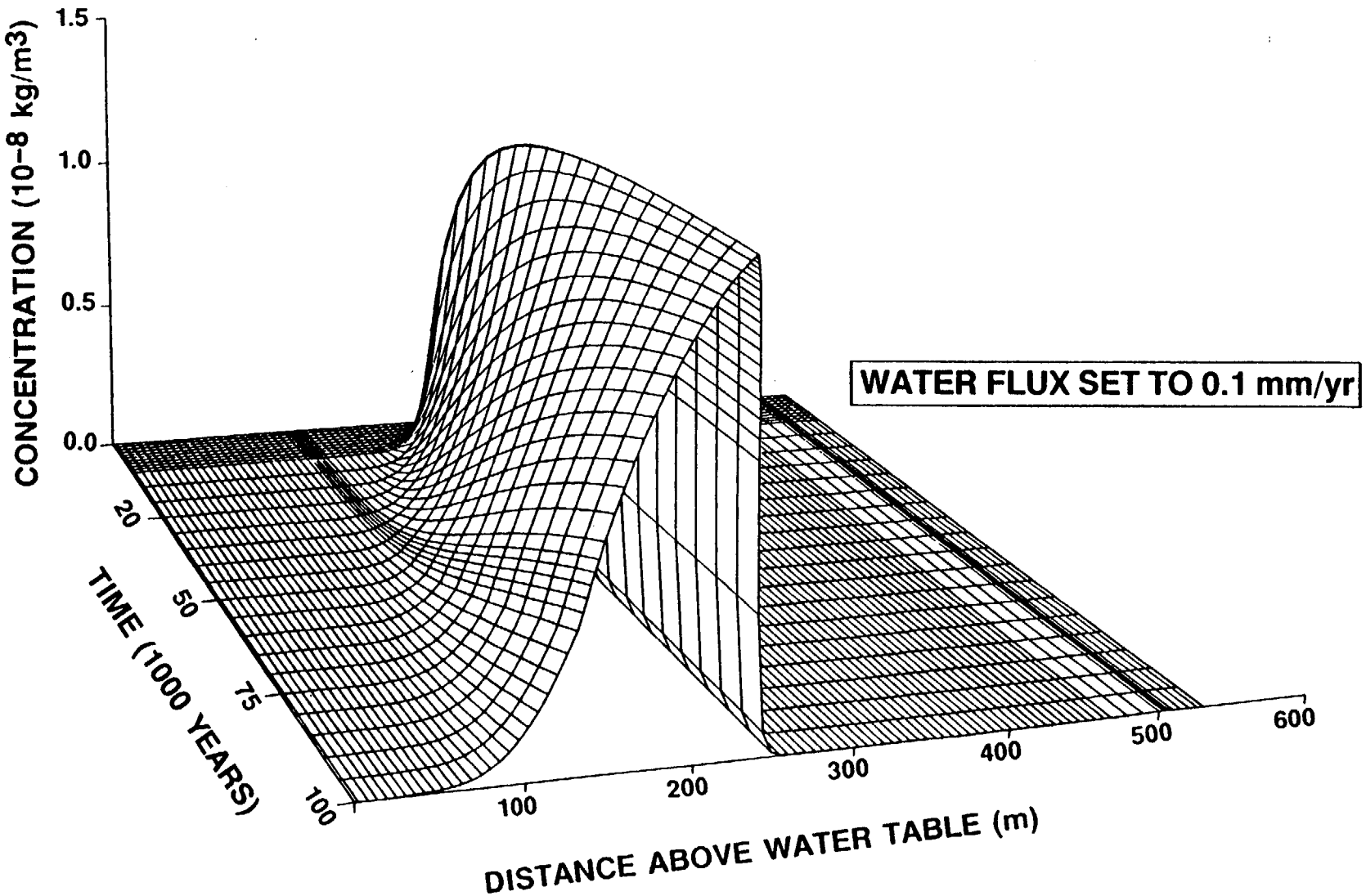
TSw1

TSw2-3

CHnv

WATER FLUX SET TO 0.1 mm/yr

TOSPAC CALCULATION OF I-129 CONCENTRATION IN THE MATRIX



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

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
  - <u>INFORMED</u> 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

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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: PRECLOSURE SAFETY ASSESSMENT

PRESENTER: DAVID MICHLEWICZ, CHP

PRESENTER'S TITLE AND ORGANIZATION: MANAGER, SAFETY ASSESSMENT SECTION
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
WESTON TECHNICAL SUPPORT TEAM

PRESENTER'S TELEPHONE NUMBER: (202) 646-6600

MAY 16-17, 1989

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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: PRECLOSURE SAFETY ASSESSMENT

PRESENTER: DAVID MICHLEWICZ, CHP

PRESENTER'S TITLE AND ORGANIZATION: MANAGER, SAFETY ASSESSMENT SECTION
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
WESTON TECHNICAL SUPPORT TEAM

PRESENTER'S TELEPHONE NUMBER: (202) 646-6600

MAY 16-17, 1989

PRECLOSURE SAFETY ASSESSMENT

ASSESSMENT OF THE RADIOLOGICAL EXPOSURES AND RISKS TO WHICH MEMBERS OF THE PUBLIC AND REPOSITORY WORKERS MAY BE EXPOSED AS A RESULT OF ACTIVITIES TO BE CARRIED OUT AT THE REPOSITORY PRIOR TO ITS PERMANENT CLOSURE

SCOPE OF PRESENTATION

- NRC & DOE PRECLOSURE SAFETY REQUIREMENTS
- RESULTS OF ASSESSMENT OF CONCEPTUAL DESIGN
- ADDITIONAL INFORMATION NEEDS
- CURRENT AND FUTURE ACTIVITIES

NRC AND DOE REQUIREMENTS

ROUTINE OPERATION

- 10 CFR 20 (PROPOSED) AND DRAFT DOE 5400.3
  - WORKERS: 5 REM EDE
  - PUBLIC: 0.1 REM EDE
- 10 CFR 60.111 (40 CFR 191, SUBPART A)
  - 25 MREM (WB), 75 MREM (THYROID), 25 MREM (OTHER ORGANS)

ACCIDENTS

- 10 CFR 60.2
  - 0.5 REM WB, ANY ORGAN (FOR SAFETY CLASSIFICATION)
- DRAFT DOE 6430.1A
  - 25 REM (WB OR EDE) 300 REM (THYROID), 75 REM (LUNG)
  - 10^{-6} PER YEAR PROBABILITY CUTOFF

SUMMARY OF SAFETY ASSESSMENTS PERFORMED TO DATE FOR REPOSITORIES

- PRELIMINARY SAFETY ASSESSMENTS AT REPOSITORIES HAVE BEEN PERFORMED BY NUMEROUS ORGANIZATIONS

- ANALYSES HAVE EXAMINED VARIOUS SITES AND REPOSITORY FACILITY DESIGNS INCLUDING TUFF, BWIP, SALT (GENERIC), AND SALT (DEAF SMITH)

SUMMARY OF RADIOLOGICAL ASSESSMENTS OF NORMAL OPERATIONS PERFORMED TO DATE FOR YUCCA MOUNTAIN

- OCCUPATIONAL EXPOSURE
  - PRIMARILY DUE TO DIRECT GAMMA RADIATION
  - CONTROLLED BY TIME-DISTANCE-SHIELDING
  - COLLECTIVE WORKER DOSE LESS THAN 100 MREM/YR (SAND83-7436/1)
- PUBLIC EXPOSURE
  - PRIMARILY DUE TO INHALATION AND SUBMERSION IN AIRBORNE EFFLUENTS FROM WASTE HANDLING (i.e. FISSION PRODUCT GASES
  - FROM FAILED FUEL RODS AND CO-60 IN CRUD PARTICLES
  - CONTROLLED BY FILTRATION
  - DOSE TO A MAXIMUM INDIVIDUAL* IS ABOUT 0.01 MREM/YR (SAND87-2070C)
  - COLLECTIVE POPULATION DOSE WITHIN 80km ABOUT 0.004 MAN-REM/YEAR
  - DOSE ESTIMATES WILL CHANGE AS DESIGN EVOLVES AND SITE DATA ARE COLLECTED

* AT AN ASSUMED DISTANCE OF 5km FROM SURFACE FACILITIES

SUMMARY OF ACCIDENT ANALYSES PERFORMED TO DATE FOR REPOSITORIES

- A LARGE VARIETY OF POTENTIAL ACCIDENTS HAVE BEEN ASSESSED INCLUDING:
  - EARTHQUAKES
  - FLOODS
  - TORNADOES
  - AIRCRAFT IMPACTS
  - UNDERGROUND NUCLEAR EXPLOSIONS (UNE)
  - HOIST CAGE DROPS
  - TRANSPORTER COLLISIONS/CRASHES
  - FUEL HANDLING ACCIDENTS
  - CRANE DROPS (CASK, CONTAINER, FUEL ASSEMBLY)

SUMMARY OF ACCIDENT ANALYSES PERFORMED TO DATE FOR REPOSITORIES

(CONTINUED)

- POTENTIAL OFFSITE DOSE CONSEQUENCES ARE MUCH LESS THAN FOR REACTORS AND REPROCESSING PLANTS BECAUSE THE SPENT FUEL IS AGED
  - LESS DECAY HEAT
  - FEWER SHORT-LIVED, HIGH SPECIFIC ACTIVITY GASES OR VOLATILE NUCLIDES
  - LESS INTRINSIC ENERGY AVAILABLE TO DISPERSE RADIOACTIVE MATERIAL

SOURCES OF RADIONUCLIDE RELEASES

SPENT FUEL

- RELEASES OF GASES, VOLATILES, AND PARTICULATES:
  - FROM GAP WHEN CLADDING BREACHED
  - FROM PULVERIZATION DURING IMPACTS (BRITTLE FRACTURE)

VITRIFIED HIGH LEVEL WASTE

- RELEASES OF PARTICULATES:
  - FROM PULVERIZATION DURING IMPACTS (BRITTLE FRACTURE)
- NO RELEASE OF GASES OR VOLATILES

RADIONUCLIDES OF CONCERN

GASES	VOLATILES	PARTICULATES: SPENT FUEL & GLASS
Kr - 85	I - 129	Pu - 238, 239, 240, 241
H - 3	Cs - 134, 137	Am - 241
C - 14		Sr - 90
		Cm - 244
		Cs - 134, 137
		Pm - 147

SUMMARY OF ACCIDENT ANALYSES PERFORMED FOR YUCCA MOUNTAIN

- BASED ON CONCEPTUAL DESIGN
- CONSIDERED SURFACE FACILITIES (SAND84-2641) UNDERGROUND FACILITIES (SAND88-7061) AND EXPLORATORY SHAFT FACILITY (SAND89-7002)
- EMPLOYED PROBABILISTIC RISK ASSESSMENT METHODOLOGY
- DIRECTED PRIMARILY AT IDENTIFYING STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY

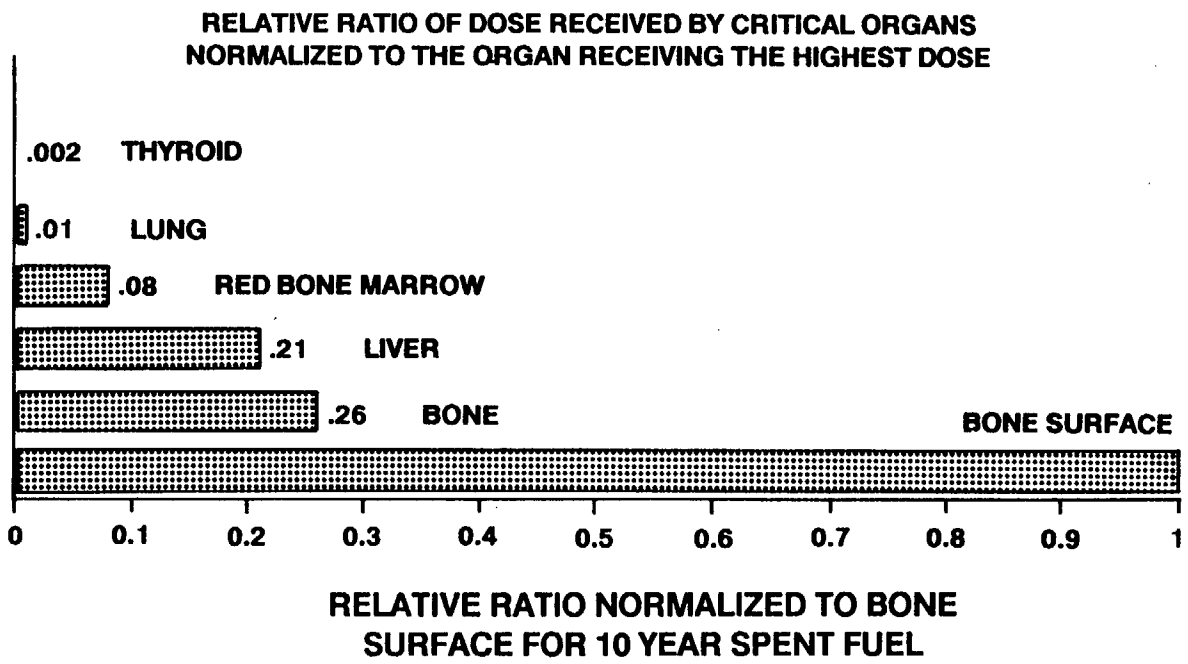
RESULTS OF SELECTED ACCIDENT ANALYSES OF YUCCA MOUNTAIN

SCENARIO ANALYZED	ANNUAL PROBABILITY	DOSE* (REM)
CASK DROP FROM A CRANE IN THE CASK RECEIVING AND PREPARATION AREA	$5X10^{-5}$	0.39
OPEN CONTAINER DROP FROM A CRANE IN THE PACKAGING HOT CELL	$5X10^{-7}$	2.1
TRANSPORTER COLLISION ON THE WASTE RAMP	$5X10^{-7}$	0.089
TRANSPORTER SLIDE DURING EMPLACEMENT	$5X10^{-6}$	0.089

SOURCE: TUFF SCP-CDR (SAND84-2641) AND SAND88-7061

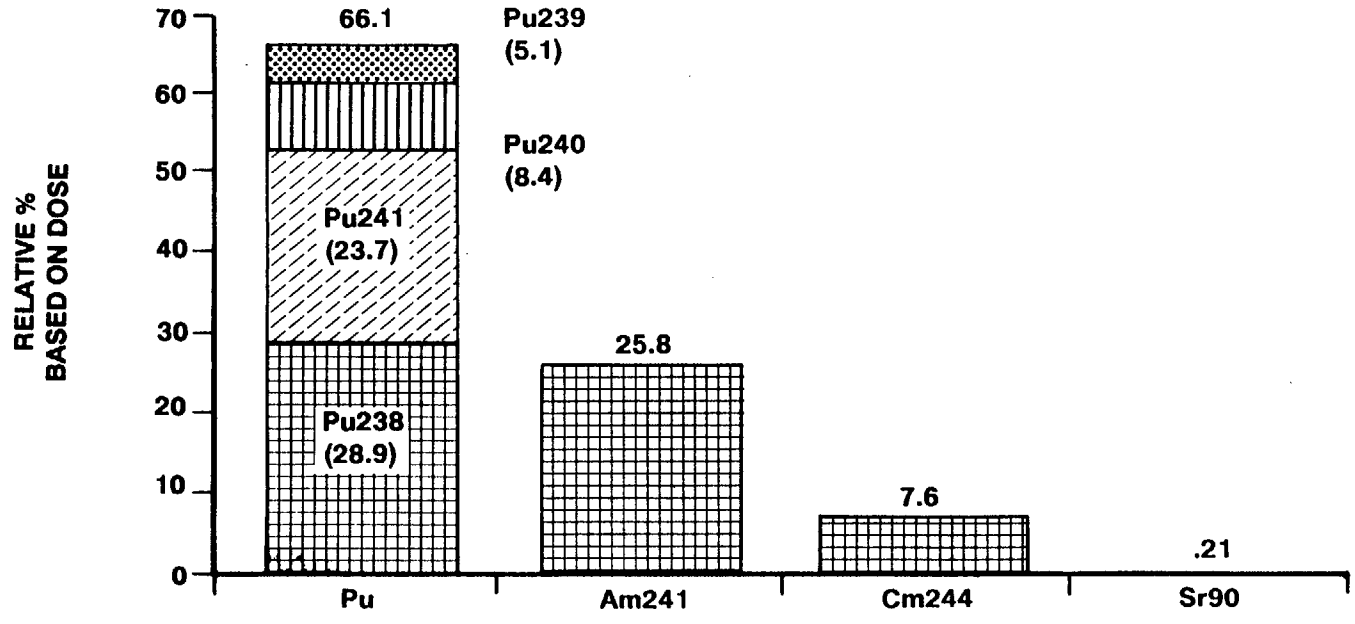
* AT AN ASSUMED DISTANCE OF 5 km FROM SURFACE FACILITIES

CRITICAL ORGANS FOR REPOSITORY ACCIDENTS...



...ARE DIFFERENT FROM THOSE FOR REACTOR ACCIDENTS

PROMINENT ISOTOPIC CONTRIBUTORS TO BONE SURFACE DOSE FOR 10 YEAR AGED PWR SPENT FUEL



ADDITIONAL INFORMATION NEEDS

- **DESIGN INFORMATION**
  - SHIELDING
  - PROCESS STEPS
  - EFFLUENT TREATMENT
  - CONFINEMENT SYSTEM
- **SITE INFORMATION**
  - ATMOSPHERIC DISPERSION
  - ENVIRONMENTAL PATHWAYS
  - POPULATION DISTRIBUTION

ADDITIONAL INFORMATION NEEDS

(CONTINUED)

- **ACCIDENT SOURCE TERM**
  - FUEL PULVERIZATION
  - PARTICLE SIZE DISTRIBUTION
  - BARRIER RETENTION
- **SCENARIO DEVELOPMENT**
  - INITIATING EVENTS
  - EQUIPMENT FAILURES
  - MINING TYPE INCIDENTS

SELECTED PRECLOSURE SAFETY ASSESSMENT ACTIVITIES FOR FY 1989

- DEFINE BOUNDING CASE RADIONUCLIDE INVENTORY; ORIGEN SENSITIVITY ANALYSIS
- EVALUATE TRANSPORTATION CASK CERTIFICATION ANALYTICAL METHODS AND RESULTS FOR APPLICABILITY TO REPOSITORY SAFETY ANALYSIS
- CHARACTERIZE PARTICLE TRANSPORT PHENOMENA
- ASSESS METHODOLOGIES FOR IDENTIFYING AND SCREENING INITIATING EVENTS

CONCLUSIONS

- REPOSITORY REQUIREMENTS FOR PRECLOSURE SAFETY SIMILAR TO OTHER FACILITIES
- EXTENSIVE BODY OF SAFETY ASSESSMENT TECHNIQUES EXISTS
- CONCEPTUAL DESIGN HAS BEEN ANALYZED
- ADDITIONAL INFORMATION NEEDED ON SOURCE TERM AND DATA BASE DEVELOPMENT

U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN

YUCCA MOUNTAIN PROJECT

PERFORMANCE ASSESSMENT BRIEFING

PRESENTED TO

NUCLEAR WASTE TECHNICAL REVIEW BOARD

MAY 16-17, 1989

UNITED STATES DEPARTMENT OF ENERGY
NEVADA OPERATIONS OFFICE/YUCCA MOUNTAIN PROJECT OFFICE

U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN

YUCCA MOUNTAIN PROJECT

PERFORMANCE ASSESSMENT BRIEFING

PRESENTED TO

NUCLEAR WASTE TECHNICAL REVIEW BOARD

MAY 16-17, 1989

UNITED STATES DEPARTMENT OF ENERGY
NEVADA OPERATIONS OFFICE/YUCCA MOUNTAIN PROJECT OFFICE

AGENDA

(CONTINUED)

MAY 17

INVESTIGATIVE APPROACH IN SUPPORT OF PERFORMANCE ASSESSMENT

8:30	MODEL VALIDATION STRATEGY	VOSS
9:00	LINKAGE FROM PERFORMANCE ASSESSMENT TO THE SITE PROGRAM	BLANCHARD
10:00	BREAK	

RECENT APPLICATIONS OF PERFORMANCE ASSESSMENTS

10:10	PERFORMANCE ASSESSMENT IN SUPPORT OF THE SITE CHARACTERIZATION PLAN	YOUNKER
10:40	PERFORMANCE ASSESSMENT OF YUCCA MOUNTAIN IN SUPPORT OF THE COMPARITIVE SITE ANALYSIS	GNIRK
11:20	POTENTIAL IMPACTS OF EXPLORATORY SHAFT FACILITY ON WASTE ISOLATION	BINGHAM
12:00	LUNCH	

DISCUSSION OF WASTE PACKAGE MODEL DEVELOPMENT

1:00	MODELS OF WASTE PACKAGE BEHAVIOR IN A REPOSITORY ENVIRONMENT	PIGFORD
1:50	CALCULATIONAL MODEL FOR WASTE PACKAGE RELEASES	APTED
2:30	SUMMARY	ALEXANDER

NWAGND5P.A12/5-16,17-89

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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: LINKAGE FROM PERFORMANCE ASSESSMENT TO THE SITE PROGRAM

PRESENTER: MAXWELL B. BLANCHARD

PRESENTER'S TITLE AND ORGANIZATION: DIRECTOR, REGULATORY AND SITE EVALUATION DIVISION
YUCCA MOUNTAIN PROJECT OFFICE
U.S. DEPARTMENT OF ENERGY

PRESENTER'S TELEPHONE NUMBER: (702) 794-7939

MAY 16-17, 1989

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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: LINKAGE FROM PERFORMANCE ASSESSMENT TO THE SITE PROGRAM

PRESENTER: MAXWELL B. BLANCHARD

PRESENTER'S TITLE AND ORGANIZATION: DIRECTOR, REGULATORY AND SITE EVALUATION DIVISION
YUCCA MOUNTAIN PROJECT OFFICE
U.S. DEPARTMENT OF ENERGY

PRESENTER'S TELEPHONE NUMBER: (702) 794-7939

MAY 16-17, 1989

SCOPE OF PRESENTATION

- OVERVIEW OF PURPOSES OF SITE CHARACTERIZATION
- APPROACH FOR REDUCING UNCERTAINTY IN CONCEPTUALIZATION OF PHYSICAL SYSTEM
- EXAMPLES OF HYPOTHESIS TESTING TABLES FROM THE SITE CHARACTERIZATION PLAN

APPROACHES TO REDUCING UNCERTAINTIES IN THE SITE PROGRAM

- THE GOAL OF THE SITE PROGRAM IS TO IMPROVE CURRENT UNDERSTANDING OF THE NATURE AND RATES OF GEOLOGIC PROCESSES OPERATING AT THE YUCCA MOUNTAIN SITE THAT MAY IMPACT CONTAINMENT AND ISOLATION

  - REDUCE UNCERTAINTY IN SITE PARAMETERS

  - REDUCE UNCERTAINTY IN CONCEPTUALIZATION OF SITE PHYSICAL SYSTEM

NWLPAS5P.A12/5-16,17-89

APPROACHES TO REDUCE UNCERTAINTY IN UNDERSTANDING THE SITE

MINIMIZE UNCERTAINTY IN SITE PARAMETER VALUES IMPORTANT TO WASTE ISOLATION

- USE MULTIPLE APPROACHES TO OBTAIN PARAMETERS (E.G. WATER INFILTRATION: CONDUCT TEST FOR NATURAL INFILTRATION, CONTROLLED FILTRATION, PROPERTIES OF SURFICIAL MATERIALS)

- MAKE MEASUREMENTS AT DIFFERENT SCALES (E.G. FRACTURE HYDROLOGIC PROPERTIES IN UNSATURATED ZONE: SINGLE FRACTURE, FRACTURE NETWORK)

NWTRBMB1P.A13-5/16-17/89

APPROACHES TO REDUCE UNCERTAINITY IN UNDERSTANDING THE SITE

CONTINUED

CURRENT PLANS CONTAIN

- SURFACE-BASED DRILLING PROGRAM (STATISTICAL & FEATURES; MONITORING; CORE RETRIEVAL)
- IN SITU TESTING IN THE EXPLORATORY SHAFT (MAPPING; WASTE PACKAGE ENVIRONMENT; HYDROLOGIC, GEO-CHEMICAL, AND ROCK MECHANICS PARAMETERS)
- SURFACE STUDIES (TRENCHING; MAPPING; MONITORING)
- LABORATORY STUDIES (BENCH-SCALE; ANALYSIS OF CORE SAMPLES)

NWTRBMB1P.A13-5/16-17/89

APPROACHES TO REDUCE UNCERTAINITY IN UNDERSTANDING THE SITE

CONTINUED

SOME UNCERTAINTY IS INEVITABLE

- GEOLOGIC PROPERTIES AND CONDITIONS VARY IN SPACE AND TIME
- MEASUREMENTS WILL CONTAIN ERRORS
- MANY NATURAL PROCESSES ARE SLOW AND DIFFICULT TO MEASURE

NWTRBMB1P.A13-5/16-17/89

APPROACH FOR REDUCING UNCERTAINTY IN CONCEPTUALIZATION OF SITE PHYSICAL SYSTEM

- IDENTIFY CURRENT CONCEPTS AND HYPOTHESES (DERIVED FROM AVAILABLE INFORMATION ABOUT THE SITE)
- SPECIFY UNCERTAINTIES IN CURRENT CONCEPTS AND HYPOTHESES (QUALITATIVE JUDGEMENTS RELATED TO UNCERTAINTY IN DATA BASE)
- IDENTIFY ALTERNATIVE CONCEPTS AND HYPOTHESES (LOW UNCERTAINTY IN CURRENT HYPOTHESES MAY RESULT IN NO ALTERNATIVES)
- ESTABLISH NEED TO REDUCE UNCERTAINTY IN CURRENT OR ALTERNATIVE HYPOTHESIS BY LINKING TO PERFORMANCE REQUIREMENTS AND DETERMINING SENSITIVITY (I.E. COULD ALTERNATIVES NEGATIVELY IMPACT PERFORMANCE?)
- COLLECT INFORMATION TO DISCRIMINATE AMONG COMPETING HYPOTHESES OR REDUCE UNCERTAINTY IN CURRENT HYPOTHESIS

NWTRBMBP.A13-5/16-17/89

FUNDAMENTAL QUESTIONS ABOUT SITE PERFORMANCE THAT RELY ON CREDIBLE CONCEPTUAL MODELS

- GEOLOGIC
  - WHAT IS THE PROBABILITY THAT BASALTIC MAGMA WILL PENETRATE THE REPOSITORY OVER THE NEXT 10,000 YEARS?
  - WHAT RANGE OF CHANGES IN THE WATER TABLE CAN BE INDUCED BY FUTURE TECTONIC EVENTS?
  - HOW LIKELY IS FAULT MOVEMENT THAT COULD BREACH AN INDIVIDUAL WASTE PACKAGE?
- HYDROLOGIC
  - WHAT IS THE MOISTURE FLUX THROUGH THE REPOSITORY HORIZON?
  - IS THE UNSATURATED-ZONE MOISTURE MOVEMENT PREDOMINANTLY IN THE MATRIX OR IN BOTH MATRIX AND FRACTURES?
  - WHAT IS THE RATE AND DIRECTION OF GROUND-WATER MOVEMENT FROM THE REPOSITORY HORIZON TO THE ACCESSIBLE ENVIRONMENT?

NWLPAS5P.A12/5-16,17-89

FUNDAMENTAL QUESTIONS ABOUT THE SITE PERFORMANCE THAT RELY ON CREDIBLE CONCEPTUAL MODELS

(CONTINUED)

- GEOCHEMICAL

  - WHAT IS THE QUANTITY AND DISTRIBUTION OF SORPTIVE MINERALS ALONG FLOW PATHS?

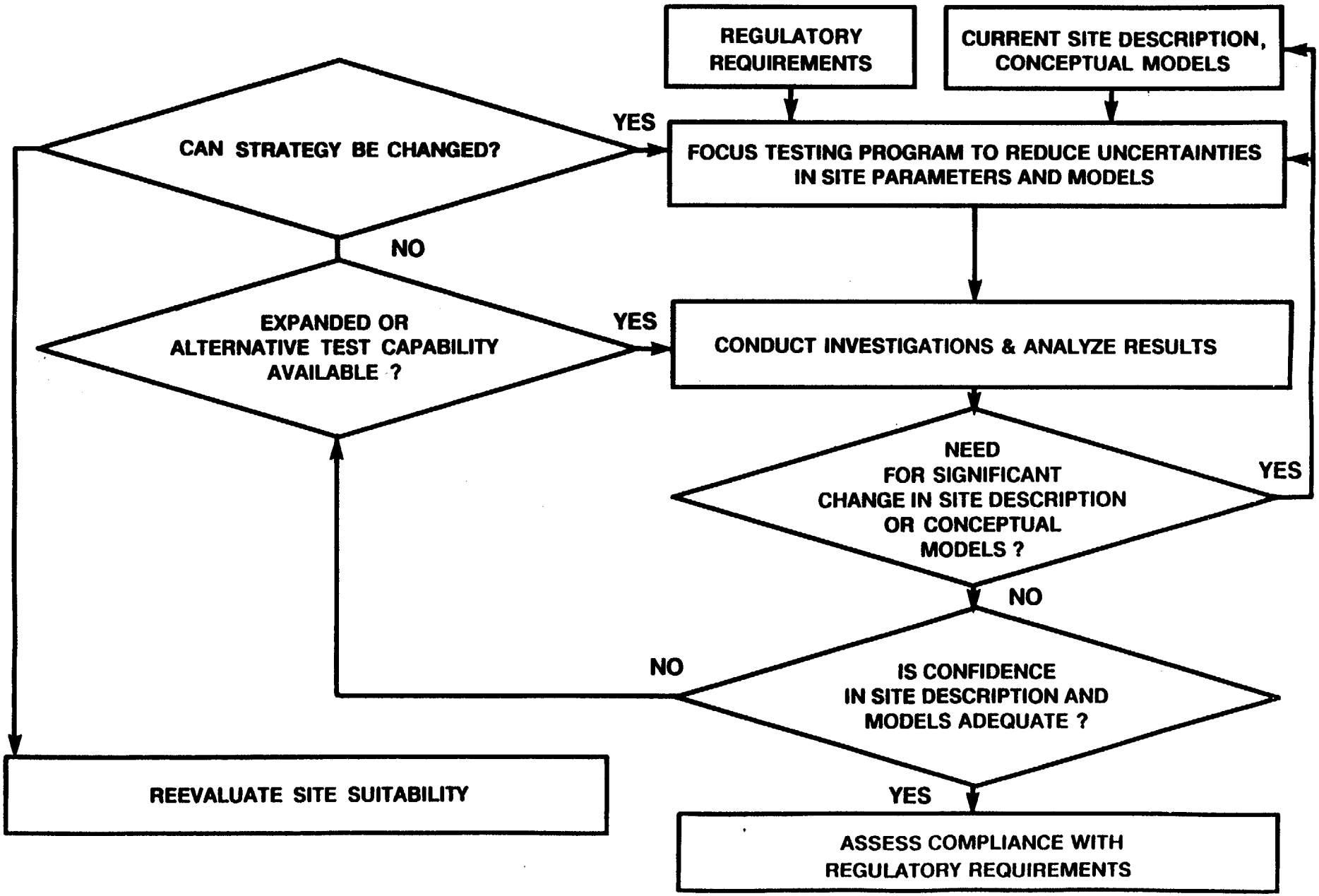
  - HOW WILL THE LABORATORY RESULTS ON MATRIX DIFFUSION AND RETARDATION BE RELIABLY TRANSLATED TO FIELD CONDITIONS?

- CLIMATE

  - HOW DO WE DETERMINE THE BOUNDS ON FUTURE CLIMATE CONDITIONS?

  - WHAT WILL THE IMPACT OF FUTURE CLIMATE CHANGES BE ON UNSATURATED-ZONE FLUX AND FLOW MECHANISMS?

STRATEGY FOR THE CONDUCT OF THE SITE PROGRAM



SITE PROGRAMS	# OF ALTERNATE CONCEPTS AND HYPOTHESES
GEOHYDROLOGY	73
GEOCHEMISTRY	22
ROCK CHARACTERISTICS	17
CLIMATE	28
HUMAN INTERFERENCE	6
THERMAL AND MECHANICAL ROCK PROPERTIES	8
PRECLOSURE AND POSTCLOSURE TECTONICS	56

EXAMPLE OF CONDENSED HYPOTHESIS TESTING TABLE
PRECLOSURE TECTONICS
(SCP SECTION 8.3.1.8)

1		2	3	4				5
Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
Faulting geometry and mechanisms	No hypothesis selected (one or more alternative hypotheses may apply to domain)	High--no data on on subsurface geometry of local faults, no measurements of strike-slip component of movement	Faults in the domain are: Planar-rotational Detachment Part of Walker Lane system	Design-basis ground-motion time histories and corresponding response spectra for facilities important to safety	Medium to high	High--local fault geometries could significantly affect ground-motion and fault slip estimates	High	Reflection and refraction surveys Age and recurrence intervals on Quaternary faults
			Related to a strike-slip fault concealed beneath a detached upper plate	Potential for vibratory ground motion at facilities important to safety	Medium to high	Same as above	High	Quaternary faulting near the site within NE-trending zone
			Normal faults resulting from thermally-driven processes	Probability of faulting with displacements over 5 cm in repository and at location of facilities important to safety	Medium to high	Same as above	High	Detachment faults at or near Yucca Mountain Monitoring current seismicity 3-Dimensional geologic model of site area

HYPOTHESIS TABLE EXAMPLE
PRECLOSURE TECTONICS

COLUMN 1: CURRENT REPRESENTATION (CONCEPT OR HYPOTHESIS)

LOCAL FAULTING GEOMETRY & MECHANISMS

NO HYPOTHESIS SELECTED (1 OR MORE ALTERNATIVES MAY APPLY)

COLUMN 2: UNCERTAINTY

HIGH: LIMITED DATA ON SUBSURFACE GEOMETRY OF LOCAL FAULTS; NO MEASUREMENTS OF STRIKE-SLIP MOVEMENT

HYPOTHESIS TABLE EXAMPLE
PRECLOSURE TECTONICS

(CONTINUED)

COLUMN 3: ALTERNATIVE HYPOTHESES

PLANAR ROTATIONAL FAULT MODEL

DETACHMENT FAULTS

LOCAL FAULTS ARE PART OF THE WALKER-LANE SYSTEM

LOCAL FAULTS ARE RELATED TO A STRIKE-SLIP FAULT CONCEALED BENEATH A DETACHED UPPER FAULT PLATE

LOCAL FAULTS ARE NORMAL FAULTS RESULTING FROM INCIPIENT RIFTING ALONG THE DEATH VALLEY-PANCAKE RANGE ZONE DUE TO THERMALLY DRIVEN PROCESSES

HYPOTHESIS TABLE EXAMPLE
PRECLOSURE TECTONICS

(CONTINUED)

COLUMN 4: SIGNIFICANCE OF ALTERNATIVE HYPOTHESIS

- **PERFORMANCE MEASURES AFFECTED**
  - DESIGN BASIS GROUND MOTION
  - RESPONSE SPECTRA
  - PROBABILITY OF >5cm DISPLACEMENTS
- **CONFIDENCE NEEDED IN PERFORMANCE MEASURE**
  - MEDIUM TO HIGH
- **SENSITIVITY TO HYPOTHESIS**
  - HIGH -- LOCAL FAULT GEOMETRIES COULD SIGNIFICANTLY AFFECT GROUND MOTION AND FAULT SLIP ESTIMATES
- **NEED TO REDUCE UNCERTAINTY**
  - HIGH

HYPOTHESIS TABLE EXAMPLE
PRECLOSURE TECTONICS

(CONTINUED)

COLUMN 5: STUDIES OR ACTIVITIES TO REDUCE UNCERTAINTY

INTERMEDIATE DEPTH REFLECTION AND REFRACTION

AGE AND RECURRENCE OF MOVEMENT ON QUATERNARY FAULTS

QUATERNARY FAULTING NEAR THE SITE WITHIN NE-TRENDING FAULT ZONES

DETACHMENT FAULTS AT OR NEAR YUCCA MOUNTAIN

MONITORING CURRENT SEISMICITY

3-DIMENSIONAL GEOLOGIC MODEL OF SITE AREA

EXAMPLE OF HYPOTHESIS TESTING TABLE GEOCHEMISTRY (SCP SECTION 8.3.1.3, TABLE 8.3.1.3-2)

1		2	3	4					5
Current representation		Uncertainty in current understanding	Alternative hypothesis and significance						Tests to distinguish hypothesis and reduce uncertainty
Model element	Current representation	Uncertainty and rationale	Alternative hypothesis	Performance measure design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty		Studies or activities to reduce uncertainty
Mineral stability	Secondary mineralogy along flow paths (particularly sorptive minerals) will remain stable under post-emplacement conditions or, at least, their alteration is predictable based on thermodynamic considerations	Medium--thermodynamic data are not extensive and low temperature alteration processes are difficult to quantify experimentally	Alteration rates are controlled by local conditions (interfaced processes) and are too complex to model reliably	Retardation factor	High	High	Low--alternate hypothesis not supported by existing data		8.3.1.3.3--stability of minerals and glasses

HYPOTHESIS TABLE EXAMPLE
GEOCHEMISTRY

COLUMN 1: CURRENT REPRESENTATION (CONCEPT OR HYPOTHESIS)

MINERAL STABILITY

MINERALS ARE STABLE

ALTERATION OF SECONDARY MINERALS ALONG FLOWPATHS IS PREDICTABLE

COLUMN 2: UNCERTAINTY

MEDIUM: AVAILABLE THERMODYNAMIC DATA NOT EXTENSIVE
LOW-TEMPERATURE PROCESSES DIFFICULT TO QUANTIFY

COLUMN 3: ALTERNATIVE HYPOTHESIS

ALTERATION RATES ARE CONTROLLED BY LOCAL CONDITIONS AND ARE TOO COMPLEX TO MODEL RELIABLY

NWTRBMBP.A13-5/16-17/89

HYPOTHESIS TABLE EXAMPLE
GEOCHEMISTRY

CONTINUED

COLUMN 4: SIGNIFICANCE OF ALTERNATIVE HYPOTHESIS

PERFORMANCE MEASURE AFFECTED
- RETARDATION FACTOR

CONFIDENCE NEEDED IN PERFORMANCE MEASURE
- HIGH

SENSITIVITY TO HYPOTHESIS
- HIGH

NEED TO REDUCE UNCERTAINTY
- LOW (ALTERNATE HYPOTHESIS NOT SUPPORTED BY EXISTING DATA)

COLUMN 5: STUDIES OR ACTIVITIES TO REDUCE UNCERTAINTY

STABILITY OF MINERALS AND GLASSES

NWTRBMBP.A13-5/16-17/89

SUMMARY

- SITE PROGRAM IS BELIEVED TO BE COMPREHENSIVE AND CONTAINS SUFFICIENT REDUNDANCY TO PROVIDE SITE PARAMETERS AT NEEDED LEVELS OF CONFIDENCE FOR PERFORMANCE ASSESSMENTS

- THE POTENTIAL FOR ALTERNATIVE CONCEPTS AND HYPOTHESIS HAS BEEN CONSIDERED IN THE PLANS FOR SITE TESTING

  - AS NEW SITE INFORMATION IS OBTAINED, THE NUMBER OF ALTERNATIVE CONCEPTS AND HYPOTHESES MAY INITALLY INCREASE

  - WITH ADDITIONAL INFORMATION AND ANALYSES, CERTAIN CONCEPTS AND HYPOTHESES ARE LIKELY TO BE FAVORED

  - IN CASES WHERE UNCERTAINTIES REMAIN LARGE AFTER SITE CHARACTERIZATION, BOUNDING ASSUMPTIONS MAY BE NECESSARY

- SITE-DERIVED CONCEPTS AND HYPOTHESIS PROVIDE A KEY INTERFACE BETWEEN PERFORMANCE ASSESSMENT AND THE SITE PROGRAM AND ARE EXPECTED TO PROVIDE CONFIDENCE IN PERFORMANCE PREDICTIONS

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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: METHODOLOGY FOR VALIDATION OF MODELS

PRESENTER: CHARLES F. VOSS

PRESENTER'S TITLE AND ORGANIZATION: STAFF SCIENTIST
GEOSCIENCES DEPARTMENT
BATTELLE PACIFIC NORTHWEST LABORATORIES

PRESENTER'S TELEPHONE NUMBER: (509) 376-5896

MAY 16-17, 1989

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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: METHODOLOGY FOR VALIDATION OF MODELS

PRESENTER: CHARLES F. VOSS

PRESENTER'S TITLE AND ORGANIZATION: STAFF SCIENTIST
GEOSCIENCES DEPARTMENT
BATTELLE PACIFIC NORTHWEST LABORATORIES

PRESENTER'S TELEPHONE NUMBER: (509) 376-5896

MAY 16-17, 1989

SCOPE OF PRESENTATION

- DISCUSS THE NEED FOR A VALIDATION METHODOLOGY
- DESCRIBE THE COMPONENTS OF THE VALIDATION METHODOLOGY
- PROVIDE AN EXAMPLE OF THE METHODOLOGY
- IMPLEMENTATION OF THE METHODOLOGY

VALIDATION METHODOLOGY FOR PERFORMANCE ASSESSMENT MODELS

- THE LICENSING RECORD MUST ADDRESS THE APPROPRIATENESS AND QUALITY OF THE DATA USED TO DERIVE THE PREDICTIVE MODELS AND THE LOGIC INVOLVED IN ARRIVING AT THE FINAL MODEL(S)

- THE VALIDATION METHODOLOGY ATTEMPTS TO PROVIDE A SYSTEMATIC APPROACH FOR DOCUMENTING THE DEVELOPMENT AND VALIDITY OF A MODEL WITH A COMMON SET OF PRINCIPLES AND WORKING RULES TO ACHIEVE MODELS OF A MORE UNIFORM QUALITY

- A DRAFT METHODOLOGY HAS BEEN COMPLETED AND IS CURRENTLY BEING REVIEWED WITHIN THE OCRWM PROGRAM

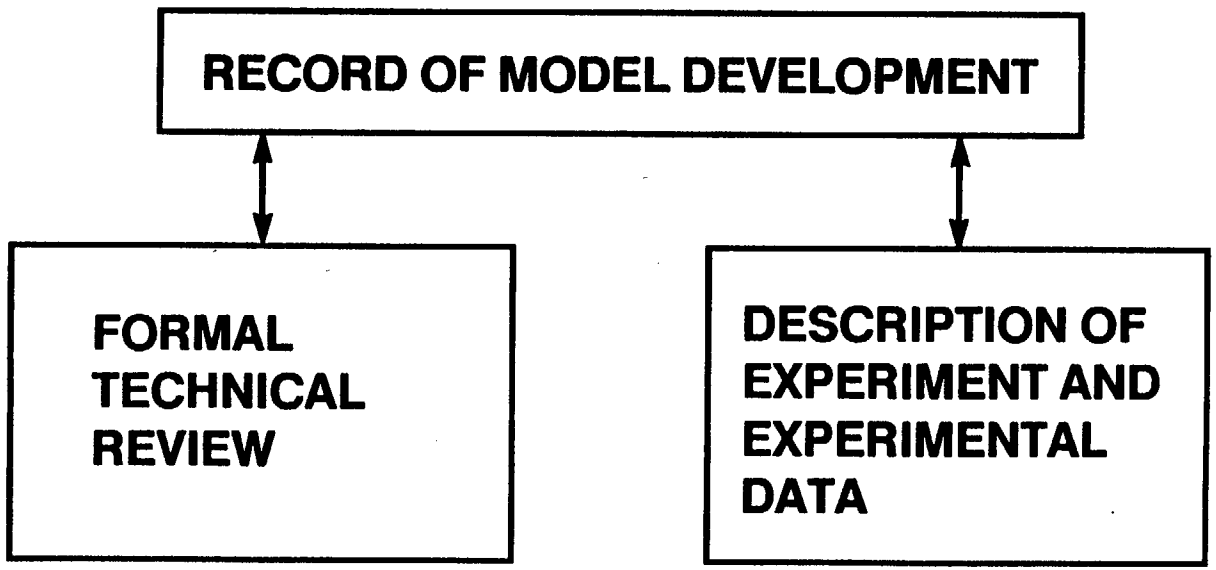
COMPONENTS OF THE METHODOLOGY

1. A RECORD OF THE DERIVATION OF THE MODEL, THE PREMISES UPON WHICH IT IS BASED, AND EVIDENCE TO SUPPORT THESE.

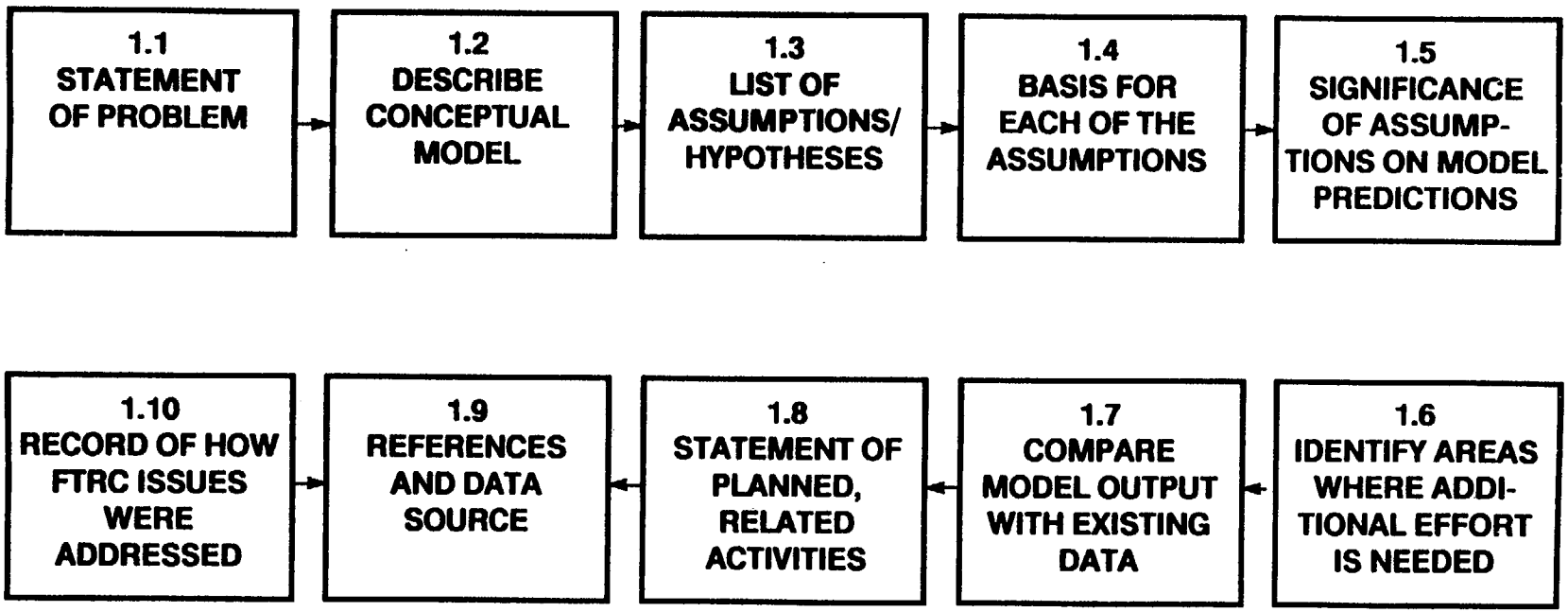
2. A DESCRIPTION OF THE LABORATORY, FIELD, AND NATURAL ANALOG EXPERIMENTS PERFORMED TO SUPPORT MODEL DEVELOPMENT AND TO PROVIDE A COMPARISON BETWEEN EXPERIMENTAL DATA AND MODEL PREDICTIONS.

3. FORMAL TECHNICAL REVIEWS OF 1 AND 2 TO ACHIEVE MODELS OF A MORE UNIFORM QUALITY.

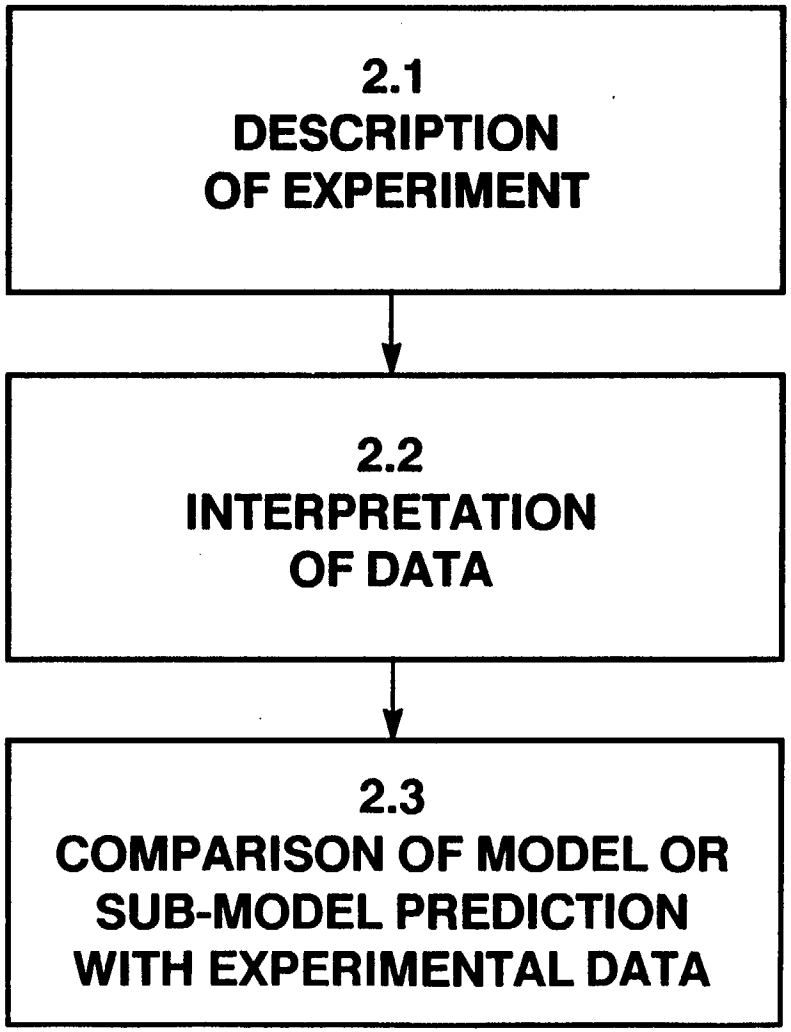
SCHEMATIC OF MODEL VALIDATION METHODOLOGY



RECORD OF MODEL DEVELOPMENT



DESCRIPTION OF EXPERIMENT AND EXPERIMENTAL DATA



FORMAL TECHNICAL REVIEW

3.1
IDENTIFY MEMBERS OF THE REVIEW COMMITTEE

↓

3.2
DIVIDE MATERIAL INTO FUNCTIONAL ELEMENTS

↓

3.3
ASSIGN ELEMENTS TO REVIEW COMMITTEE MEMBERS

↓

3.4
HOLD REVIEW(S) MODEL AUTHOR(S) EXPLAIN MODEL DEVELOPMENT

↓

3.5
ISSUE REPORT IDENTIFYING REMAINING TECHNICAL ISSUES

APPLICATION OF VALIDATION METHODOLOGY

PURPOSE:

- DEMONSTRATE PROPOSED VALIDATION METHODOLOGY
  - EXAMPLE: MODELING OF RADIONUCLIDE RELEASE FROM EBS
  - EXAMPLE WILL FOCUS ON ONE ASSUMPTION THAT DETERMINES THE CONCEPTUAL AND MATHEMATICAL FORM OF THE RELEASE MODEL
    - * CONGRUENT RELEASE OF RADIONUCLIDES FROM SPENT FUEL UO_2 MATRIX
  - AND AN EXPERIMENT TO TEST THE ASSUMPTION

RECORD OF MODEL DEVELOPMENT

1.1 STATEMENT OF PROBLEM BEING ADDRESSED

- EBS RELEASE OF RADIONUCLIDES ASSUMING SPENT FUEL AS WASTE FORM

- CONCERN: CONSEQUENCES OF UNEXPECTED CONDITIONS (SIGNIFICANT WATER CONTACT WITH SPENT FUEL)

- MECHANISM OF RELEASE (CONGRUENT OR INCONGRUENT) OF RADIONUCLIDES FROM UO_2 MATRIX MAY SIGNIFICANTLY AFFECT COMPLIANCE WITH 10 CFR 60.113

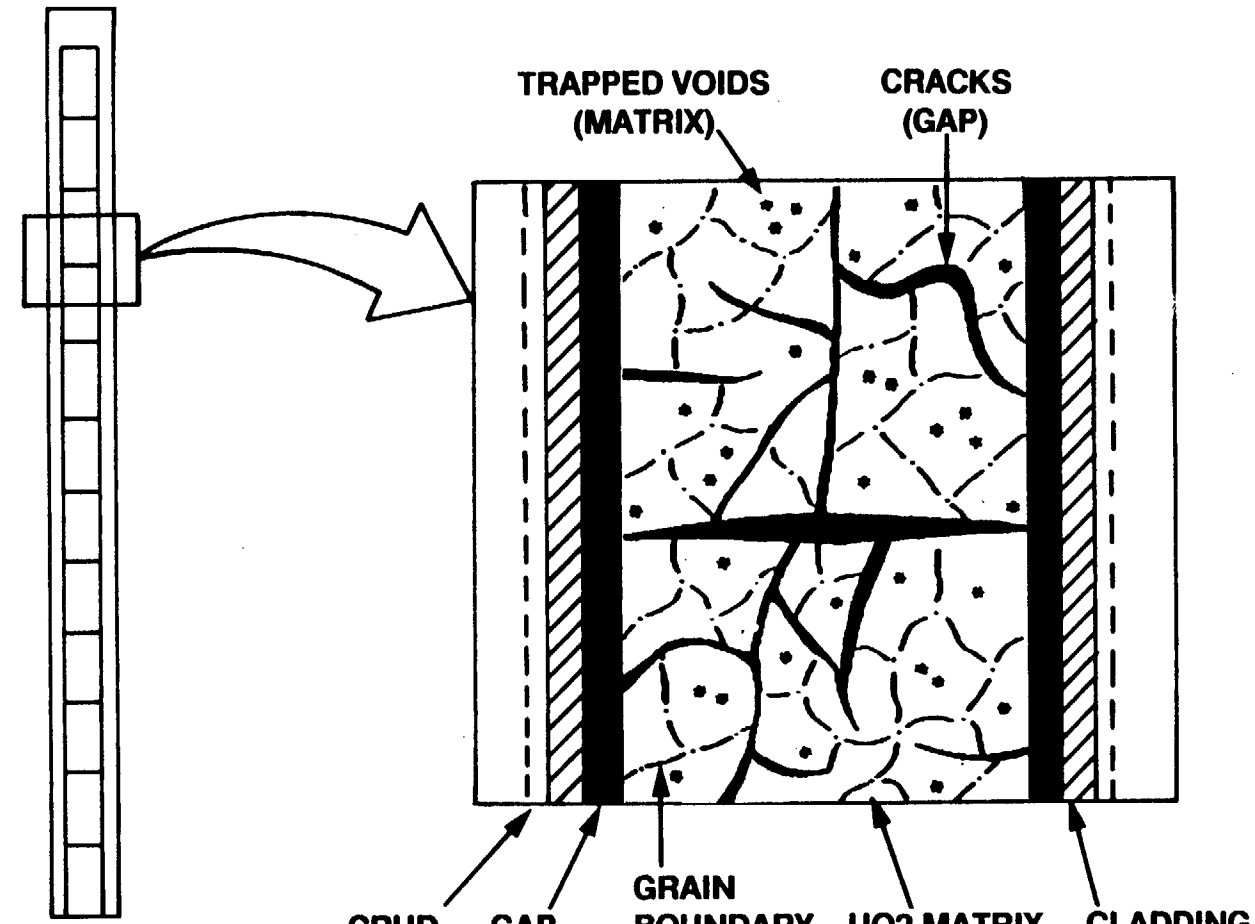
RECORD OF MODEL DEVELOPMENT

1.2 CONCEPTUAL MODEL DESCRIPTION - - FOUR COMPONENTS OF SPENT FUEL AFFECT RELEASE

REFERENCES: JOHNSON, ET AL. 1985, APTED, ET AL. 1987

- CLADDING AND CRUD LAYERS
- FUEL/CLADDING GAP
- GRAIN BOUNDARIES
- UO_2 MATRIX (>98% OF FISSION PRODUCTS)

SCHEMATIC OF SPENT NUCLEAR FUEL



CRUD	GAP	GRAIN BOUNDARY	UO2 MATRIX	CLADDING
C-14	C-14	C-14	ACTINIDES	C-14
	I-129	1-129	~98% FISSION	
	Cs-135	Cs-135	PRODUCTS	
	Ca-137	CS-137		
	Se-79	Se-79		
	Tc-99	Tc-99		
	Sr-90	Sr-90		

RECORD OF MODEL DEVELOPMENT

1.2 CONCEPTUAL MODEL DESCRIPTION

- IMPORTANT VARIABLES AND PARAMETERS
  - TEMPERATURE
  - GROUND-WATER CHEMISTRY pH
  - INITIAL CHEMICAL STATE OF FUEL
  - GROUND-WATER FLOW RATES

RECORD OF MODEL DEVELOPMENT

1.2 CONCEPTUAL MODEL DESCRIPTION

- CONGRUENT/INCONGRUENT DISSOLUTION ASSUMPTION AFFECTS MODEL:

  * CONGRUENT: SLOWER RELEASE OF SOLUBLE NUCLIDES
    $RATE_I = R(MATRIX) * X_I$

  * INCONGRUENT: LARGE RELEASES OF SOLUBLE NUCLIDES
    $RATE_I = C_I(SAT) * FLOW$

    USED TO CALCULATE GAP AND GRAIN BOUNDARY RELEASES

    NO CONSENSUS OF WHAT EXPERIMENTAL EVIDENCE SHOWS

RECORD OF MODEL DEVELOPMENT

1.3 IDENTIFICATION OF ASSUMPTIONS AND HYPOTHESES

- PHYSICOCHEMICAL PROCESSES
  (FOR THIS PRESENTATION - FOCUS ON ONE ASSUMPTION)

  * CONGRUENT DISSOLUTIONING OF RADIONUCLIDES IN UO_2 MATRIX

RECORD OF MODEL DEVELOPMENT

1.4 TECHNICAL BASIS FOR ASSUMPTIONS

- CONGRUENT DISSOLUTIONING OF RADIONUCLIDES IN MATRIX
  - PROFESSIONAL JUDGMENT
  - SOME DATA - INTERPRETATION AMBIGUOUS

RECORD OF MODEL DEVELOPMENT

1.5 DISCUSSION AND QUANTIFICATION OF ASSUMPTION

- ASSUMPTION IS A SWITCH: DETERMINING WHICH MODEL TO USE
- WHAT IS IMPACT ON RELEASE CALCULATION UNDER IN-CONGRUENT DISSOLUTION FOR SOLUBLE RADIONUCLIDES?
  - FAILURE TO MEET 10^{-5} FRACTIONAL RELEASE RATES
- PERFORM EXPERIMENT TO DETERMINE IF RELEASE IS CONGRUENT

RECORD OF MODEL DEVELOPMENT

1.6 IDENTIFICATION OF ASSUMPTIONS WHERE ADDITIONAL SUPPORT INFORMATION NEEDED

- ASSUMPTION OF CONGRUENT DISSOLUTION OF SPENT FUEL MATRIX
  - NO UNAMBIGUOUS EVIDENCE THAT IT HOLDS
  - MODEL RESULTS ARE VERY SENSITIVE TO THIS ASSUMPTION

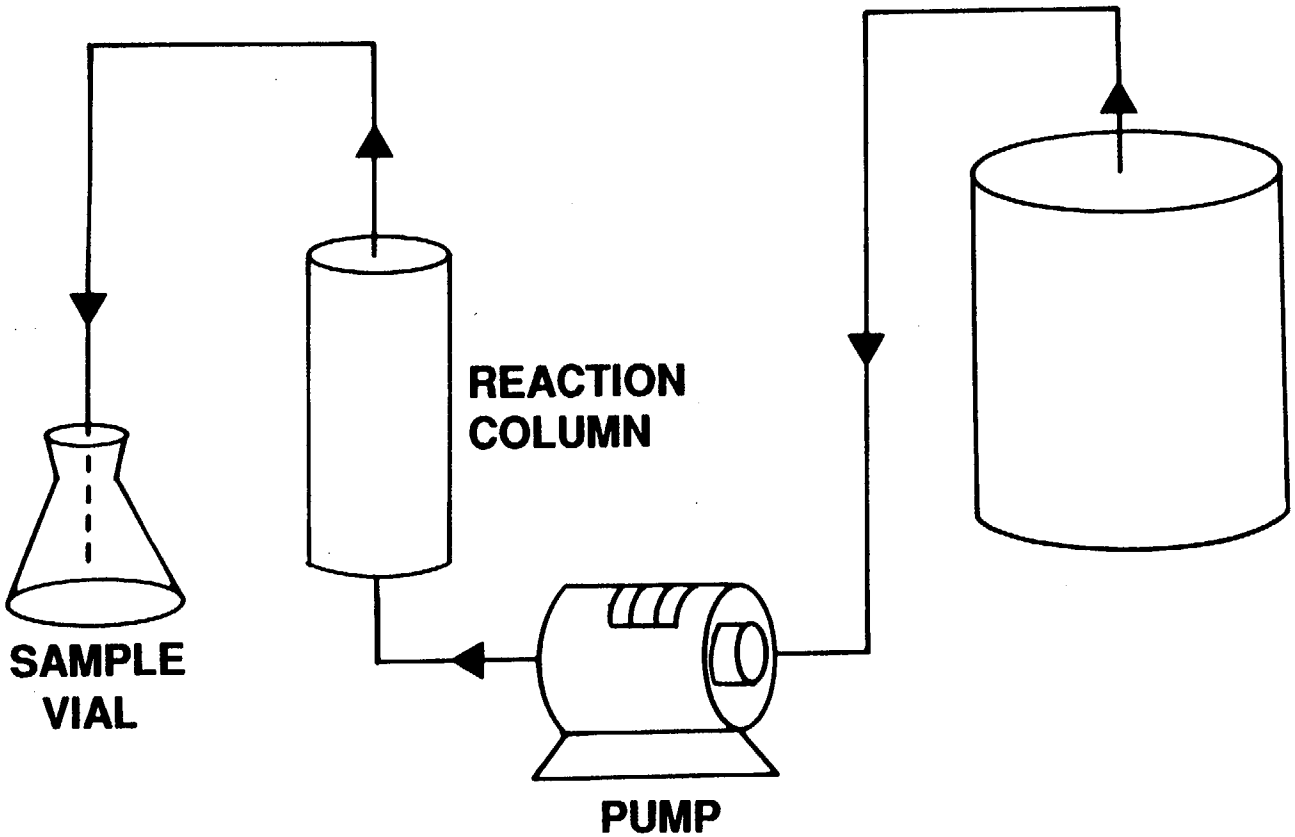
DESCRIPTION OF EXPERIMENT

OBJECTIVE: TEST HYPOTHESIS THAT DISSOLUTION OF THE SPENT FUEL WILL BE CONGRUENT

EXPERIMENTAL DESIGN:

- OXIDIZE FUEL AT 150 °C IN AIR
- CRUSH OXIDIZED FUEL TO PRODUCE INDIVIDUAL GRAINS
- DISSOLVED EXPOSED GRAIN BOUNDARY MATERIAL
- DETERMINE GRAIN BOUNDARY INVENTORY
- LEAVE UNALTERED UO_2 MATRIX AND CONTAINED RADIONUCLIDES
- MEASURE DISSOLUTION RATE OF UO_2 MATRIX AND CONTAINED RADIONUCLIDES

CONGRUENT DISSOLUTION APPARATUS



SOLVENT RESERVOIR

- DEIONIZED WATER
- J13 WELL WATER
- WATER SATURATED WITH URANIUM
- ANOXIC WATER

DESCRIPTION OF EXPERIMENT AND EXPERIMENTAL DATA

2.1 DESCRIPTION OF EXPERIMENT

- NUMBER OF TESTS NEEDED TO EVALUATE HYPOTHESIS
- SOURCES OF VARIATION:
  - NON-HOMOGENEITY OF FUEL (NO QUANTITATIVE ESTIMATE)
  - NON-UNIFORM EFFECTS OF OXIDATION (NO QUANTITATIVE ESTIMATE)
  - ANALYTICAL ERROR ($\pm$ 10%)

DESCRIPTION OF EXPERIMENT AND EXPERIMENTAL DATA

2.2 INTERPRETATION OF DATA

- BECAUSE OF SOURCES OF VARIATION:

  - WITH ABOVE ANALYTICAL ERROR, ASSUMING RATIO IS 1.0, OBSERVABLE RATIO RANGE IS .80

  - ASSUMING GAUSSIAN DISTRIBUTION:
    * FOR 3 TESTS, s(STANDARD DEVIATION) = .47
    * FOR 5 TESTS, s = .34
    * FOR 9 TESTS, s = .27

  - ASSUME WITH ALL SOURCES OF VARIATIONS, s = .80

DESCRIPTION OF EXPERIMENT AND EXPERIMENTAL DATA

2.3 COMPARISON OF MODEL PREDICTION WITH EXPERIMENTAL DATA

- **HYPOTHESIS TEST FOR MEAN OF GAUSSIAN POPULATION:**

$\frac{\overline{X}-\mu}{s/\sqrt{n}} = t$, COMPARE TO $t_a(n-1)$

$\overline{X}$ - **MEAN OF OBSERVED RATIOS**
μ - **TRUE RATIO VALUE**
n - **NUMBER OF TESTS**
a - **CONFIDENCE LEVEL**

WITH $\overline{X} = 2,\ \mu = 1,\ s = .80,\ n = 3,\ a = .05$

$t = 2.17 < t_a(2)$

IF MEAN RATIO $\leq$ 2, THEN CONGRUENT DISSOLUTIONING CONFIRMED

DESCRIPTION OF EXPERIMENT AND EXPERIMENTAL DATA

2.3 COMPARISON OF MODEL PREDICTION WITH EXPERIMENTAL DATA

- VIEWING HYPOTHESIS AS TOLERANCE INTERVAL ON INDIVIDUAL RATIOS:

  - WITH 95% CONFIDENCE, THAT 95% OF POPULATION OF OBSERVED RATIOS $\leq$ LIMIT

  - LIMIT = $\bar{X} + K(.95, .95, n)$
    FOR $N = 5, s = .80, X = 1.0$
    LIMIT = 4.37

  - IMPLICATION: SMALL PROBABILITY THAT OBSERVED RATIO > 4.37

RECORD OF MODEL DEVELOPMENT

1.7 COMPARISON OF MODEL OUTPUT AND EXPERIMENTAL DATA FROM HYPOTHESIS OF CONGRUENT DISSOLUTION:

$$H_0: \frac{\text{Cs/U IN SOLUTION}}{\text{Cs/U IN MATRIX}} = 1.0$$

$$H_1: \frac{\text{Cs/U IN SOLUTION}}{\text{Cs/U IN MATRIX}} > 1.0$$

RECORD OF MODEL DEVELOPMENT

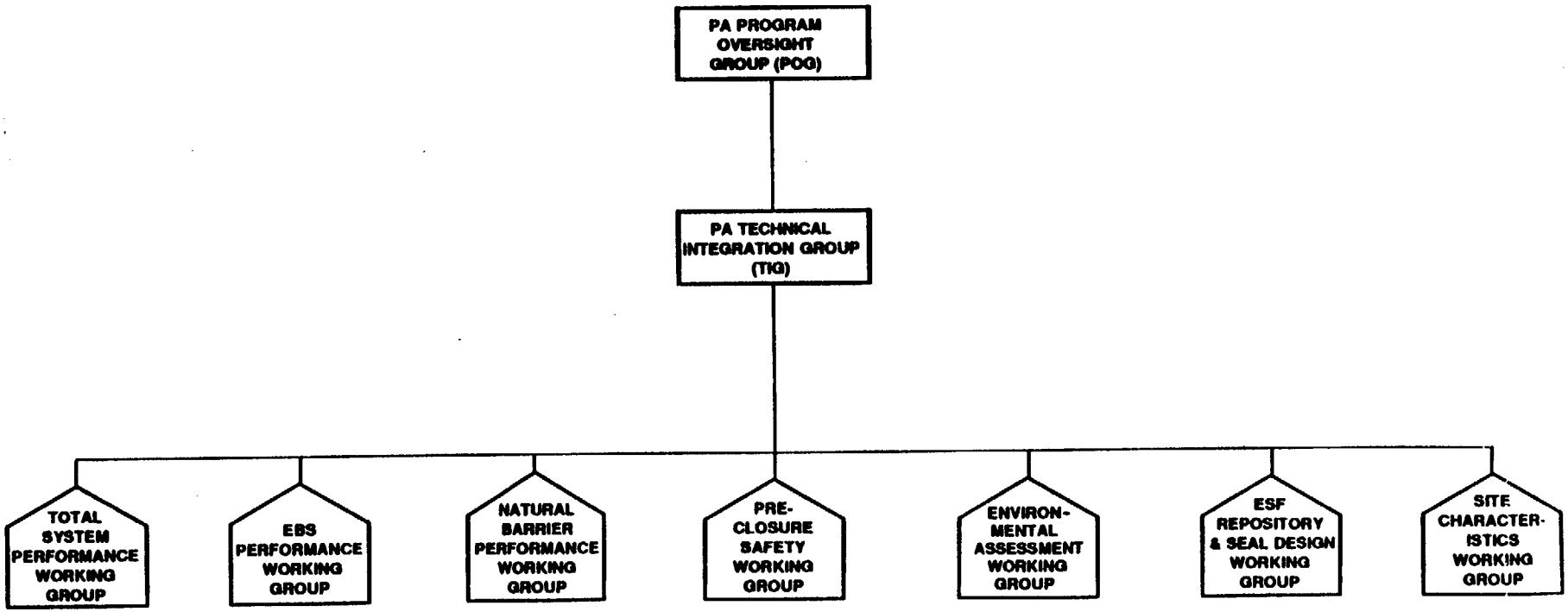
1.8 RELATED PLANNED ACTIVITIES

- DYNAMIC DISSOLUTION EXPERIMENTS
  - DETERMINE EFFECTS OF IMPORTANT PARAMETERS FOR RELEASE MODEL:
    - * RANGE OF TEMPERATURES
    - * RANGE OF WATER COMPOSITIONS
    - * RANGE OF OXIDATION STATES OF FUEL
    - * EFFECT OF LOW FLOW RATES (USE OF WATER SATURATED WITH U)

IMPLEMENTATION OF MODEL VALIDATION METHODOLOGY

- WORKING GROUP 7 WILL ACT AS THE LEAD FOR INTEGRATING THE METHODOLOGY WITHIN OCRWM
- A SET OF MORE DETAILED EXAMPLES OF THE METHODOLOGY IS BEING PREPARED IN EACH OF THE PERFORMANCE ASSESSMENT AREAS TO ILLUSTRATE THE CONCEPTS
- THE OCRWM PROGRAM IS PARTICIPATING IN THE INTRAVAL PROGRAM, AN INTERNATIONAL COOPERATIVE EFFORT IN THE AREA OF MODEL VALIDATION

PERFORMANCE ASSESSMENT INTEGRATION STRUCTURE



INTRAVAL TEST CASES

1a	Radionuclide migration through clay samples by diffusion and advection based on laboratory experiments performed at Harwell, U.K.
1b	Uranium migration in crystalline bore cores based on experiments performed at PSI, Switzerland.
2	Radionuclide migration in single natural fissures in granite, based on laboratory experiments performed at KTH.
3	Tracer tests in a deep basalt flow top performed at the Hanford reservation, Washington, USA.
4	Flow and tracer experiments in crystalline rock base on the Stripa 3-D experiment performed within the International Stripa Project.
5	Tracer experiments in a fracture zone at the Finnsjön research area, Sweden.
6	Synthetic data base, based on single fracture migration experiments in Grimsel Rock Laboratory in Switzerland.
7a	Redox-front and radionuclide movements in an open pit uranium mine. Natural analogue studies at Poços de Caldas (Minas Gerais), Brazil.
7b	Morro do Ferro colloid migration studies. Natural analogue studies at Poços de Caldas (Minas Gerais), Brazil.
8	Natural analogue studies at the Koongarra site in the Alligator Rivers area of the Northern Territory, Australia.
9	Radionuclide migration in a block of crystalline rock based on laboratory experiments performed at AECL, Canada.
10	Evaluation of unsaturated flow and transport in porous media using an experiment with migration of a wetting front in a superficial desert soil performed within a U.S. NRC trench study at Las Cruces, New Mexico.
11	Evaluation of flow and transport in unsaturated fractured rock using studies at the U.S. NRC Apache Leap Tuff Site, near Superior, Arizona.
12	Experiments with changing near-field hydrologic conditions in partially saturated tuffaceous rocks performed in the G-Tunnel Underground Facility at the Nevada Test Site, performed by the Nevada Nuclear Waste Investigation Project of the U.S. DOE.
13	Experimental study of brine transport in porous media performed at RIVM, the Netherlands.
14a	Pumping test in highly saline groundwater performed at the Gorleben site.
14b	Saline groundwater movements in an erosional channel crossing the salt dome at the Gorleben site.

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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: ROLE OF PERFORMANCE ASSESSMENT IN PRIORITIZATION OF SITE CHARACTERIZATION PROGRAM

PRESENTER: DR. JEAN L. YOUNKER

PRESENTER'S TITLE AND ORGANIZATION:
SENIOR STAFF GEOLOGIST
SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
TECHNICAL & MANAGEMENT SUPPORT SERVICES
CONTRACTOR FOR THE
YUCCA MOUNTAIN PROJECT OFFICE
U.S. DEPARTMENT OF ENERGY

PRESENTER'S TELEPHONE NUMBER: (702) 794-7650

MAY 16-17, 1989

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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: ROLE OF PERFORMANCE ASSESSMENT IN PRIORITIZATION OF SITE CHARACTERIZATION PROGRAM

PRESENTER: DR. JEAN L. YOUNKER

PRESENTER'S TITLE AND ORGANIZATION:
SENIOR STAFF GEOLOGIST
SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
TECHNICAL & MANAGEMENT SUPPORT SERVICES
CONTRACTOR FOR THE
YUCCA MOUNTAIN PROJECT OFFICE
U.S. DEPARTMENT OF ENERGY

PRESENTER'S TELEPHONE NUMBER: (702) 794-7650

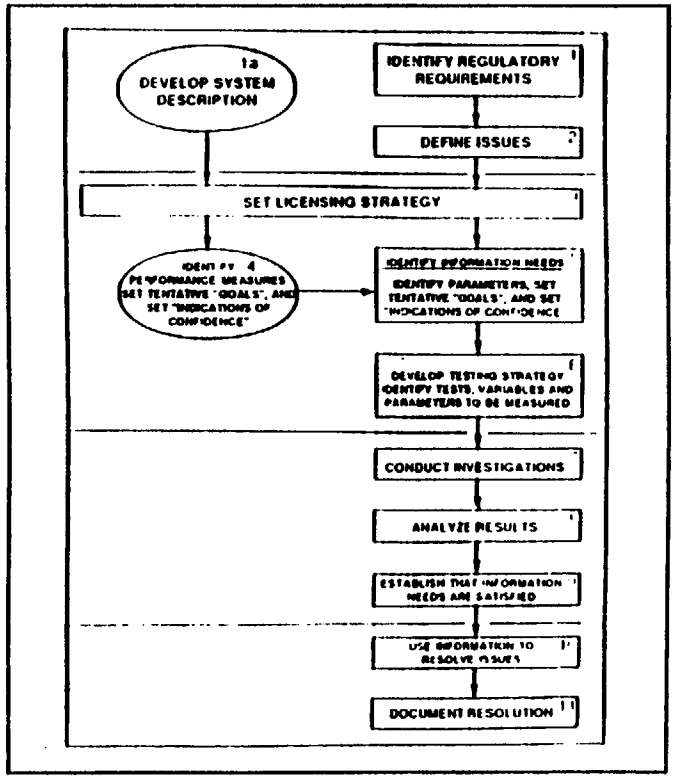
MAY 16-17, 1989

SCOPE OF PRESENTATION

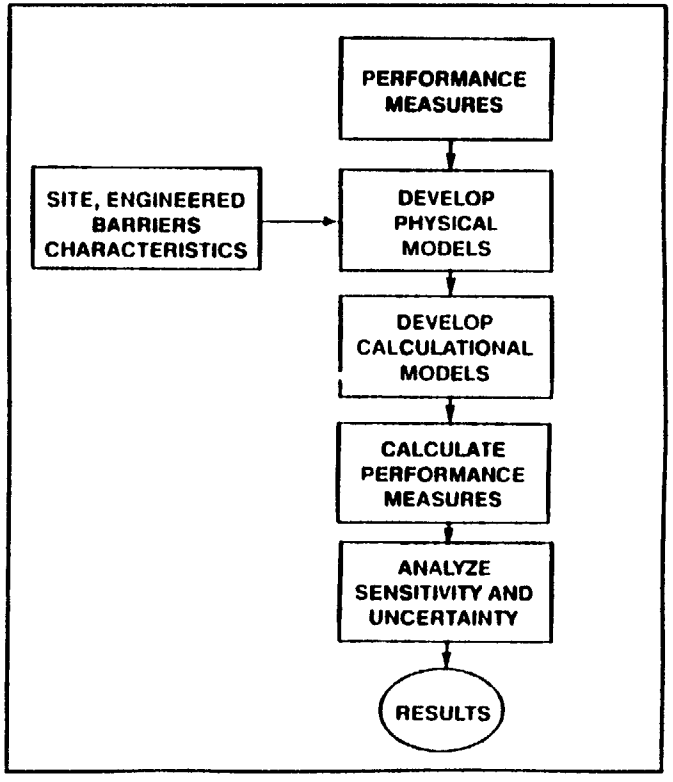
- INTERFACE FROM PERFORMANCE ASSESSMENT TO THE SITE CHARACTERIZATION PROGRAM
- RELATION OF THE SITE PROGRAM TO ISSUE RESOLUTION STRATEGIES
- USE OF PERFORMANCE ALLOCATION TO GUIDE THE SITE TESTING PROGRAM
- EXAMPLES OF FLOWDOWN FROM PERFORMANCE MEASURES TO SITE STUDIES AND ACTIVITIES

INTERFACE FROM PERFORMANCE ASSESSMENT TO SITE PROGRAM

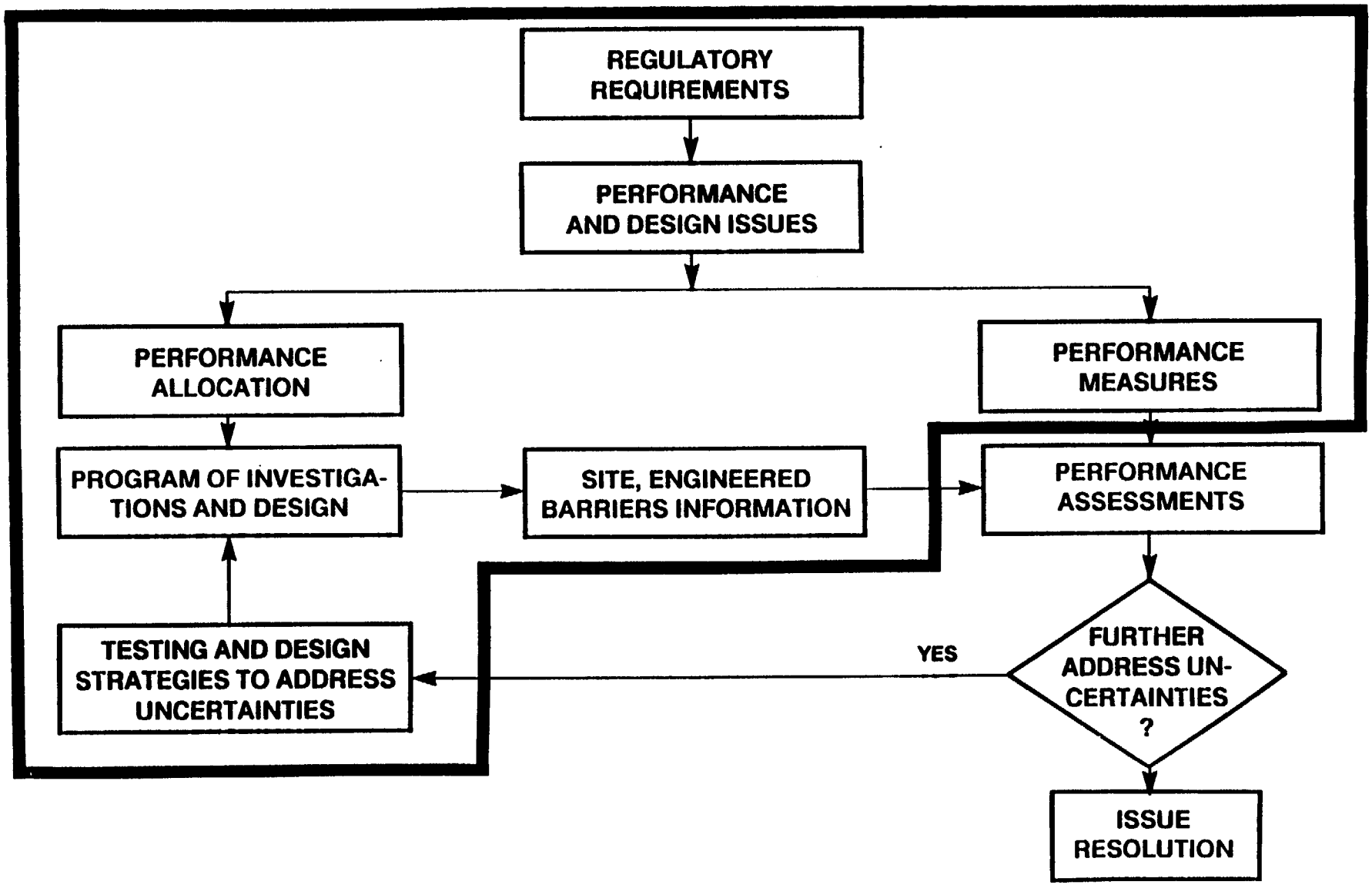
SITE CHARACTERIZATION PLAN STUDY PLANS



PERFORMANCE ASSESSMENT STRATEGY PLAN (PASP) IMPLEMENTATION PLAN (PAIP)

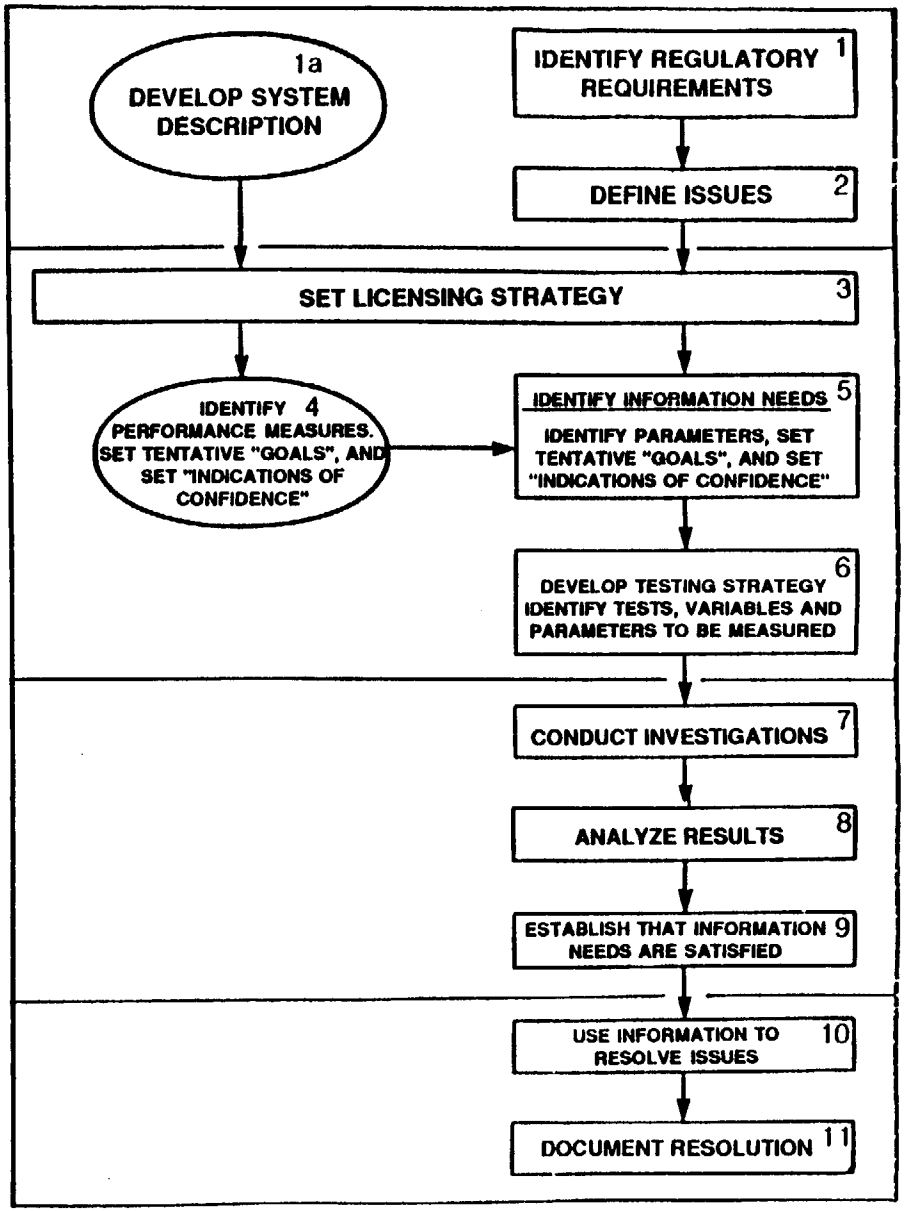


CONTENT OF SITE CHARACTERIZATION PLAN AND STUDY PLANS



ISSUE RESOLUTION STRATEGY

- ISSUE IDENTIFICATION
- PERFORMANCE ALLOCATION
- DATA COLLECTION AND ANALYSES
- ISSUE RESOLUTION



DOE ISSUES HIERARCHY

POSTCLOSURE PERFORMANCE ISSUES

1.1 CUMULATIVE RELEASE TO THE ACCESSIBLE ENVIRONMENT (40 CFR 191.13)

1.2 INDIVIDUAL PROTECTION (40 CFR 191.15)

1.3 GROUND-WATER PROTECTION (40 CFR 191.16)

1.4 CONTAINMENT BY WASTE PACKAGES (10 CFR 60.113)

1.5 RATE OF RELEASE FROM THE EBS (10 CFR 60.113)

1.6 GROUND WATER TRAVEL TIME (10 CFR 60.113)

1.7 SEALS SYSTEM PERFORMANCE

1.8 NRC SITING CRITERIA (10 CFR 60.122)

1.9 POSTCLOSURE SITING GUIDELINES (10 CFR 960.4)

PRECLOSURE PERFORMANCE ISSUES

2.1 DOSE TO PUBLIC FROM ROUTINE OPERATIONS (10 CFR 60.111(a))

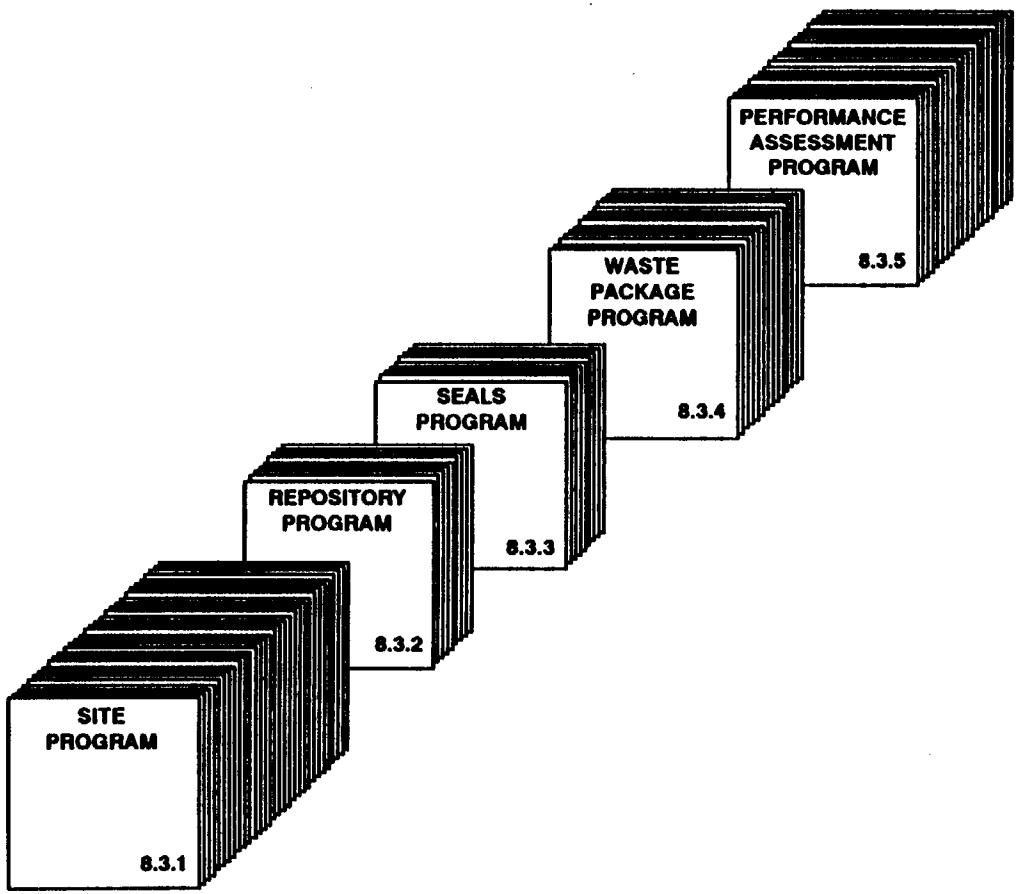
2.2 DOSE TO WORKERS FROM ROUTINE OPERATIONS (10 CFR 60.111(a))

2.3 DOSE TO PUBLIC FROM ACCIDENTS

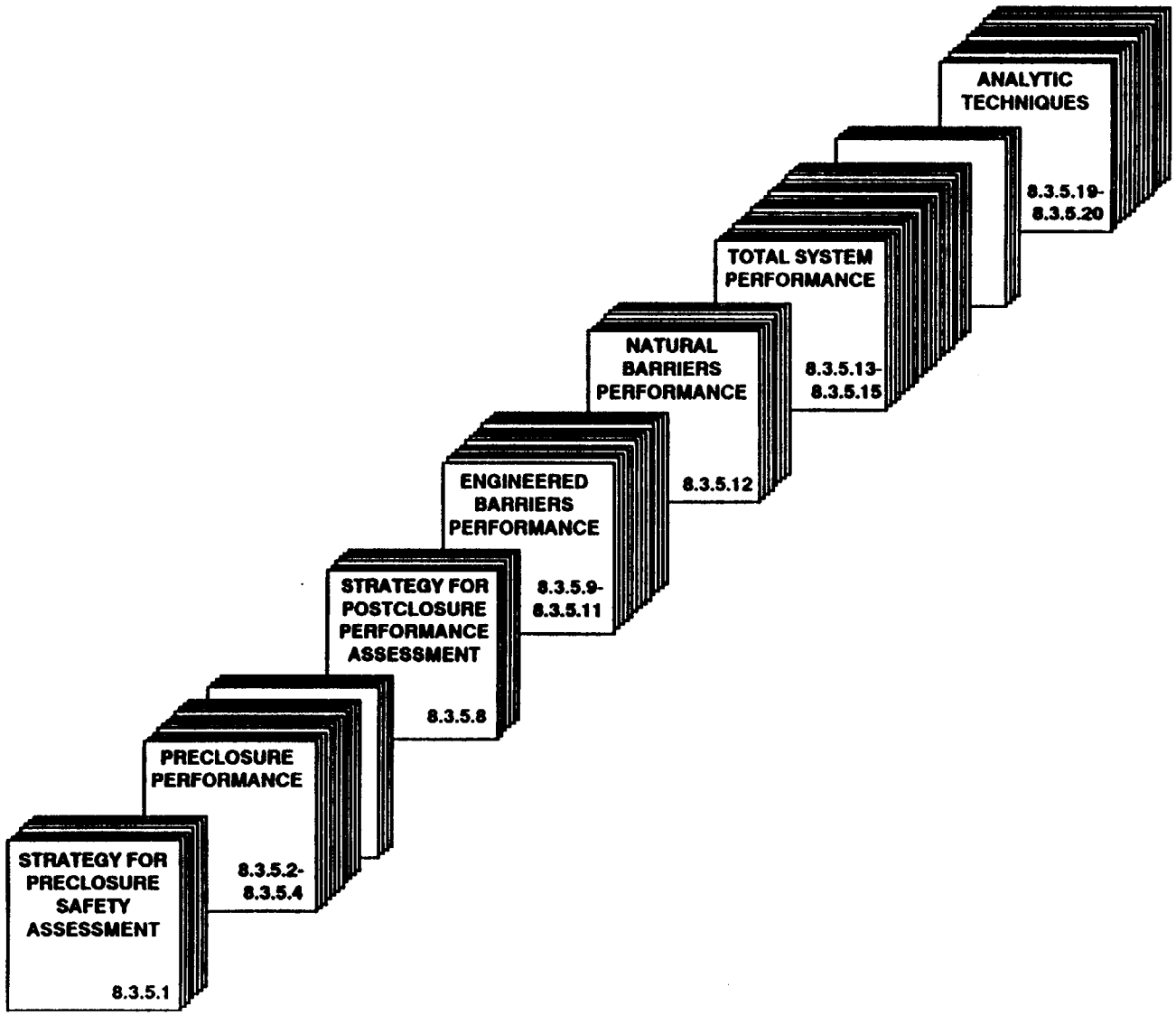
2.4 RETRIEVABILITY (10 CFR 60.111(b)

2.5 PRECLOSURE SITING GUIDELINES (10 CFR 960.5)

SCP SECTION 8.3 STRUCTURE



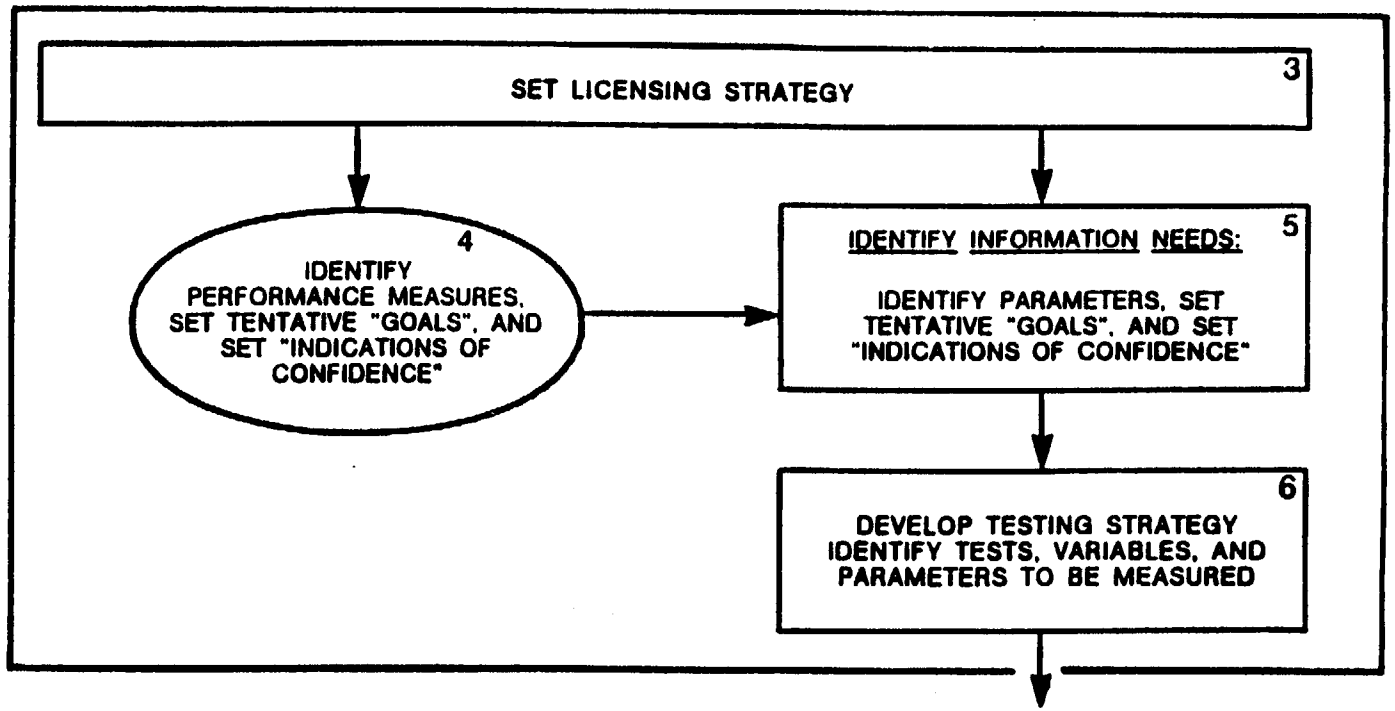
SCP PERFORMANCE ASSESSMENT PROGRAM STRUCTURE



ROAD MAP TO PERFORMANCE ISSUE RESOLUTION STRATEGIES IN THE SCP

TOTAL SYSTEM PERFORMANCE	SCP SECTION
1.1 CUMULATIVE RELEASE TO ACCESSIBLE ENVIRONMENT (CCDF)	8.3.5.13
1.2 INDIVIDUAL PROTECTION (INDIVIDUAL DOSE)	8.3.5.14
1.3 GROUND-WATER PROTECTION (CONCENTRATION)	8.3.5.15
ENGINEERED BARRIERS PERFORMANCE	
1.4 CONTAINMENT BY WASTE PACKAGES (CONTAINER LIFETIME)	8.3.5.9
1.5 RATE OF RELEASE FROM THE EBS	8.3.5.10
1.7 SEALS SYSTEM PERFORMANCE	8.3.5.11
NATURAL BARRIERS PERFORMANCE	
1.6 GROUND-WATER TRAVEL TIME	8.3.5.12
PRECLOSURE RADIOLOGICAL SAFETY	
2.1 DOSE TO PUBLIC FROM ROUTINE OPERATIONS	8.3.5.2
2.2 DOSE TO WORKERS FROM ROUTINE OPERATIONS	8.3.5.3
2.3 DOSE TO PUBLIC FROM ACCIDENTS	8.3.5.4

ISSUE RESOLUTION STRATEGY: PERFORMANCE ALLOCATION



ISSUE RESOLUTION STRATEGY
STEP 3

- DEVELOP PRELIMINARY SITE DESCRIPTION INCLUDING RANGE OF CONCEPTUAL MODELS CONSISTENT WITH AVAILABLE DATA

- DEVELOP PRELIMINARY DESIGNS FOR REPOSITORY AND ENGINEERED BARRIERS

- DEFINE ELEMENTS OF NATURAL AND ENGINEERED SYSTEMS TO BE RELIED UPON IN MEETING REGULATORY REQUIREMENTS

  (E.G. - UNSATURATED ZONE ROCK UNITS; ZEOLITES ALONG FLOWPATHS; WASTE PACKAGE)

- IDENTIFY PROCESSES RELATED TO THOSE ELEMENTS THAT MUST BE UNDERSTOOD TO PREDICT BEHAVIOR OF THE NATURAL AND ENGINEERED SYSTEMS

  (E.G. - UNSATURATED-ZONE FLUX AND FLOW MECHANISMS; THERMO-DYNAMIC STABILITY OF ZEOLITES; CORROSION MECHANISMS AND RATES)

PERFORMANCE MEASURES AND GOALS
STEP 4

- PERFORMANCE MEASURES

  - USING PREVIOUS PERFORMANCE ASSESSMENTS AND SENSITIVITY STUDIES, DEFINE PARAMETERS (E.G. MEASURES) THAT DESCRIBE THE BEHAVIOR OF THE NATURAL OR ENGINEERED BARRIER SYSTEM OR SUBSYSTEMS

- PERFORMANCE GOALS

  - VALUE OR LIMIT FOR A MEASURE OR PARAMETER DERIVED FROM PREVIOUS SENSITIVITY STUDIES OR PROFESSIONAL JUDGEMENT
  - USED TO GUIDE AND FOCUS THE SITE TESTING PROGRAM
  - COULD CHANGE WITH NEW SITE DATA AND FURTHER SENSITIVITY STUDIES

- CURRENT/NEEDED CONFIDENCE

  - INDICATION OF THE IMPORTANCE OF REDUCING UNCERTAINITY IN PARAMETER OR MEASURE

STEP 5
IDENTIFY INFORMATION NEEDS

DETERMINE INFORMATION NEEDED TO CALCULATE PERFORMANCE MEASURES

- HIERARCHY OF PARAMETERS NEEDED TO CALCULATE THE MEASURE
- SITE CONCEPTUAL MODELS
- PROCESS/MECHANISTIC MODELS
- CALCULATIONAL MODELS/CODES

STEP 5
(CONTINUED)

USING AVAILABLE SITE DESCRIPTION, PERFORMANCE ASSESSMENT CALCULATIONS, AND SENSITIVITY STUDIES

- DEFINE PARAMETERS NEEDED AT LEVEL OF DETAIL ADEQUATE TO INTERFACE WITH SITE TESTING PROGRAM
- DEVELOP GOALS AND ESTIMATES OF CURRENT/NEEDED CONFIDENCE FOR SITE PARAMETERS

STEP 6
DEVELOP TESTING STRATEGY

- COMPILE SET OF PARAMETERS REQUESTED
- DOCUMENT GOALS AND CURRENT/NEEDED CONFIDENCE
- CONSIDER CONSTRAINTS ON TESTING DUE TO POTENTIAL FOR IMPACTS ON SITE
- DEVELOP PLANS FOR LABORATORY AND FIELD STUDIES

RESULTS OF PERFORMANCE ALLOCATION ARE PRESENTED IN TABLES IN THE SCP

SYSTEM ELEMENT	PERFORMANCE/ DESIGN MEASURE	TENTATIVE GOAL	NEEDED CONFIDENCE

PERFORMANCE/ DESIGN PARAMETER	TENTATIVE GOAL	NEEDED CONFIDENCE

PERFORMANCE & DESIGN SECTIONS 8.3.2-8.3.5

CHARACTERIZATION PARAMETER	CURRENT ESTIMATE	CONFIDENCE IN CURRENT ESTIMATE	NEEDED CONFIDENCE

SITE PROGRAM SECTION 8.3.1

CRITERIA FOR PRIORITIZATION OF SITE PROGRAM RESULTING FROM PERFORMANCE ALLOCATION

- THE NEEDED CONFIDENCE FOR PARAMETERS TO BE DETERMINED BY THE STUDY OR ACTIVITY IS HIGH
- THE STUDY OR ACTIVITY CHARACTERIZES A PRIMARY BARRIER
- THERE IS A SUBSTANTIAL DIFFERENCE BETWEEN THE CURRENT AND NEEDED CONFIDENCE FOR THE PARAMETER [I.E. CURRENT = LOW OR MEDIUM; NEEDED = HIGH]
- THERE IS A STRONG TIE BETWEEN THE PARAMETERS PROVIDED BY THE STUDY/ACTIVITY AND THE PERFORMANCE REQUIREMENTS
- THERE IS A STRONG TIE BETWEEN THE STUDY/ACTIVITY AND THE DESIGN REQUIREMENTS

PERFORMANCE ALLOCATION EXAMPLES

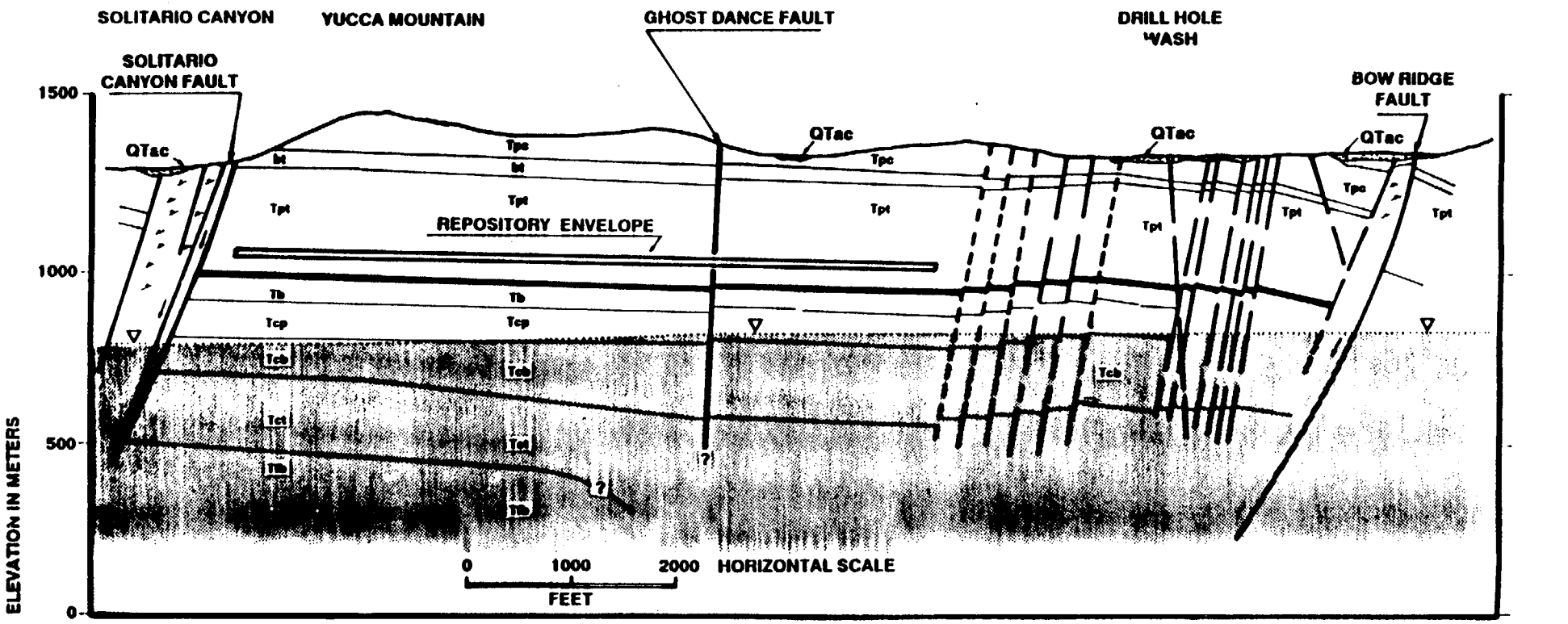
FLOWDOWN FROM PERFORMANCE REQUIREMENTS TO PLANS FOR SITE TESTING

EXAMPLE 1: PRE-WASTE EMPLACEMENT GROUND-WATER TRAVEL TIME/GEOHYDROLOGY PROGRAM

EXAMPLE 2: TOTAL SYSTEM PERFORMANCE/HUMAN INTERFERENCE PROGRAM

EXAMPLE 3: TOTAL SYSTEM PERFORMANCE/POSTCLOSURE TECTONICS PROGRAM

EXAMPLE 1: GROUND-WATER TRAVEL TIME/GEOHYDROLOGY



Tpc TIVA CANYON MEMBER	Tcp PROW PASS MEMBER	HIGHLY FAULTED AND BRECCIATED ZONE	? STRATIGRAPHY UNCERTAIN
bt BEDDED TUFF	Tcb BULLFROG MEMBER	QTac ALLUVIUM & COLLUVIUM	▽ WATER TABLE
Tpt TOPOPAH SPRING MEMBER	Tm TRAM MEMBER	BASAL VITROPHYRE	ARROWS SHOW DIRECTION OF RELATIVE DISPLACEMENT
Tb TUFFACEOUS BEDS OF CALICO HILLS	Tfb FLOW BRECCIA		

— — FAULTS WITH MINOR DIP-SLIP DISPLACEMENTS POSITIONS KNOWN OR CONCEALED AT SURFACE

——— FAULTS WITH MAJOR DIP-SLIP DISPLACEMENTS POSITIONS KNOWN OR CONCEALED AT SURFACE

– – – – UNMAPPED & INFERRED FAULTS WITH SMALL DISPLACEMENT

LICENSING STRATEGY FOR GROUND-WATER TRAVEL TIME

- HIGHEST PRIORITY ON CALICO HILS UNIT IN THE SATURATED ZONE
- LOWER PRIORITY ON OTHER UNITS IN UNSATURATED ZONE
- LOWEST PRIORITY ON SATURATED ZONE

EXAMPLE OF PERFORMANCE MEASURES FOR GROUND-WATER TRAVEL TIME

HYDROLOGIC COMPONENTS AVAILABLE	PERFORMANCE MEASURE	PERFORMANCE GOAL (YR)	NEEDED CONFIDENCE
TOPOPAH SPRING	GWTT	1,000	LOW
		10,000	VERY LOW
CALICO HILLS (VITRIC)	GWTT	1,000	HIGH
		10,000	LOW
CALICO HILLS (ZEOLITIC)	GWTT	1,000	HIGH
		10,000	LOW

EXAMPLE OF PERFORMANCE PARAMETERS FOR GROUND-WATER TRAVEL TIME

HYDROGEO-LOGIC UNIT	PERFORMANCE PARAMETER	ESTIMATED RANGE	TENTATIVE GOAL	NEEDED CONFIDENCE
TOPOPAH SPRING	q	<0.5 mm/yr	<0.5 mm/yr	LOW
	q/K_s	0.005 to 50	<0.85	LOW
	n_e	0.01 to 0.2	>0.05	LOW
	d	0 to 56 m	10 m (100%)	LOW
CALICO HILLS (VITRIC)	q	<0.5 mm/yr	<0.5 mm/yr	HIGH
	q/K_s	0.00005 to 5	<0.95	HIGH
	n_e	0.15 to 0.45	>0.2	HIGH
	d	0 to 160 m	>2.5 m (100%)	HIGH
			>25 m (80%)	MEDIUM
CALICO HILLS (ZEOLITIC)	q	<0.5 mm/yr	<0.5 mm/yr	HIGH
	q/K_s	0.005 to 50	<0.9	HIGH
	n_e	0.2 to 0.4	>0.2	HIGH
			>2.5 m (100%)	HIGH
	d	0 to 140 m	>25 m (80%)	MEDIUM

PARAMETERS PROVIDED BY THE UNSATURATED ZONE GEOHYDROLOGY PROGRAM

CALLS BY PERFORMANCE AND DESIGN ISSUES		PARAMETER	RESPONSE BY GEOHYDROLOGY CHARACTERIZATION PROGRAM	
ISSUE	SCP SECTION	CATEGORY	ACTIVITY PARAMETER	SCP ACTIVITY
1.1, 1.5, 1.6, 1.12	8.3.5.13, 8.3.5.10, 8.3.5.12, 8.3.3.2	FLUID FLUX	FLUX, LIQUID AND GASEOUS PHASE GHOST DANCE FAULT ZONE	8.3.1.2.2.6.1
			FLUX, VOLUMETRIC, THROUGH FRACTURE/MATRIX NETWORKS	8.3.1.2.2.4.2
			FLUX, VOLUMETRIC, THROUGH THE TOPOPAH SPRINGWELDED UNIT	8.3.1.2.2.4.3
1.1, 1.4, 1.6, 4.4, 1.8, 1.9 1.5, 4.2	8.3.5.13 8.3.5.9, 8.3.5.12, 8.3.2.5, 8.3.5.17, 8.3.5.18, 8.3.5.10, 8.3.2.4	SYNTHESIS CHARACTER-ISTICS	FLOW PATHS, MOISTURE IN UNSATURATED ZONE	8.3.1.2.2.10.2
			GROUND-WATER TRAVEL TIME, FRACTURE/MATRIX ZONE	8.3.1.2.2.4.2
			MOISTURE FLUXES, FLOW PATHS, AND TRAVEL TIMES WITHIN THE UNSATURATED ZONE	8.3.1.2.2.10.1

PARAMETER TRACKED INTO APPROPRIATE STUDY

8.3.1.2.2.4 STUDY: CHARACTERIZATION OF YUCCA MOUNTAIN PERCOLATION IN THE UNSATURATED ZONE--EXPLORATORY SHAFT FACILITY STUDY

8.3.1.2.2.4.1 ACTIVITY: INTACT FRACTURE TEST IN THE ESF

8.3.1.2.2.4.2 ACTIVITY: INFILTRATION TESTS IN THE ESF

ACTIVITY PARAMETER	SCP ACTIVITY
FLUX, VOLUMETRIC THROUGH FRACTURE/MATRIX NETWORKS	8.3.1.2.2.4.2

⋮

EXAMPLE 2: TOTAL SYSTEM PERFORMANCE/ HUMAN INTERFERENCE PROGRAM

TOTAL SYSTEM PERFORMANCE MEASURE	INITIATING EVENT	PERFORMANCE PARAMETERS	TENTATIVE PARAMETER GOAL	CURRENT & NEEDED CONFIDENCE
EPPM	EXPLORATORY DRILLING INTERCEPTS A WASTE PACKAGE AND BRINGS UP WASTE WITH CORE OR CUTTINGS	PRESENCE AND READABILITY OF C-AREA MARKERS OVER 10,000 YR	> 50% CHANCE THAT MARKERS ARE READABLE OVER NEXT 10,000 YR	LOW/MEDIUM
		EXPECTED DRILLING RATE (NO. OF BORE-HOLES/km^2/YR)IN R-AREA OVER THE NEXT 10,000 YR	EXPECTED DRILLING RATE $\leq 3 \times 10^{-4}$ BOREHOLES/ km^2/YR	LOW/LOW
		DISTRIBUTION OF DIAMETERS AND DEPTHS OF EXPLORATORY DRILLING	NO GOAL	LOW/LOW

EXAMPLE 2: TOTAL SYSTEM PERFORMANCE/HUMAN INTERFERENCE PROGRAM

CONTINUED

PERFORMANCE PARAMETERS	TENTATIVE GOAL	SITE PARAMETERS TO BE PROVIDED	STUDY OR ACTIVITY
PRESENCE AND READABILITY OF C-AREA MARKERS OVER 10,000 YR	> 50% CHANCE THAT MARKERS ARE READABLE OVER NEXT 10,000 YR	RATES OF EROSION, WEATHERING, DEPOSITION, IGNEOUS ACTIVITY,SEISMIC ACTIVITY AT MARKER LOCATIONS	LONG-TERM PROCESSES THAT COULD AFFECT MARKER STABILITY(8.3.1.9.1.1)
EXPECTED DRILLING RATE (NO. OF BOREHOLES/km²/YR) IN R-AREA OVER THE NEXT 10,000 YR	EXPECTED DRILLING RATE $\leq 3 \times 10^{-4}$ BOREHOLES/km²/YR RESOURCES	QUANTITIES, TONNAGES, AND GRADES OF KNOW OR INFERRED	NATURAL RESOURCE ASSESSMENT OF YUCCA MOUNTAIN, NYE COUNTY, NV (8.3.1.9.2.1)
DISTRIBUTION OF DIAMETERS AND DEPTHS OF EXPLORATORY DRILLING	NO GOAL	TYPES OF KNOWN OR INFERRED RESOURCES AT YUCCA MOUNTAIN	VALUE OF RESOURCES (8.3.1.9.2) EFFECTS OF HUMAN INTERFERENCE (8.3.1.9.3)

EXAMPLE 3: TOTAL SYSTEM PERFORMANCE/ POSTCLOSURE TECTONICS PROGRAM

TOTAL SYSTEM PERFORMANCE MEASURE	INITIATING EVENT	PERFORMANCE PARAMETERS	TENTATIVE PARAMETER GOAL	CURRENT & NEEDED CONFIDENCE
EPPM	VOLCANIC ERUPTION PENETRATES REPOSITORY/CAUSES DIRECT RELEASE	ANNUAL PROBABILITY VOLCANIC ERUPTION THAT PENETRATES THE REPOSITORY	$< 10^{-6}$/YR	LOW/HIGH
		EFFECTS OF VOLCANIC ERUPTION PENETRATING REPOSITORY, INCLUDING AREA OF REPOSITORY DISRUPTED	SHOW <0.1% OF REPOSITORY AREA IS DISRUPTED WITH CONDITIONAL PROBABILITY OF <0.1% OF BEING EXCEEDED IN 10,000 YR	LOW/MEDIUM

EXAMPLE 3: TOTAL SYSTEM PERFORMANCE/ POSTCLOSURE TECTONICS PROGRAM

PERFORMANCE PARAMETERS	TENTATIVE GOAL	SITE PARAMETERS TO BE PROVIDED	STUDY OR ACTIVITY
ANNUAL PROBABILITY VOLCANIC ERUPTION THAT PENETRATES THE REPOSITORY	$< 10^{-6}$/YR	LOCATION AND TIMING OF VOLCANIC EVENTS	VOLCANISM DRILL-HOLES (8.3.1.8.5.1.1)
			GEOCHRONOLOGY (8.3.1.8.5.1.2)
			GEOCHEM. SCORIA SEQUENCES (8.3.1.8.5.1.4)
		EVALUATION OF STRUCTURAL CONTROLS ON VOLCANISM	LOCATION/TIMING VOLCANIC EVENTS (8.3.1.8.1.1.1)
			GEOCHEMICAL CYCLES IN BASALT FIELDS (8.3.1.8.5.1.5)
		PRESENCE OF MAGMA BODIES IN VICINITY OF SITE	SUBSURF. GEOMETRY QUATERNARY FAULTS (8.3.1.17.4.7)
			EVALUATION OF DEPTH OF CURIE TEMP.ISOTH. (8.3.1.8.5.2.1)
			HEAT FLOW (8.3.1.8.5.2.3)

SUMMARY

- STRATEGIES FOR MEETING THE PERFORMANCE AND DESIGN REQUIREMENTS WERE DEVELOPED AND USED AS A GUIDE FOR THE SITE CHARACTERIZATION PROGRAM

- AS PART OF IMPLEMENTING THE STRATEGIES, PERFORMANCE ALLOCATION WAS USED TO DETERMINE THE PERFORMANCE MEASURES, GOALS AND CONFIDENCE NEEDED FOR EACH REQUIREMENT

- EXPANSION OF THE PERFORMANCE MEASURES INTO A HIERARCHY OF PARAMETERS ALLOWED A LINK TO BE ESTABLISHED WITH THE SITE PARAMETERS NEEDED FOR PERFORMANCE ASSESSMENT CALCULATIONS

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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: PERFORMANCE ASSESSMENT OF YUCCA MOUNTAIN IN SUPPORT OF THE COMPARATIVE SITE ANALYSIS

PRESENTER: DR. PAUL GNIRK

PRESENTER'S TITLE AND ORGANIZATION: PRINCIPAL CONSULTANT
RE/SPEC INC.

PRESENTER'S TELEPHONE NUMBER: (505) 293-2000

MAY 16-17, 1989

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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: PERFORMANCE ASSESSMENT OF YUCCA MOUNTAIN IN SUPPORT OF THE COMPARATIVE SITE ANALYSIS

PRESENTER: DR. PAUL GNIRK

PRESENTER'S TITLE AND ORGANIZATION: PRINCIPAL CONSULTANT
RE/SPEC INC.

PRESENTER'S TELEPHONE NUMBER: (505) 293-2000

MAY 16-17, 1989

INTRODUCTION

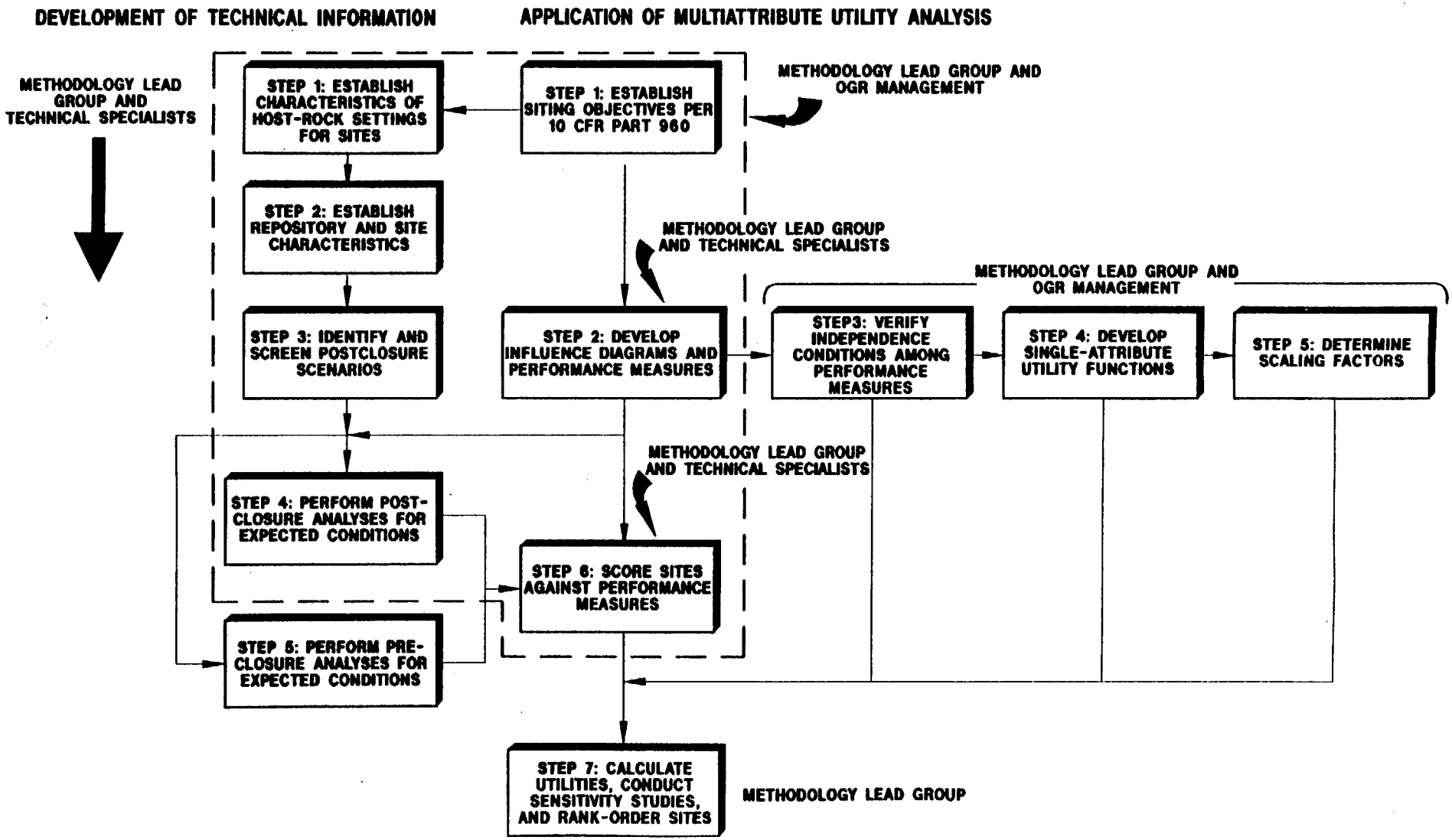
- FROM SEPT. 1985 - MAY 1986, DOE CONDUCTED A COMPARATIVE EVALUATION OF 5 REPOSITORY SITES BY MULTIATTRIBUTE UTILITY ANALYSIS (DECISION-AIDING METHODOLOGY)
- PURPOSE OF COMPARATIVE EVALUATION WAS TO AID DOE IN THE SELECTION OF THREE SITES FOR CHARACTERIZATION FOR DEVELOPMENT AS THE FIRST REPOSITORY
- AFTER REVIEWING THE APPLICATION OF THE DECISION-AIDING METHODOLOGY ON THREE SEPARATE OCCASIONS, THE NAS-BOARD OF RADIOACTIVE WASTE MANAGEMENT ENDORSED THE APPLICATION IN A LETTER FROM FRANK PARKER TO BEN RUSCHE IN APRIL 1986

INTRODUCTION

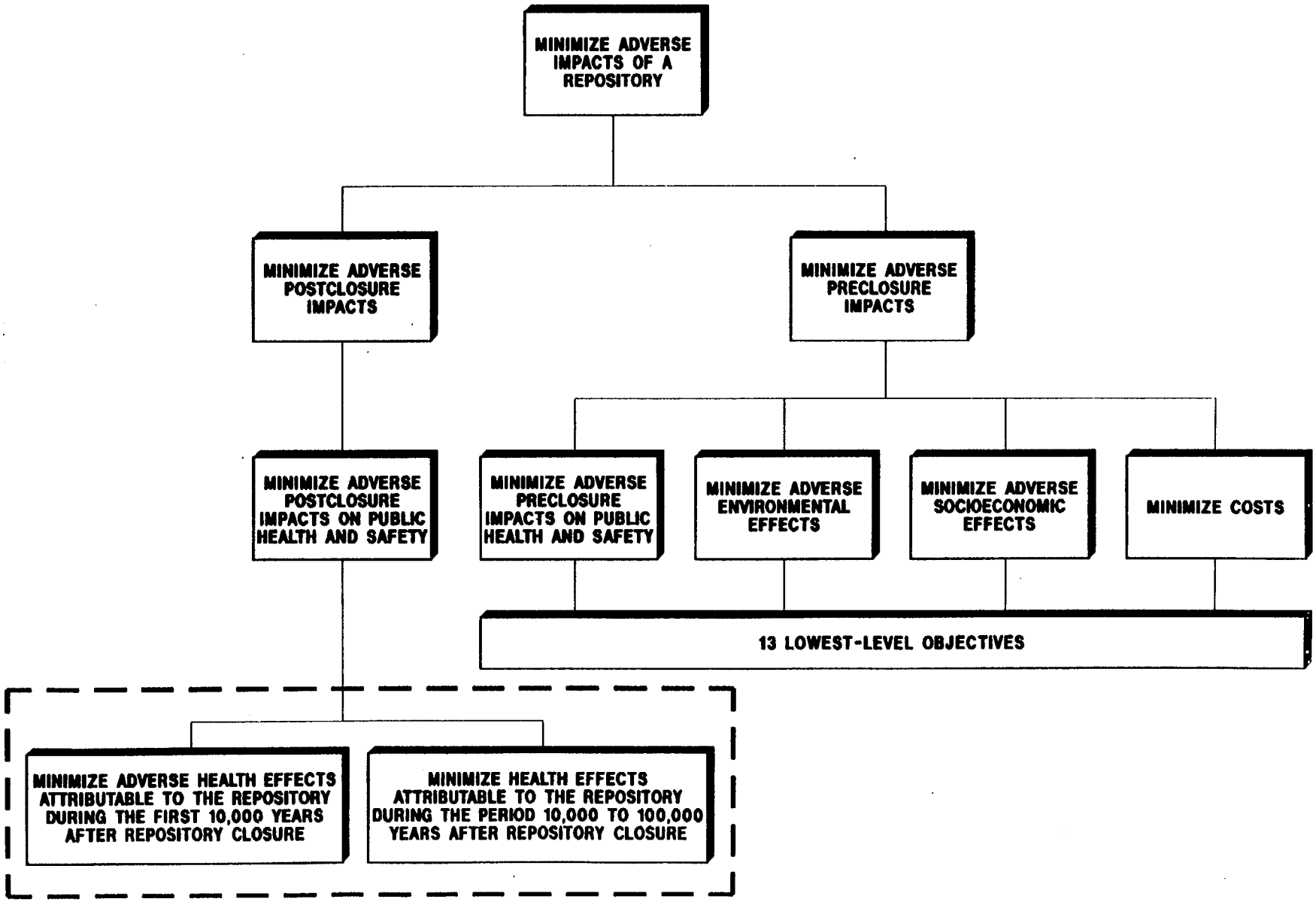
(CONTINUED)

- IN LATE MAY 1986, DOE SELECTED THREE SITES, INCLUDING THE YUCCA MOUNTAIN SITE, FOR DETAILED CHARACTERIZATION
- IN DECEMBER 1987, CONGRESSIONAL LEGISLATION DECREED THAT ONLY THE YUCCA MOUNTAIN SITE WOULD BE CHARACTERIZED
- THIS PRESENTATION WILL FOCUS ON THE POSTCLOSURE PERFORMANCE ASSESSMENT OF THE YUCCA MOUNTAIN SITE THAT WAS CONDUCTED IN SUPPORT OF THE DECISION METHODOLOGY APPLICATION, AND <u>NOT</u> ON THE COMPARATIVE EVALUATION ITSELF

GENERAL FLOW OF ACTIVITIES AND DIVISION OF RESPONSIBLITIES FOR IMPLEMENTATION OF COMPARATIVE SITE EVALUATION (DOE/RW-0074)



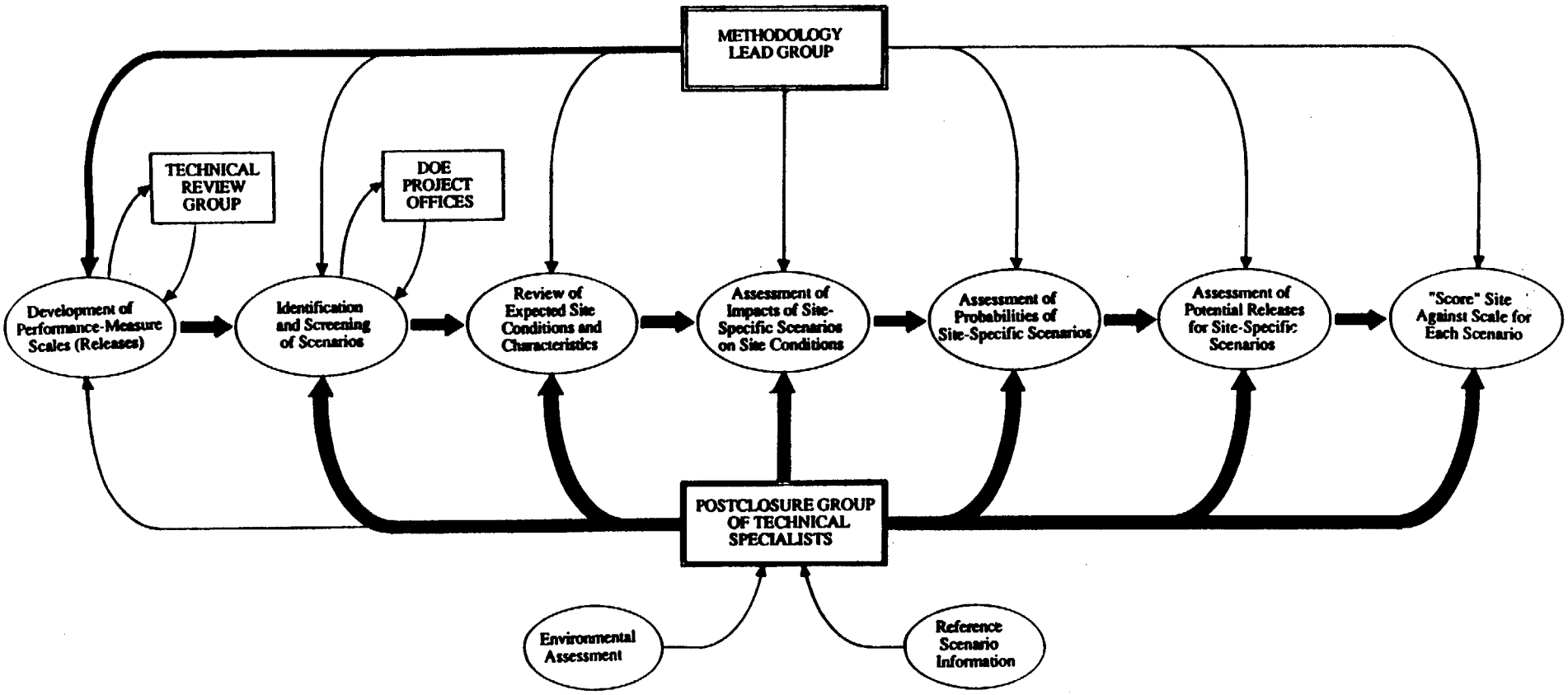
OBJECTIVES HIERARCHY FOR GEOLOGIC DISPOSAL (DOE/RW-0074)



RSI-150-89-050

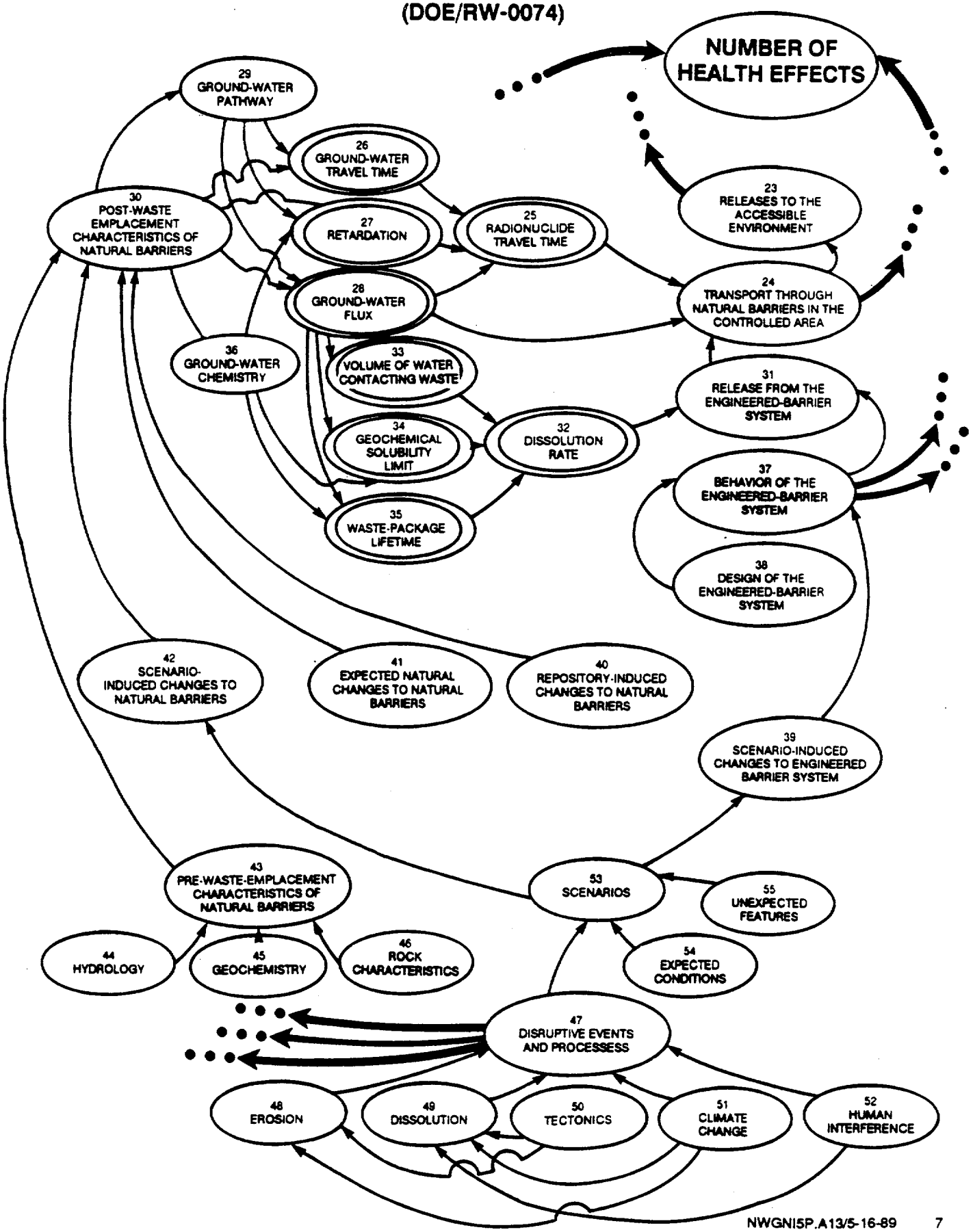
PROCESS FOR "SCORING" YUCCA MOUNTAIN SITE AGAINST POSTCLOSURE PERFORMANCE MEASURES

(DOE/RW-0074)



FACTORS THAT INFLUENCE NUMBER OF POSTCLOSURE HEALTH EFFECTS

(DOE/RW-0074)



POST-WASTE-EMPLACEMENT PERFORMANCE FACTORS FOR SITE

- RADIONUCLIDE RELEASE FROM ENGINEERED BARRIER SYSTEM
  - MEASURE OF AMOUNT OF RADIONUCLIDES DISSOLVED INTO GROUND WATER DURING A SPECIFIED TIME PERIOD, BASED ON GROUND-WATER FLOW AND GROUND-WATER CHEMISTRY
  - $$F = \sum \frac{QC_i}{RL_i}$$

    <u>WHERE:</u>

    Q = TOTAL VOLUME OF GROUND WATER CONTACTING WASTE (CUBIC METERS PER 1,000 MTHM)

    C_i = MAXIMUM CONCENTRATION OF EACH KEY RADIONUCLIDE BASED ON SOLUBILITY, INVENTORY, ETC. (CURIES PER 1,000 MTHM)

    RL_i = RELEASE LIMIT FOR EACH RADIONUCLIDE BASED ON TABLE 1 OF APPENDIX A OF 40 CFR PART 191 (CURIES PER 1,000 MTHM)

POST-WASTE-EMPLACEMENT PERFORMANCE FACTORS FOR SITE

(CONTINUED)

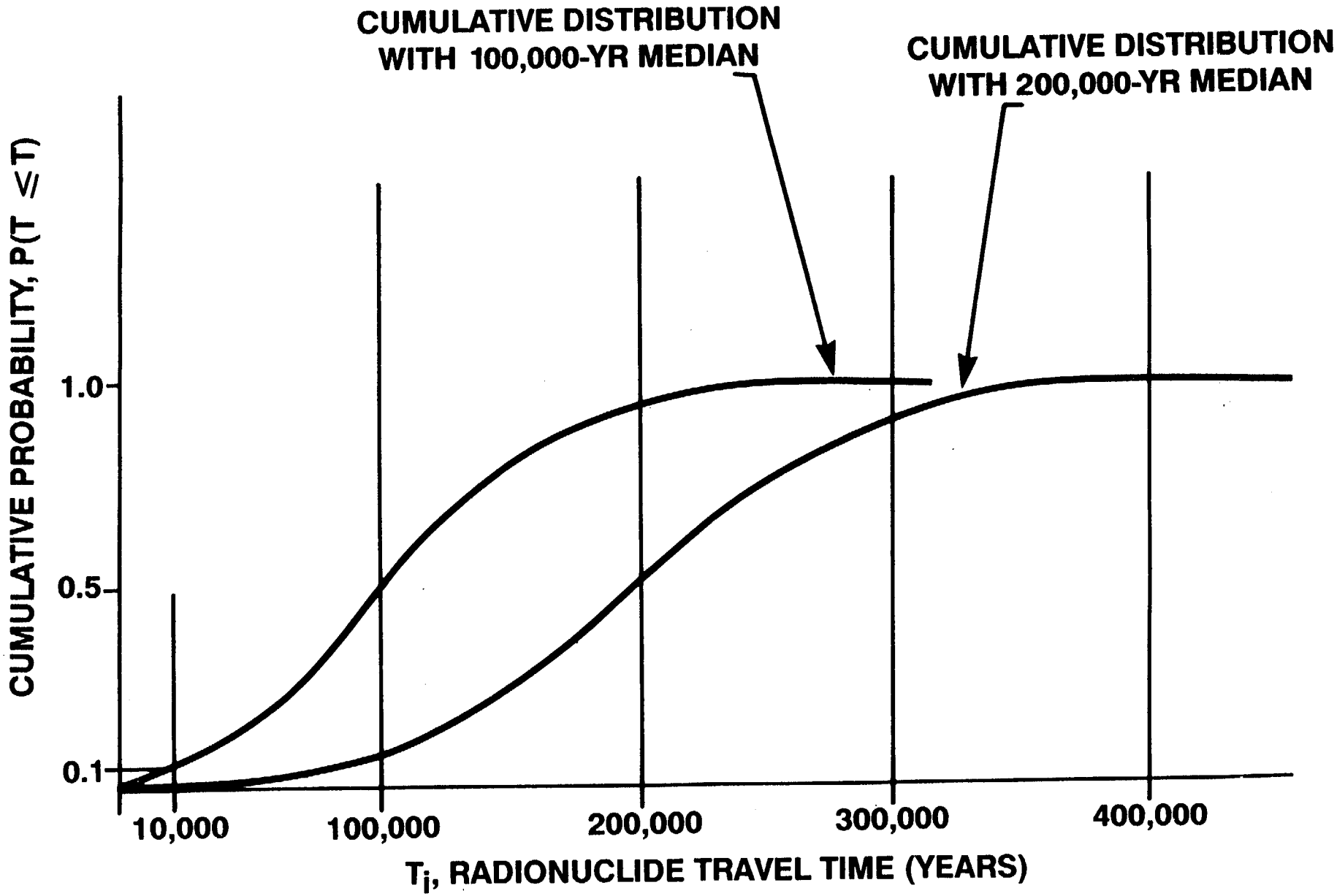
- RADIONUCLIDE TRANSPORT THROUGH NATURAL BARRIERS
  - MEASURE OF TRAVEL TIME OF KEY RADIONUCLIDES THROUGH NATURAL BARRIERS FROM ENGINEERED BARRIER SYSTEM TO ACCESSIBLE ENVIRONMENT, BASED ON CHEMICAL AND PHYSICAL RETARDATION CHARACTERISTICS OF ROCK AND GROUND-WATER TRAVEL TIME
  - $T_i = R_i T$

    <u>WHERE:</u>

    R_i = RETARDATION FACTOR FOR KEY RADIONUCLIDES (DIMENSIONLESS)

    T = GROUND-WATER TRAVEL FROM ENGINEERED BARRIER SYSTEM TO ACCESSIBLE ENVIRONMENT (YEARS)

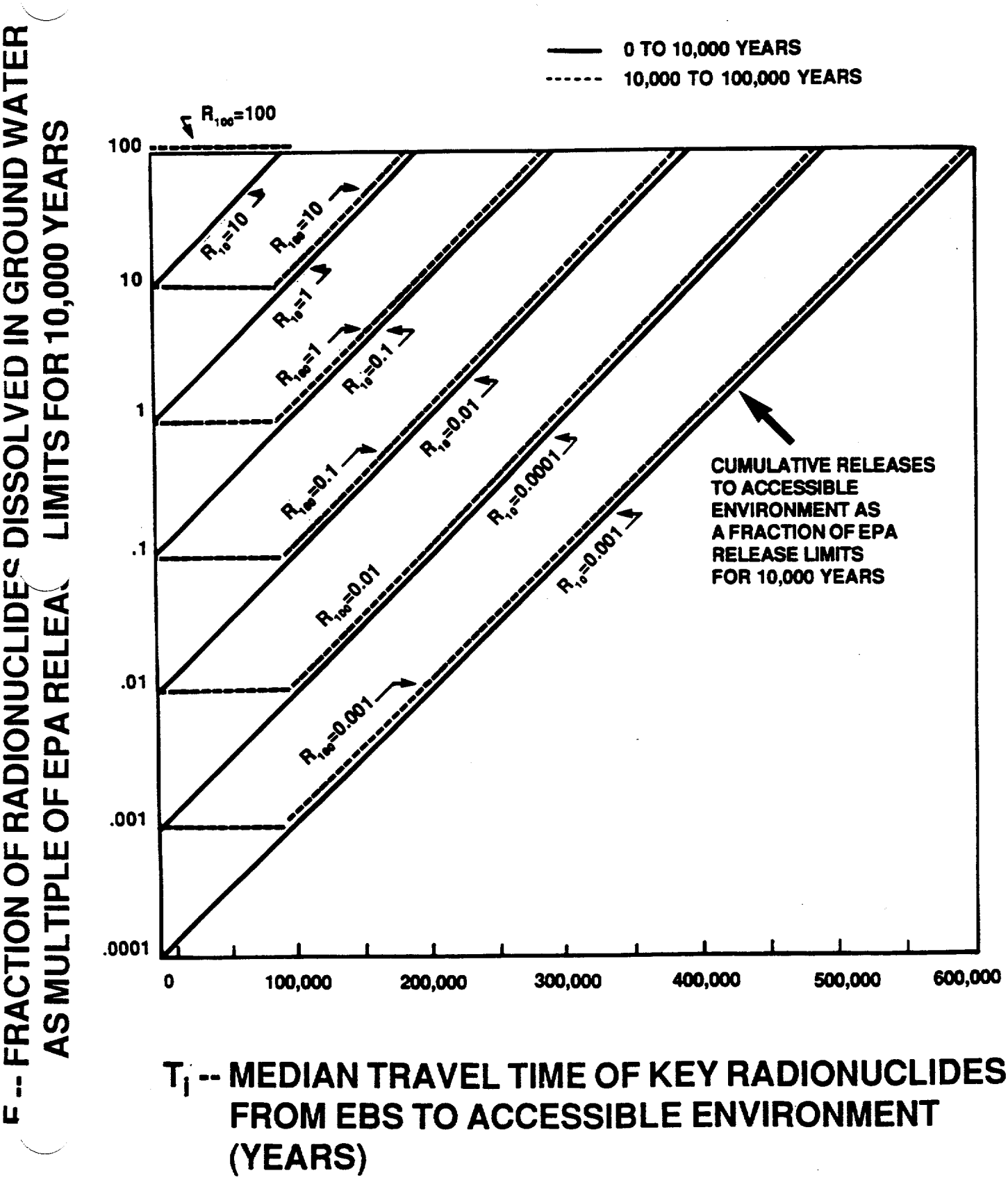
ILLUSTRATION OF RELATIONSHIP BETWEEN MEDIAN RADIONUCLIDE TRAVEL TIME AND FRACTION OF RELEASED RADIONUCLIDES REACHING ACCESSIBLE ENVIRONMENT



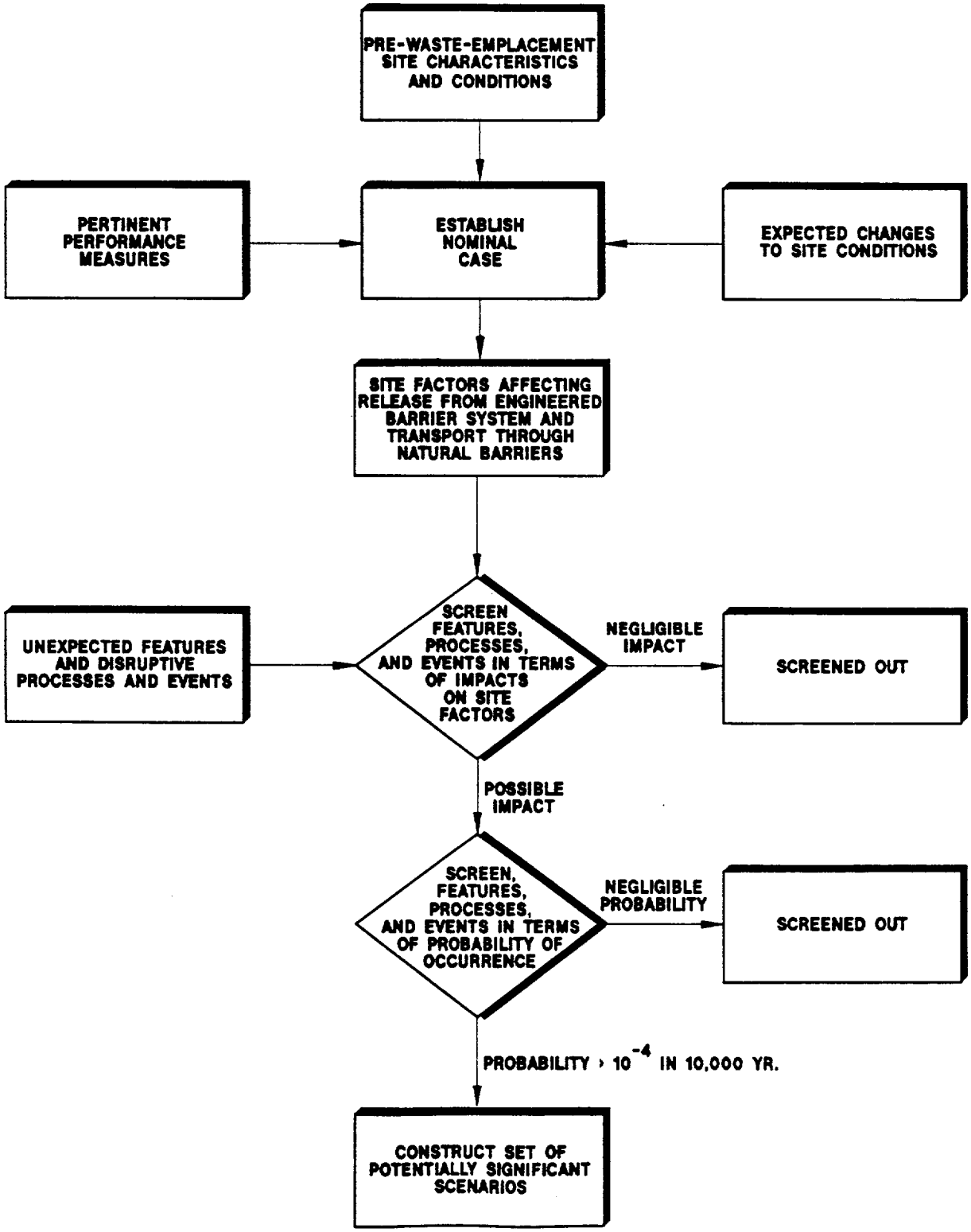
RELATIONSHIPS TO AID JUDGMENTAL ESTIMATION OF CUMULATIVE RELEASES TO THE ACCESSIBLE ENVIRONMENT DURING THE FIRST 10,000 YEARS AFTER REPOSITORY CLOSURE (DOE/RW-0074)

		EXAMPLE COMBINATION OF SITE CHARACTERISTICS						
		WASTE FORM DISSOLUTION			KEY RADIONUCLIDE TRAVEL TIME			ESTIMATED RELEASES
CUMULA-TIVE RELEASES	SCORE	VOLUMETRIC GW FLOW RATE	INHIBITING GEOCHEM-ISTRY	EST. % OF EPA RE-LEASE LIMITS	GW TRAVEL TIME	RETARDATION CAPABILITY	EST. TIME IN YEARS	
0.0001	10	EXTREMELY LOW	EXCELLENT	<1	EXTREMELY LONG	EXTREMELY FAVORABLE	200,000	INSIGNIFICANT
0.001	8	EXTREMELY LOW	VERY GOOD	~3	EXTREMELY LONG	EXTREMELY FAVORABLE	150,000	EXTREMELY SMALL
0.01	6	VERY LOW	GOOD	~10	VERY LONG	VERY FAVORABLE	100,000	VERY SMALL
0.1	4	LOW	GOOD	~30	LONG	FAVORABLE	50,000	SMALL
1	2	HIGH	POOR	~100	MODERATE	MODERATE	<10,000	SIGNIFICANT
10	0	EXTREMELY HIGH	VERY POOR	~1,000	SHORT	LITTLE	<3,000	EXTREMELY SIGNIFICANT

RELEASES TO THE ACCESSIBLE ENVIRONMENT (DOE/RW-0074)



GENERAL STEPS IN THE SCREENING AND DEVELOPMENT OF SCENARIOS (DOE/RW-0074)



PHENOMENA THAT ARE POTENTIALLY RELEVANT TO RELEASE SCENARIOS (DOE/RW-0074)

EXPECTED CONDITIONS

- BRINE-INCLUSION MIGRATION
- BUOYANCY AND CONVECTIVE CELLS
- CHANGES IN ROCK CHARACTERISTICS
- CLIMATE CHANGES
- CORROSION
- DIAGENESIS
- GEOCHEMICAL CHANGES
- GEOHYDROLOGY CHANGES
- LOCALIZED ROCK FRACTURING
- SEA-LEVEL CHANGES
- THERMAL EFFECTS
- THERMOMECHANICAL EFFECTS

UNEXPECTED FEATURES

- EXTREME CHANGES IN ROCK CHARACTERISTICS, GEO-HYDROLOGY, OR GEO-CHEMISTRY, INDUCED BY EXCAVATION OR HEAT GENERATED BY WASTE
- UNDETECTED FEATURES, SUCH AS FAULTS, SHEAR ZONES, BRECCIA PIPES, DIKES, GAS POCKETS, BOREHOLES

PHENOMENA THAT ARE POTENTIALLY RELEVANT TO RELEASE SCENARIOS (DOE/RW-0074)

(CONTINUED)

DISRUPTIVE PROCESSES AND EVENTS

- BRINE POCKETS
- DEPOSITION
- DIAPIRISM
- DISSOLUTION
- EPEIROGENY
- EROSION
- METEORITE IMPACT
- SEVERE-WEATHER PHENOMENA
- SURFACE-WATER CHANGES
- TECTONIC ACTIVITY
  - FAULTING
  - MAGMATIC ACTIVITY
- HUMAN INTERFERENCE
  - DRILLING
  - GROUND-WATER WITHDRAWAL
  - INJECTION
  - IRRIGATION
  - MILITARY ACTIVITIES
  - MINING
  - RECHARGE
  - UNDERGROUND STORAGE
- PREMATURE FAILURE OF WASTE PACKAGES
- INCOMPLETE SEALING OF THE SHAFTS AND THE REPOSITORY

POSTCLOSURE SCENARIOS FOR THE YUCCA MOUNTAIN SITE (DOE/RW-0074)

SCENARIO	PROBABILITY (in 10,000 yrs)	EXPECTED CONSEQUENCES
EXPECTED CONDITIONS	0.8 TO 1	TBD
UNEXPECTED FEATURES	10^{-10} TO 0.2	TBD
EXTRUSIVE MAGMATIC EVENT DURING FIRST 500 YEARS	10^{-10} TO 10^{-6}	TBD
EXTRUSIVE MAGMATIC EVENT AFTER FIRST 500 YEARS	10^{-10} TO 10^{-4}	TBD
REPOSITORY-INDUCED DISSOLUTION OF HOST ROCK	NOT CREDIBLE	–
ADVANCE OF A DISSOLUTION FRONT	NOT CREDIBLE	–
LARGE FAULT MOVEMENT INSIDE CONTROLLED AREA BUT OUTSIDE REPOSITORY	–	NOT SIGNIFICANT
LARGE-FAULT MOVEMENT WITHIN REPOSITORY	NOT CREDIBLE	–
SMALL-FAULT MOVEMENT INSIDE CONTROLLED AREA BUT OUTSIDE REPOSITORY	–	NOT SIGNIFICANT
SMALL-FAULT MOVEMENT WITHIN REPOSITORY	–	NOT SIGNIFICANT
LARGE-FAULT MOVEMENT OUTSIDE CONTROLLED AREA	–	NOT SIGNIFICANT
INTRUSIVE MAGMATIC EVENT	NOT CREDIBLE	–
LARGE-SCALE EXPLORATORY DRILLING	$<<10^{-4}$	–
SMALL-SCALE EXPLORATORY DRILLING	–	NOT SIGNIFICANT
FAILURE OF SHAFT AND REPOSITORY SEALS	–	NOT SIGNIFICANT

SOLUBILITY FACTORS FOR SPENT FUEL IN THE SUBSURFACE ENVIRONMENT AT THE YUCCA MOUNTAIN SITE (DOE/RW-0074)

RADIONUCLIDE	SOLUBILITY LIMIT (PPM)
C-14, Tc-99, I-129 Cs-135	LARGE
Np-237, Sr-90 WASTEFORM (UO_2) Ra-226	MODERATE TO SMALL (<1,000 TO 1)
Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Am-241, Am-242, Am-243, Sn-126	VERY SMALL (<1)

TIME PERIOD (YEARS)	FRACTIONAL RELEASE (PER m^3 OF gw PER 1,000 MTHM
0 TO 1,000	5.3×10^{-4}
1,000 TO 10,000	2.2×10^{-4}
10,000 TO 100,000	9.4×10^{-6}

SITE CHARACTERISTICS AND PERFORMANCE FACTORS FOR EXPECTED CONDITIONS AT YUCCA MOUNTAIN (DOE/RW-0074)

PARAMETER	RANGE OF PARAMETER VALUES	
	0 TO 10,000 YEARS	10,000 TO 100,000 YEARS
Q - VOLUME OF WATER AVAILABLE FOR DISSOLUTION OF WASTE (m^3/1,000 MTHM)	0 TO 44,000	0 TO 400,000
$\sum \frac{C_i}{RL_i}$ (1,000 MTHM/m^3)	2.2×10^{-8} TO 2.2×10^{-4}	9.4×10^{-10} TO 9.4×10^{-6}
F - RADIONUCLIDE RELEASE FROM ENGINEERED BARRIER SYSTEM*	0.001 TO 9.7	0.0001 TO 3.8
T - MEDIAN GROUND-WATER TRAVEL TIME (YEARS)	42,000 TO 200,000	42,000 TO 200,000
R - RETARDATION FACTOR	100 TO 1,000	100 TO 1,000
T_i - MEDIAN RADIONUCLIDE TRAVEL TIME (YEARS)	4.3×10^6 TO 2×10^8	> 4.3×10^6
WASTE PACKAGE LIFETIME (YEARS)	3,000 TO 30,000	

* MULTIPLE OF EPA RELEASE LIMITS FOR 10,000 YEARS

ESTIMATED RADIONUCLIDE RELEASES TO ACCESSIBLE ENVIRONMENT FROM YUCCA MOUNTAIN REPOSITORY (DOE/RW-0074)

SCENARIO	JUDGEMENT	PROBABILITY	RADIONUCLIDE RELEASES *	
			0 TO 10,000 YEARS	10,000 TO 100,000 YEARS
EXPECTED CONDITIONS	HIGH BEST JUDGEMENT LOW	~1 0.98 0.80	0.0001 0.0001 0.032	0.001 0.0032 0.32
EXPECTED FEATURES	HIGH BEST JUDGEMENT LOW	10^{-10} 0.019 0.20	0.0001 0.001 1	0.001 0.01 10
EXTRUSIVE MAGMATIC EVENT DURING FIRST 500 YEARS	HIGH BEST JUDGEMENT LOW	10^{-10} $5X10^{-8}$ $5X10^{-6}$	0.0032 1 10	0.0032 0.032 3.2
EXTRUSIVE MAGMATIC EVENT AFTER FIRST 500 YEARS	HIGH BEST JUDGEMENT LOW	10^{-10} 10^{-6} 10^{-4}	0.0032 0.32 10	0.001 0.032 10

* MULTIPLE OF EPA RELEASE LIMITS FOR 10,000 YEARS

SUMMARY OF ESTIMATED RADIONUCLIDE RELEASES TO ACCESSIBLE ENVIRONMENT FROM REPOSITORY AT THE YUCCA MOUNTAIN SITE

REFERENCE	SITE CONDITIONS	FRACTIONAL RELEASE RATE FROM EBS (PER YEAR)	RADIONUCLIDE RELEASES *	
			0 TO 10,000 YEARS	0 TO 100,000 YEARS
MULTIATTRIBUTE UTILITY ANALYSIS OF NOMINATED SITES (DOE/RW-0074)	EXPECTED CONDITIONS HIGH BEST JUDGEMENT LOW	10^{-10} TO 10^{-3}	 10^{-4} 10^{-4} 0.032	 $1.1X10^{-3}$ $3.3X10^{-5}$ 0.35
	ALL SCENARIOS (RELEASES WEIGHTED BY PROBABILITIES) HIGH BEST JUDGEMENT LOW	10^{-10} TO 10^{-3}	 10^{-4} $1.2X10^{-4}$ 0.23	 $1.1X10^{-3}$ $3.4X10^{-3}$ 0.35
ENVIRONMENTAL ASSESSMENT FOR YUCCA MOUNTAIN SITE (DOE/RW-0073)	REFERENCE CASE (EXPECTED CONDITIONS WITH UPPER BOUND FLUX OF $5X10^{-4}$ M^3/M^2-yr)	$2.5X10^{-9}$	$<10^{-7}$	$1.4X10^{-3}$
	PERFORMANCE-LIMITS CASE (EXPECTED CONDITIONS, BUT WITH SHORT WASTE-PACKAGE LIFETIME AND HIGH RELEASE RATES CONSIDERED NOT REALISTIC)	10^{-6} 10^{-5} 10^{-4}	$<2X10^{-6}$ $<2X10^{-5}$ $<2X10^{-4}$	$2.7X10^{-3}$ $2.7X10^{-2}$ 0.23

* MULTIPLE OF EPA RELEASE LIMITS FOR 10,000 YEARS

CONCLUSIONS

- ORDERLY AND DOCUMENTED PROCESS, USING A GROUP OF TECHNICAL SPECIALISTS, WAS ORGANIZED AND IMPLEMENTED TO:
  - IDENTIFY AND SCREEN DISRUPTIVE SCENARIOS ON BASIS OF EXPECTED IMPACT AND PROBABILITY OF OCCURRENCE
  - ESTIMATE RADIONUCLIDE RELEASES TO THE ACCESSIBLE ENVIRONMENT ON BASIS OF SITE CHARACTERISTICS (PERFORMANCE FACTORS)

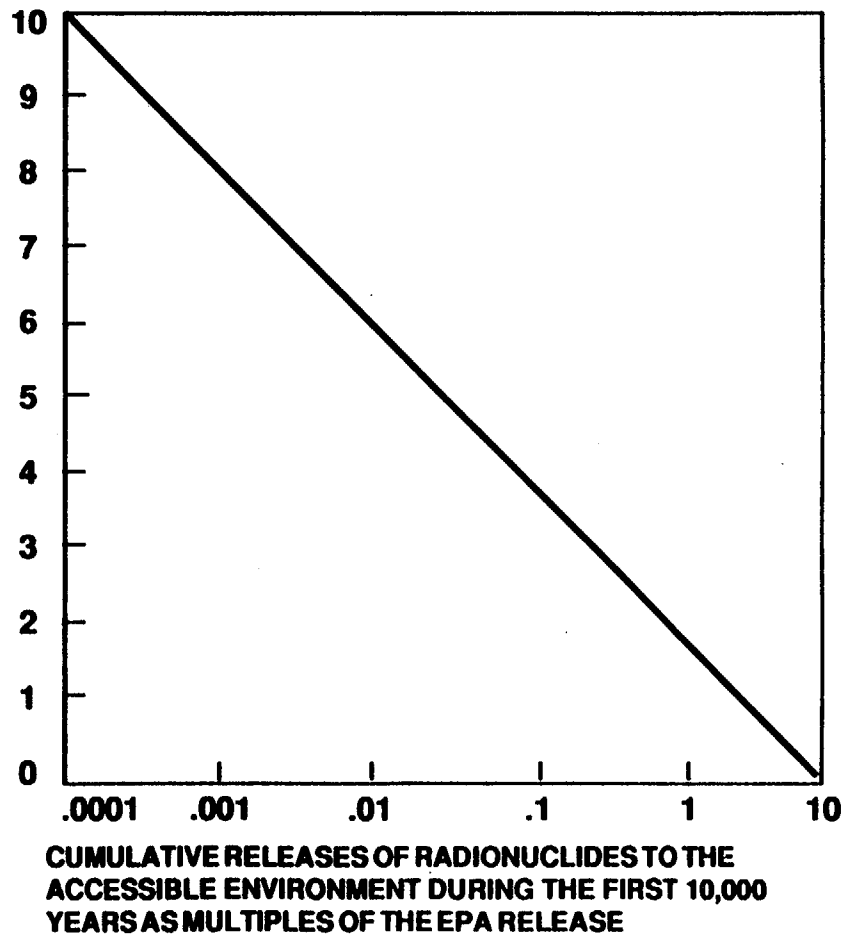
- RESULTS OF THE PROCESS INDICATED THAT:
  - THE RELEASES ARE PROJECTED TO BE VERY SMALL AND WELL WITHIN THE EPA LIMITS FOR 10,000 YEARS
  - THE SCENARIO OF "UNEXPECTED FEATURES" WAS FOUND TO HAVE THE HIGHEST PROBABILITY OF OCCURRENCE AMONG THE SET OF SCENARIOS CONSIDERED DISRUPTIVE
  - THE RELEASES BOUNDED THOSE REPORTED IN THE ENVIRONMENTAL ASSESSMENT FOR THE YUCCA MOUNTAIN SITE

APPENDIX

CORRESPONDENCE BETWEEN THE SITE SCORING SCALE AND THE PERFORMANCE MEASURE FOR THE 10,000-YEAR POST CLOSURE SITING OBJECTIVE (DOE/RW-0074)

OBJECTIVE:
MINIMIZE THE TOTAL NUMBER OF HEALTH EFFECTS ATTRIBUTABLE TO THE REPOSITORY DURING THE FIRST 10,000 YEARS AFTER CLOSURE

PERFORMANCE MEASURE:
CUMULATIVE RELEASES OF RADIONUCLIDES TO THE ACCESSIBLE ENVIRONMENT



SITE SCORING SCALE

SITE CONDITIONS AND CHARACTERISTICS AFFECTING REPOSITORY-PERFORMANCE FACTORS (DOE/RW-0074)

CONDITIONS AFFECTING WASTE-PACKAGE LIFETIME

- THERMAL CONDITIONS
- MECHANICAL CONDITIONS (THERMOMECHANICAL STRESSES, GROUND MOVEMENT)
- VOLUME OF, AND REPLACEMENT RATE FOR, FLUIDS NEAR WASTE PACKAGE
- CORROSION RATE

LOCAL FLUID CONDITIONS AFFECTING THE RATE OF RELEASE FROM THE ENGINEERED-BARRIER SYSTEM

- GROUND-WATER FLUX THROUGH THE HOST ROCK OR SEEPAGE INTO REPOSITORY
- NUMBER OF PACKAGES EXPOSED TO WATER

LOCAL CHEMICAL CONDITIONS AFFECTING THE RATE OF RELEASE FROM THE ENGINEERED-BARRIER SYSTEM

- RADIONUCLIDE SOLUBILITY
- WASTE-FORM DISSOLUTION RATE
- THERMAL EFFECTS ON LEACH RATES AND LOCAL CHEMICAL CONDITIONS

PARTICIPANTS IN POSTCLOSURE PERFORMANCE ASSESSMENT FOR COMPARATIVE SITE EVALUATION (DOE/RW-0074)

METHODOLOGY LEAD GROUP

GEOLOGIC DISPOSAL	DECISION ANALYSIS
TOM LONGO* (DOE-OGR) PAUL GNIRK (RE/SPEC) 21 YEARS OF COMBINED EXPERIENCE IN GEOLOGIC DISPOSAL OF RADIOACTIVE WASTES	LEE MERKHOFER (APPLIED DECISION ANALYSIS) RALPH KEENEY** (UNIV. SOUTHERN CALIFORNIA) 29 YEARS OF COMBINED EXPERIENCE IN DECISION ANALYSIS AND RISK ASSESSMENT

* MLG LEAD

** JAN. - APRIL 1986

AD HOC TECHNICAL ADVISORY GROUP

FELTON BINGHAM (SANDIAL NATIONAL LABORATORY)	BUDI SAGAR (ROCKWELL-HERFORD OPS.)
JAMES CAMPBELL (INTERA TECH.)	WENDALL WEART (SANDIAL NATIONAL LABORATORY)

31 YEARS OF COMBINED EXPERIENCE IN GEOLOGIC DISPOSAL OF RADIOACTIVE WASTES, INCLUDING PERFORMANCE ASSESSMENT

POST CLOSURE TECHNICAL SPECIALISTS

ALLEN JELACIC*** (DOE-OGR)	JEFF KIMBALL (WESTON)
JAY RHODERICK (DOE-OGR)	SAM PANNO (WESTON)
GLEN FAULKNER (USGS–DOE–OGR)	MARTHA PENDLETON (WESTON)
KENNETH CZYSCINSKI (WESTON)	LARRY RICKERTSEN (WESTON)
WILLIAM HEWITT (WESTON)	DAVID SIEFKEN (WESTON)
ROBERT JACKSON (WESTON)	ROBERT JACKSON (WESTON)

62 YEARS OF COMBINED EXPERIENCE IN GEOLOGIC DISPOSAL OF RADIOACTIVE WASTES, PLUS 26 YEARS OF COMBINED EXPERIENCE IN GEOLOGY, GEOPHYSICS, HYDROLOGY, GEOCHEMISTRY, GEOTECHNICAL ENGINEERING, SAFETY ASSESSMENT, AND NUMERICAL MODELING

*** LEAD

SITE CONDITIONS AND CHARACTERISTICS AFFECTING REPOSITORY-PERFORMANCE FACTORS (DOE/RW-0074)

CONDITIONS AFFECTING GROUND-WATER MOVEMENT TO ACCESSIBLE ENVIRONMENT

- ROCK CHARACTERISTICS THAT DETERMINE GROUND-WATER PATHWAYS
- HYDRAULIC PROPERTIES
- HEAD GRADIENTS
- UNSATURATED FLOW CHARACTERISTICS
- CONSTRAINTS DUE TO REGIONAL FLOW CONDITIONS

CONDITIONS AFFECTING RETARDATION

- SORPTION
- PRECIPITATION
- PHYSICAL RETARDATION
- DISPERSION

OTHER CONDITIONS AFFECTING RADIONUCLIDE-TRAVEL TIME

- DIFFUSION TRANSPORT
- TRANSPORT OF GASES

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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: POTENTIAL IMPACTS OF EXPLORATORY-SHAFT FACILITY (ESF) ON WASTE ISOLATION

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

SCOPE OF PRESENTATION
(TWO EXAMPLE ANALYSES)

1. THE REASON THE COMPLETE SET OF ANALYSES WAS DONE:

   TO ANSWER NRC STAFF CONCERNS ABOUT THE EXPLORATORY-SHAFT FACILITY (ESF)

2. EXAMPLE 1: MOVEMENT OF WATER USED IN CONSTRUCTING SHAFTS

3. EXAMPLE 2: FLOODING OF SHAFTS

4. CONCLUSIONS OF COMPLETE STUDY

SCOPE OF ANALYSIS OF EFFECTS ON WASTE ISOLATION

THE NRC STAFF REQUESTED STUDIES OF HOW THE ESF MIGHT AFFECT THE SITE (LATE 1987)

- THE ESF WILL EVENTUALLY BECOME PART OF THE REPOSITORY
- NO WASTE WILL BE EMPLACED IN THE ESF

ANALYSES EXAMINE HOW ESF COULD AFFECT WASTE ISOLATION

ANALYSES EXAMINE CHANGES INDUCED BY ESF

EVALUATIONS ARE BASED ON THESE CHANGES BECAUSE CONSTRUCTION OF FULL CCDF, WITH AND WITHOUT ESF, IS IMPRACTICAL

EVALUATIONS OF CHANGES INDUCED BY ESF CONSTRUCTION AND TESTING

- COMPILATION OF DATA:

  - LOCATIONS
  - AMOUNTS OF FLUIDS AND MATERIALS TO BE INTRODUCED

- ESTIMATIONS OF EFFECTS ON SITE CONDITIONS:

  - HYDROLOGIC
  - GEOCHEMICAL
  - MECHANICAL

- ANALYSES DETERMINE PERSISTENCE OF EFFECTS

  - TRANSIENT (INSIGNIFICANT AFTER CLOSURE)
  - PERMANENT (PERSISTING INTO ISOLATION PERIOD)

- SUMMARIES OF DATA ANALYSES: SCP SECTION 8.4.3.2

- THIS PRESENTATION REPORTS TWO EXAMPLES OF HYDROLOGIC ANALYSES

EXAMPLE 1:

WHAT HAPPENS TO THE WATER USED TO CONSTRUCT AN EXPLORATORY SHAFT?

CALCULATIONAL APPROACH FOR ESTIMATES OF MOVEMENT OF RETAINED CONSTRUCTION WATER

- INITIAL ANALYTIC SOLUTION SHOWED ONLY SMALL CHANGES IN SATURATION

- RADIAL MOVEMENT CALCULATED WITH NORIA COMPUTER CODE

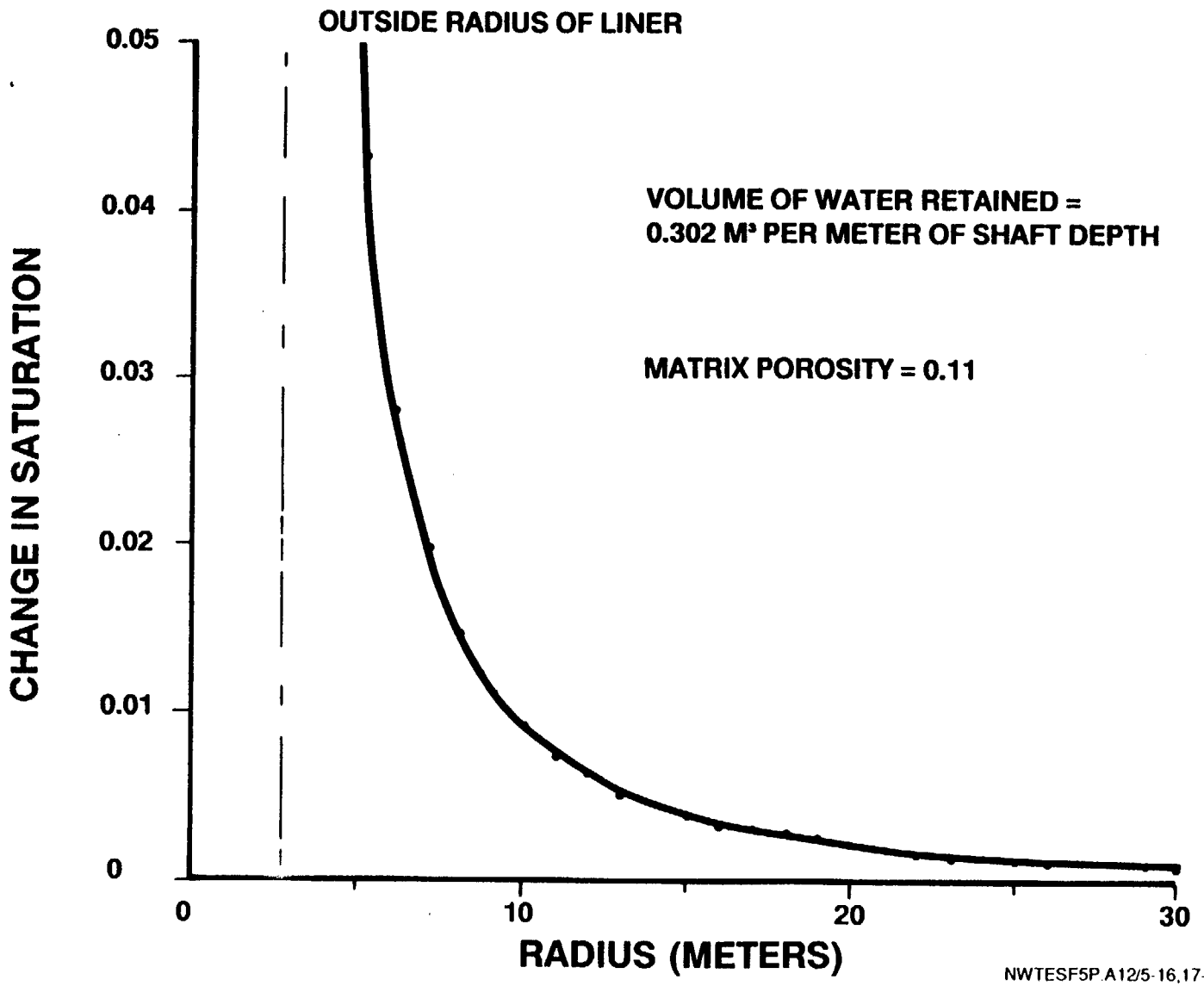
  - FINITE-ELEMENT CODE TO ANALYZE WATER, VAPOR, AIR, AND ENERGY TRANSPORT IN POROUS MEDIUM
  - USES COMPLEX DESCRIPTION OF HYDROLOGIC PROPERTIES

- RETAINED WATER INITIALLY CONTAINED IN MODIFIED-PERMEABILITY ZONE (MPZ)

- MATRIX PERMEABILITY INCREASED TO 80 TIMES NOMINAL IN MPZ

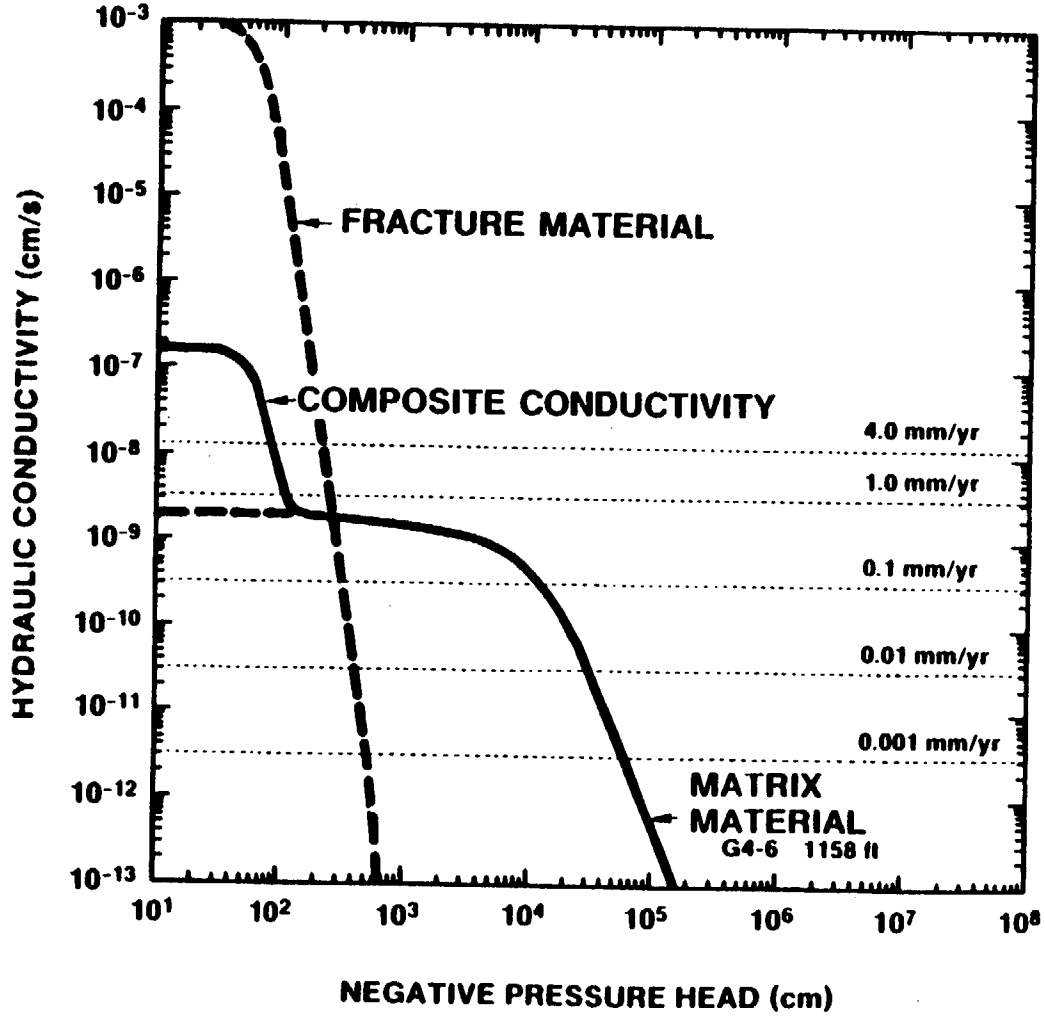
  - FROM CONSERVATIVE ANALYTICAL MODEL
  - TENDS TO OVERESTIMATE MOVEMENT OF WATER

CHANGE IN SATURATION OF ROCK AROUND EXPLORATORY SHAFT

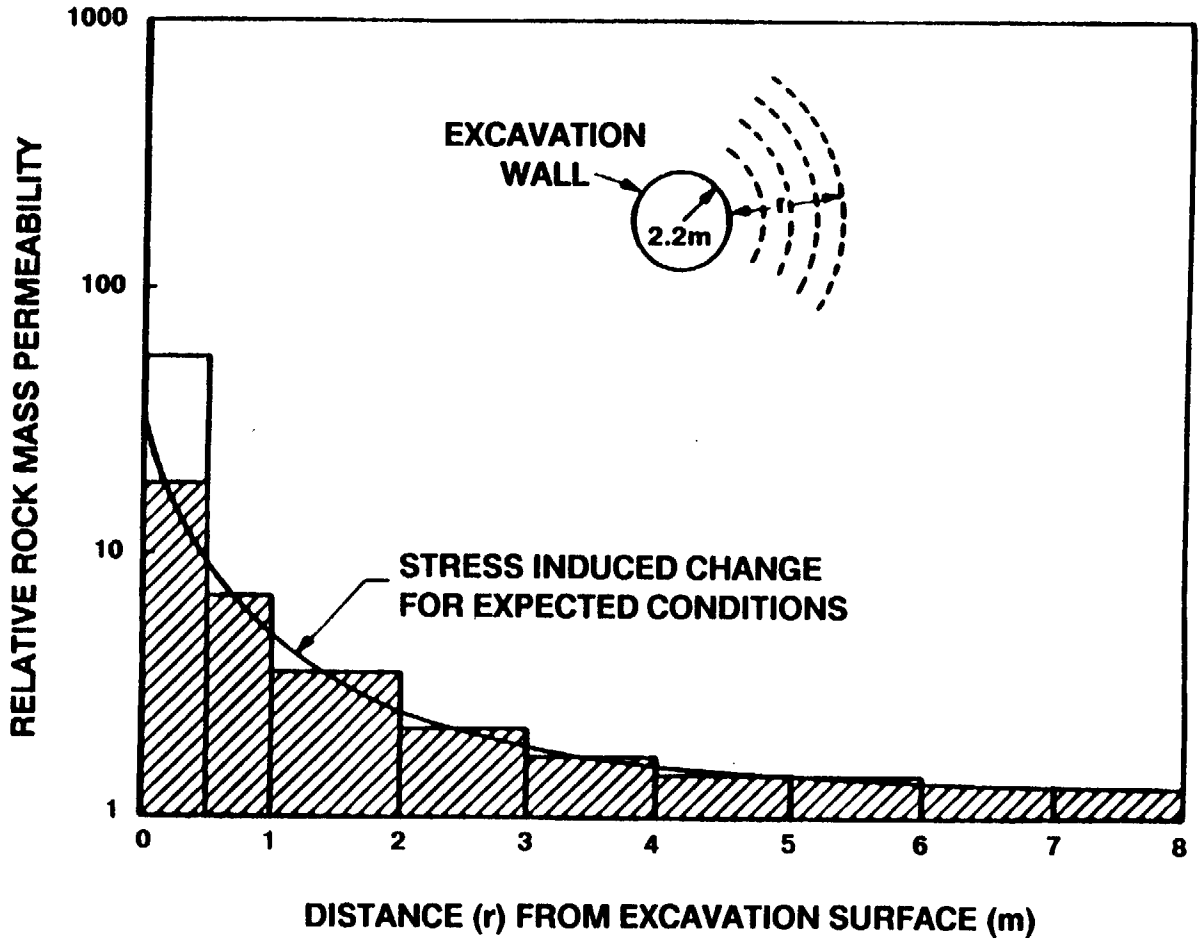


NWTESF5P.A12/5-16,17-89

COMPOSITE HYDRAULIC CONDUCTIVITY FOR TOPOPAH SPRING WELDED UNIT (REPOSITORY ZONE)



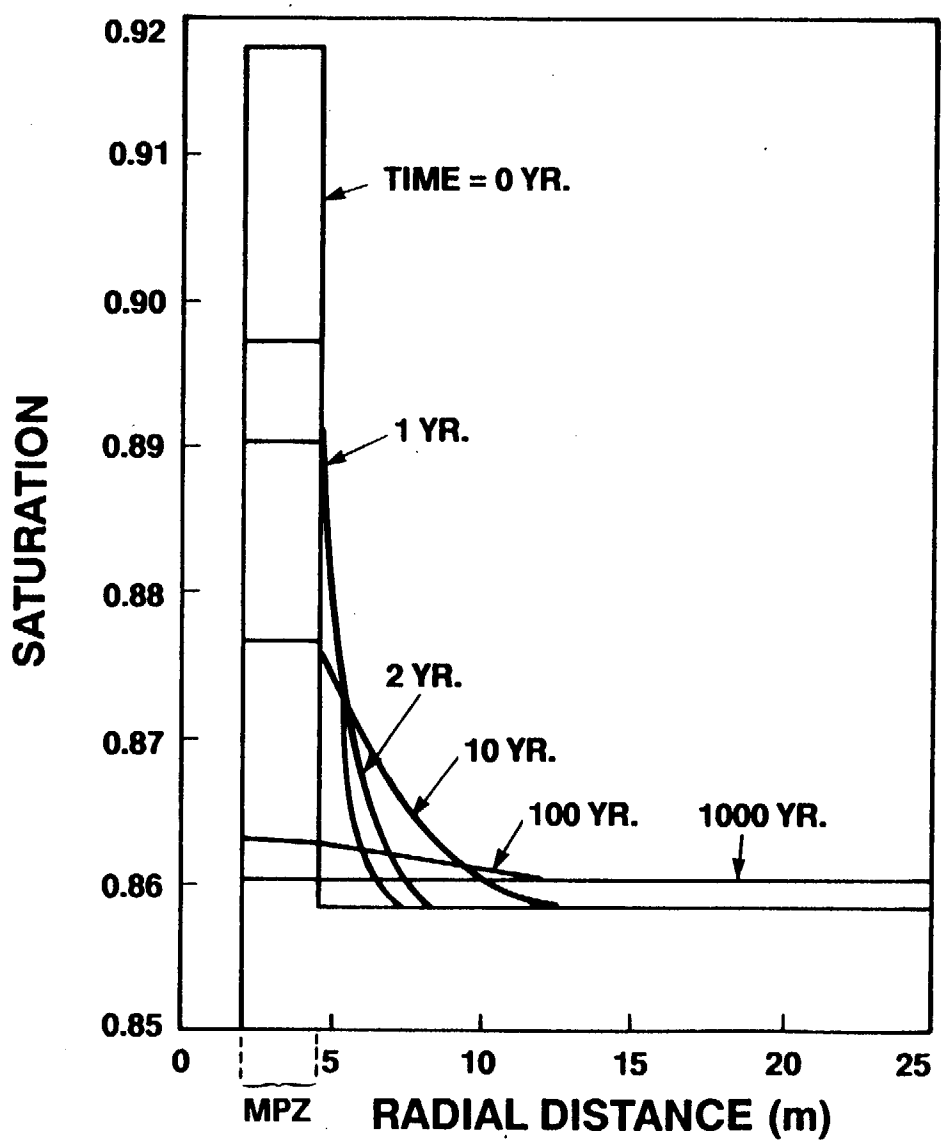
MODIFIED-PERMEABILITY ZONE
(FOR EXPECTED CONDITIONS AT 310-M DEPTH)



LEGEND

- PRELIMINARY ESTIMATE BLAST INDUCED DAMAGE
- STRESS INDUCED CHANGE IN PERMEABILITY

SATURATION CHANGE WITH TIME AT REPOSITORY HORIZON



RESULTS OF NORIA CALCULATIONS

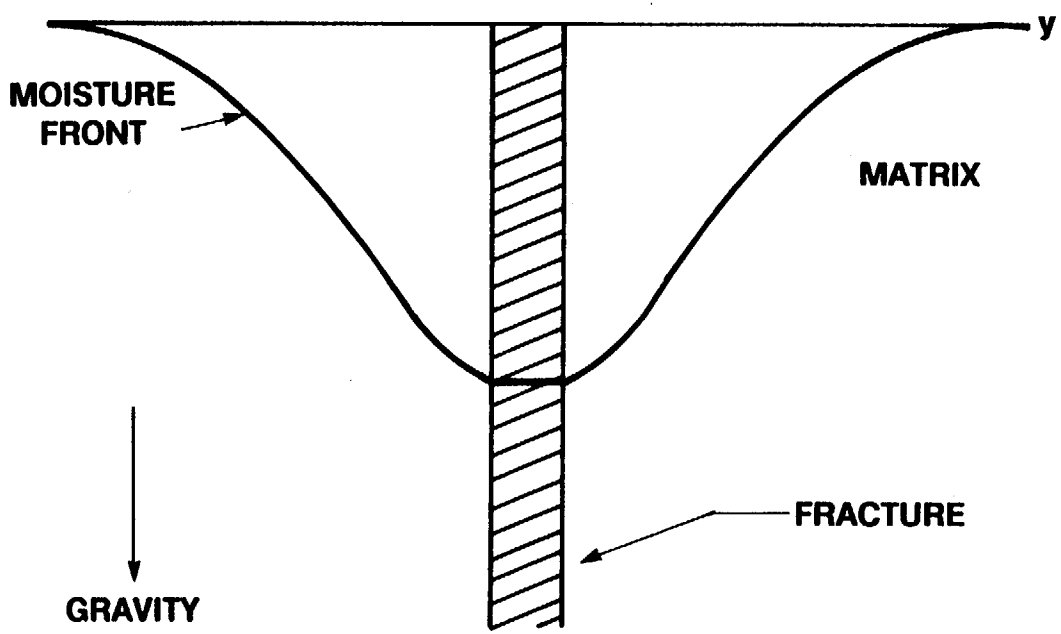
- WATER MOVES RELATIVELY SLOWLY FROM MPZ INTO ROCK
- SATURATION INCREASES AT RADIAL DISTANCES GREATER THAN 5 m FROM SHAFT WALL WERE LESS THAN 0.03
- AT 10 YEARS WATER MOVED ABOUT 10 m FROM SHAFT WALL

CALCULATIONAL APPROACH TO ESTIMATE PENETRATION DISTANCES IN FRACTURES

REFERENCE: "CAPILLARY-DRIVEN FLOW IN A FRACTURE LOCATED IN A POROUS MEDIUM," BY M. J. MARTINEZ, SAND84-1697, 1988

- MODEL INCORPORATES CAPILLARY-DRIVEN IMMISCIBLE DISPLACEMENT OF AIR BY WATER IN A SINGLE FRACTURE
- ANALYSES ASSUME EITHER PERMEABLE MATRIX OR IMPERMEABLE MATRIX SURROUNDING THE FRACTURE
- DATA CONSIDERED REPRESENTATIVE OF CURRENT ESTIMATES OF YUCCA MOUNTAIN HYDROLOGIC PROPERTIES

SCHEMATIC OF FRACTURE-ANALYSIS MODEL



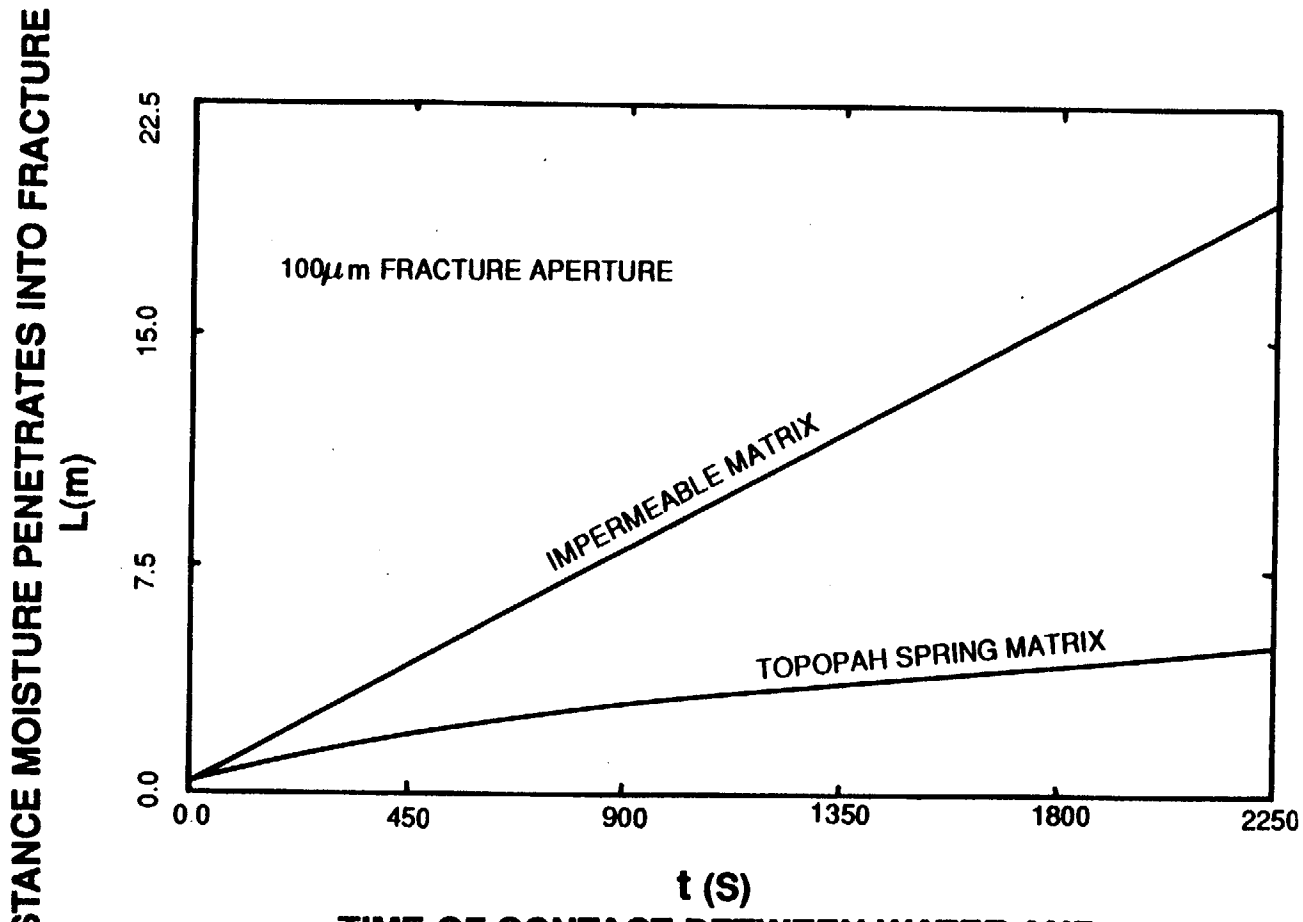
ANALYSIS RESULTS

- FRACTURE-PENETRATION DISTANCES DEPEND ON THE SQUARE ROOT OF THE RATIO OF MATRIX PERMEABILITY AND FRACTURE PERMEABILITY

- FOR TOPOPAH SPRING (THE REPOSITORY HORIZON) HYDROLOGIC PROPERTIES:

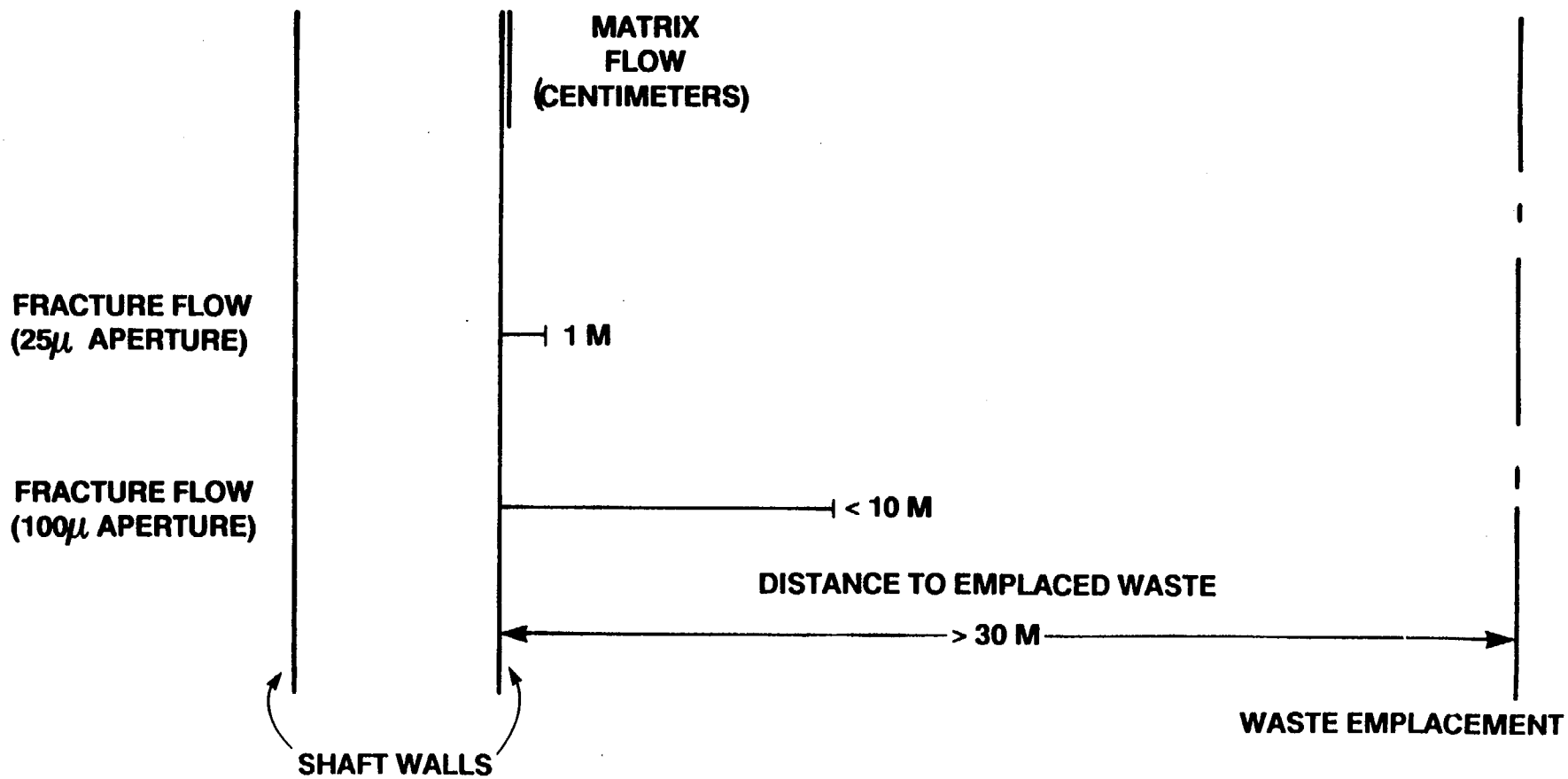
  - FRACTURE APERTURE IS 25 μm → PENETRATION DISTANCE <1 m [FOR 30 MIN OF WATER INFILTRATION]
  - FRACTURE APERTURE IS 100 μm → PENETRATION DISTANCE <10 m
  - FRACTURE APERTURES IN THE UNIT ARE GENERALLY MUCH LESS THAN 100 μm

- OTHER STUDIES GIVE SIMILAR RESULTS



TIME OF CONTACT BETWEEN WATER AND FRACTURE OPENING

SCHEMATIC SHOWING PENETRATION DISTANCES FOR MATRIX AND FRACTURE FLOWS AT REPOSITORY HORIZON RELATIVE TO DISTANCE FROM EMPLACED WASTE



EFFECTS ON HYDROLOGIC CONDITIONS

(CONTINUED)

CONCLUSION: CHANGES ARE TRANSIENT AND LIMITED TO ABOUT 10 METERS FROM ESF

WATER WILL THEREFORE NOT REACH WASTE AND TRANSPORT RADIONUCLIDES

FURTHER ACTION: CONTROL WATER USE: LOW PRESSURES, SMALL VOLUMES, TAGGED WATER

EXAMPLE 2:

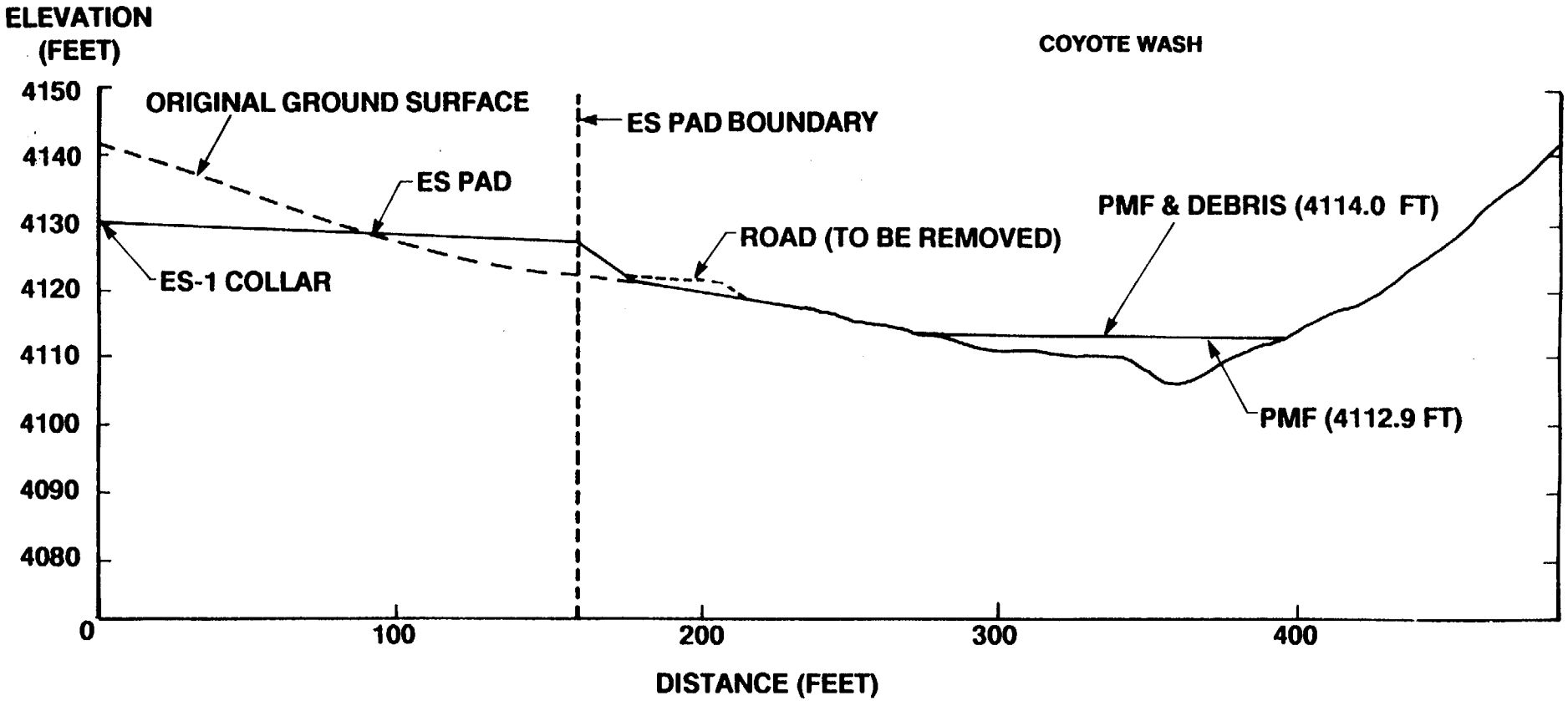
CAN FLOOD WATERS ENTER A SHAFT AND AFFECT WASTE ISOLATION?

LIQUID-PHASE MOVEMENT THROUGH SHAFTS

ANALYSES ASSUME FLOODING FROM PROBABLE MAXIMUM FLOOD (PMF)

- ELEVATION OF SHAFT COLLARS IS ABOVE ELEVATION OF PMF PLUS ASSOCIATED DEBRIS
- SEVERAL ANALYSES HAVE BEEN REPORTED
- THIS PRESENTATION DESCRIBES TWO ANALYSES:
  - "BOUNDING" CASE
  - "REALISTIC" CASE

PMF LEVELS AND LOCATION OF EXPLORATORY SHAFT ES-1 (THUNDERSTORM EVENT)



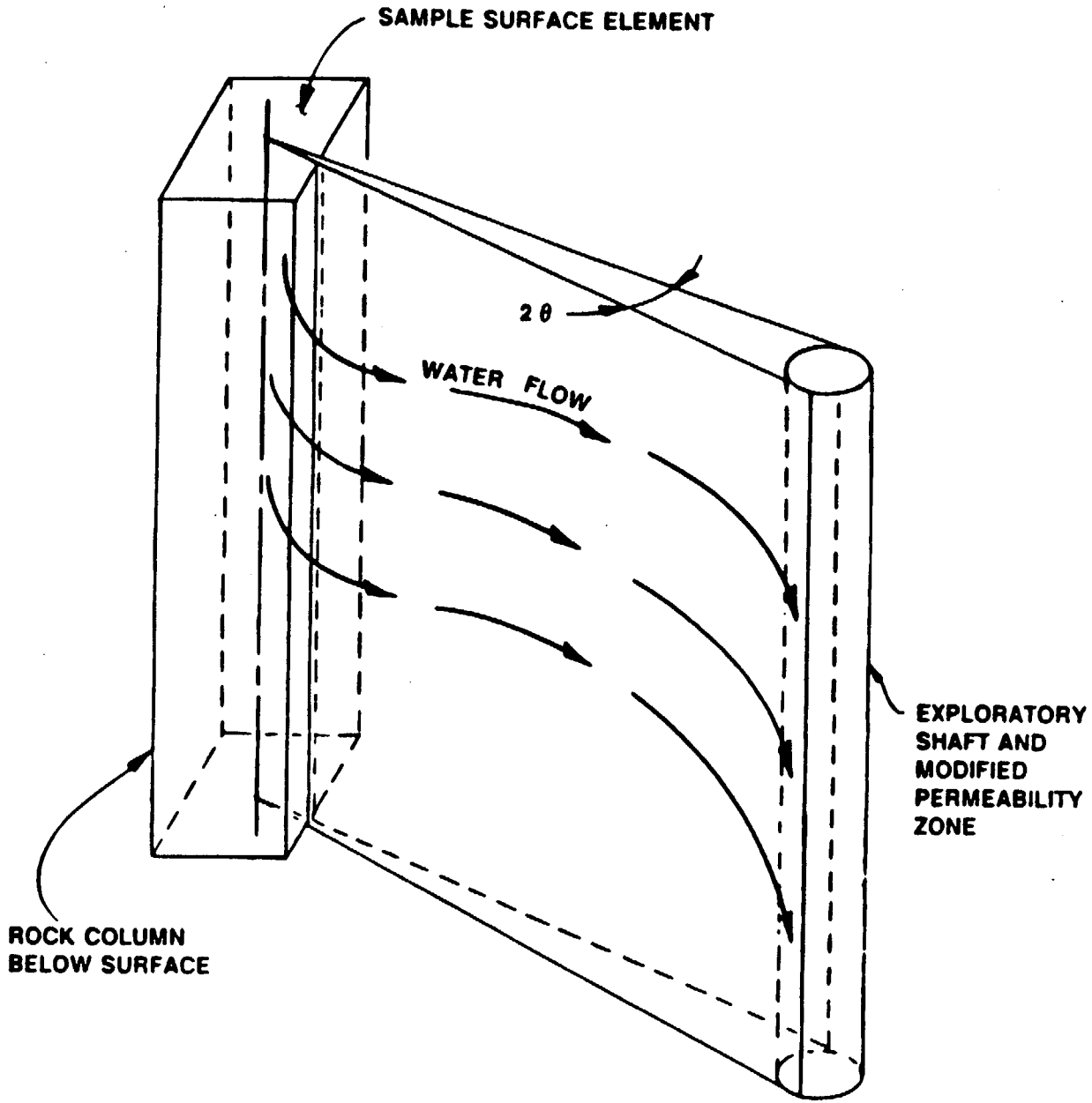
COMPARATIVE FLOOD PEAK DISCHARGES IN YUCCA MOUNTAIN AREA

WASH	DRAINAGE AREA (SQUARE MILES)	ESTIMATED PEAK FLOOD DISCHARGE (CUBIC FEET PER SECOND)
FORTYMILE	312	540,000[1]
BUSTED BUTTE	6.6	44,000[1]
DRILL HOLE	15.4	86,000[1]
YUCCA	16.6	92,000[1]
COYOTE	0.2	3,350[2]
COYOTE - DISCHARGE TO REACH ES-1 COLLAR	0.2	150,000[3]
COYOTE - DISCHARGE TO REACH ES -2 COLLAR	0.2	820,000[4]

[1] FROM SQUIRES AND YOUNG FOR THE REGIONAL MAXIMUM FLOOD
[2] FROM BULLARD 1986 FOR THUNDERSTORM PMF
[3] COMPUTED PEAK DISCHARGE TO REACH ES-1 COLLAR (45 TIMES PMF DISCHARGE)
[4] COMPUTED PEAK DISCHARGE TO REACH ES-2 COLLAR (2401 TIMES PMF DISCHARGE)

SURFACE-WATER INFLOW ANALYSES
BOUNDING CASE - PMF

- INTENSE RAINFALL IN COYOTE WASH - PROBABLE MAXIMUM FLOOD
- ALL RAINFALL INFILTRATES GROUND SURFACE (2 CASES: UNIFORMLY AND IN DRAINAGE COURSES)
- UNIFORM LATERAL DISPERSION OF FLOW UNDERGROUND
- NO RETENTION OF FLOW IN FORMATION
- FLOW INTO EXPLORATORY SHAFTS CALCULATED ON BASIS OF DISTANCE FROM SHAFTS AND CROSS SECTION OF SHAFTS AND MPZ POTENTIALLY INTERSECTED BY FLOW


SAMPLE SURFACE ELEMENT
2θ
WATER FLOW
EXPLORATORY SHAFT AND MODIFIED PERMEABILITY ZONE
ROCK COLUMN BELOW SURFACE

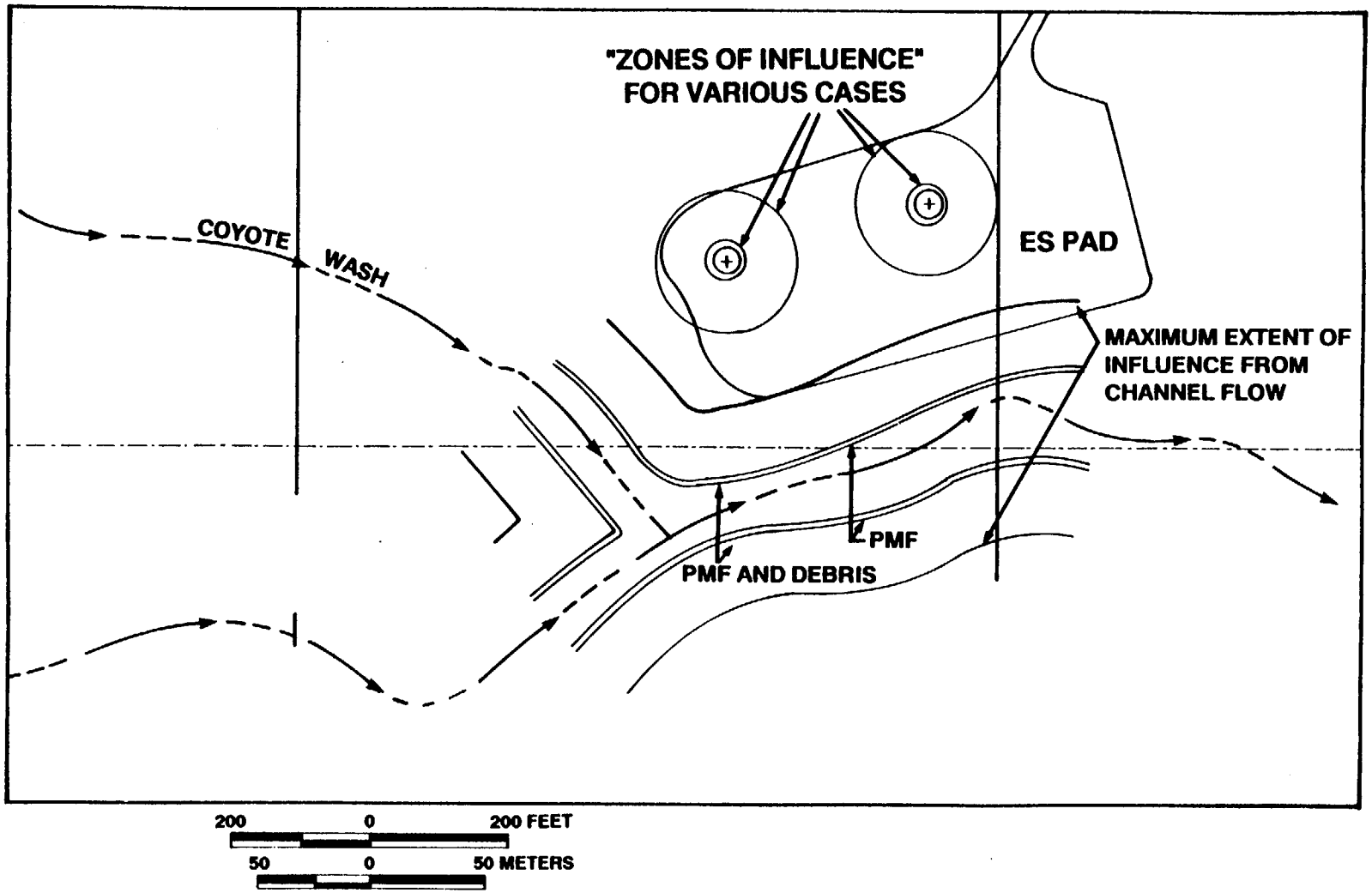
SURFACE-WATER INFLOW ANALYSES
BOUNDING CASE-PMF
(CONTINUED)

- RESULTS
  - TOTAL PREDICTED FLOW (EITHER CASE) INTO EXPLORATORY SHAFTS IS ABOUT 1200 m^3
    - * VOLUME COULD BE CONTAINED (EVEN WITHOUT DRAINAGE) WITHIN ESF
  - WATER THEREFORE WOULD NOT REACH WASTE-EMPLACEMENT AREA
- ESTIMATION: A MORE REALISTIC INFLOW (CONSIDERING RUNOFF AND RETENTION WITHIN FORMATION) IS LIKEY TO BE 1-2 ORDERS OF MAGNITUDE LESS THAN FLOW PREDICTED ABOVE

SURFACE-WATER INFLOW ANALYSES
REALISTIC CASE - PMF

- TWO PMF EVENTS: GENERAL STORM AND THUNDERSTORM
- NEAR-SURFACE FRACTURES ARE OPEN
- FRACTURE FLOW OCCURS FROM WATER IN CHANNEL AND OVER PAD
- NO ALLUVIAL RESISTANCE OCCURS
- MATRIX IMBIBITION OCCURS

SURFACE-WATER INFLOW ANALYSES REALISTIC CASE-PMF



SURFACE-WATER INFLOW ANALYSES
REALISTIC CASE - PMF

- **RESULTS**

  - TOTAL PREDICTED FLOW (EITHER EVENT) IS LESS THAN 50 m^3

    * VOLUME COULD EASILY BE CONTAINED AND DRAINED WITHIN ESF

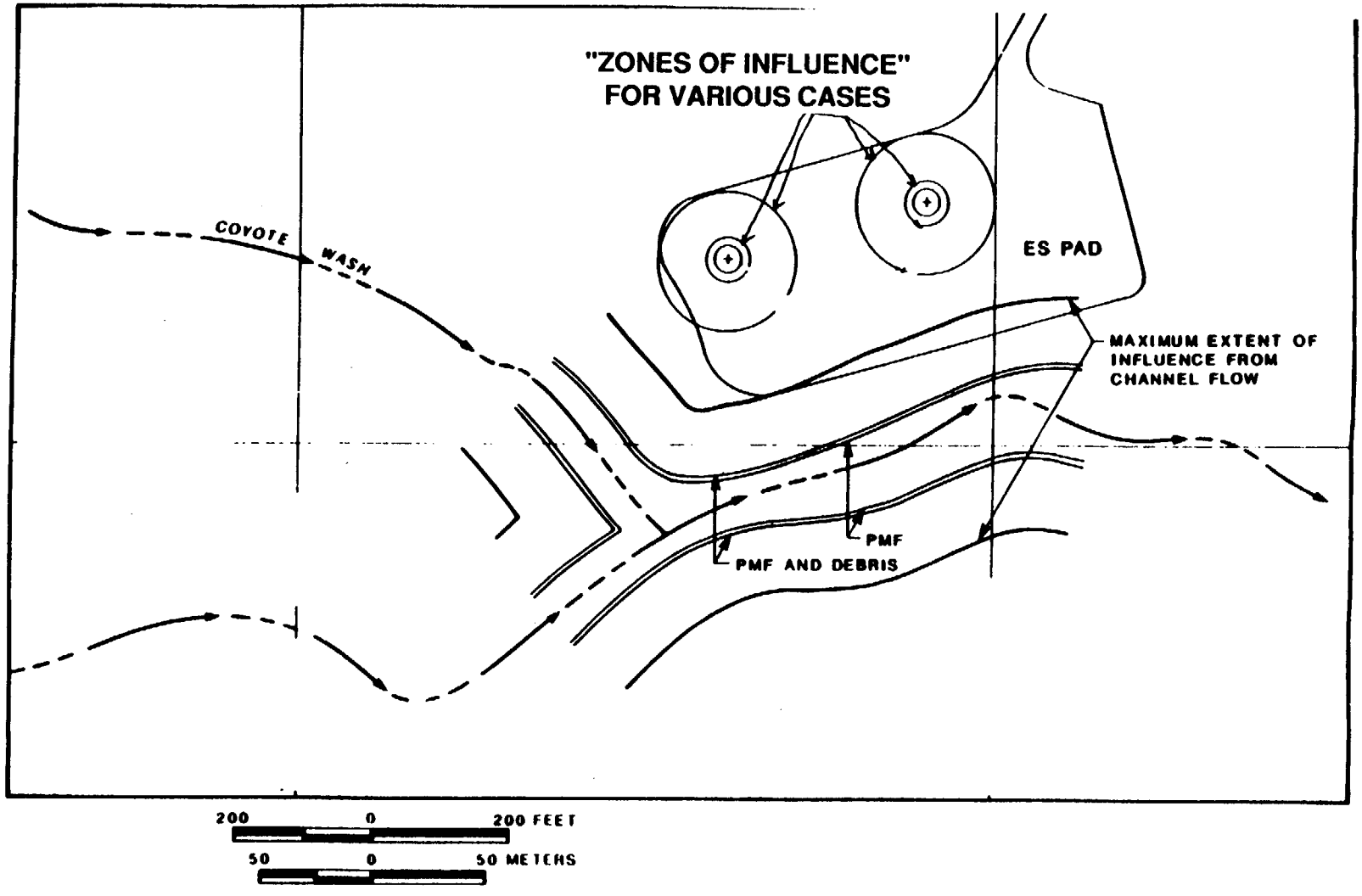
  - WATER THEREFORE WOULD NOT REACH WASTE-EMPLACEMENT AREA

CONCLUSIONS OF COMPLETE STUDY
(ONLY TWO EXAMPLES PRESENTED HERE)

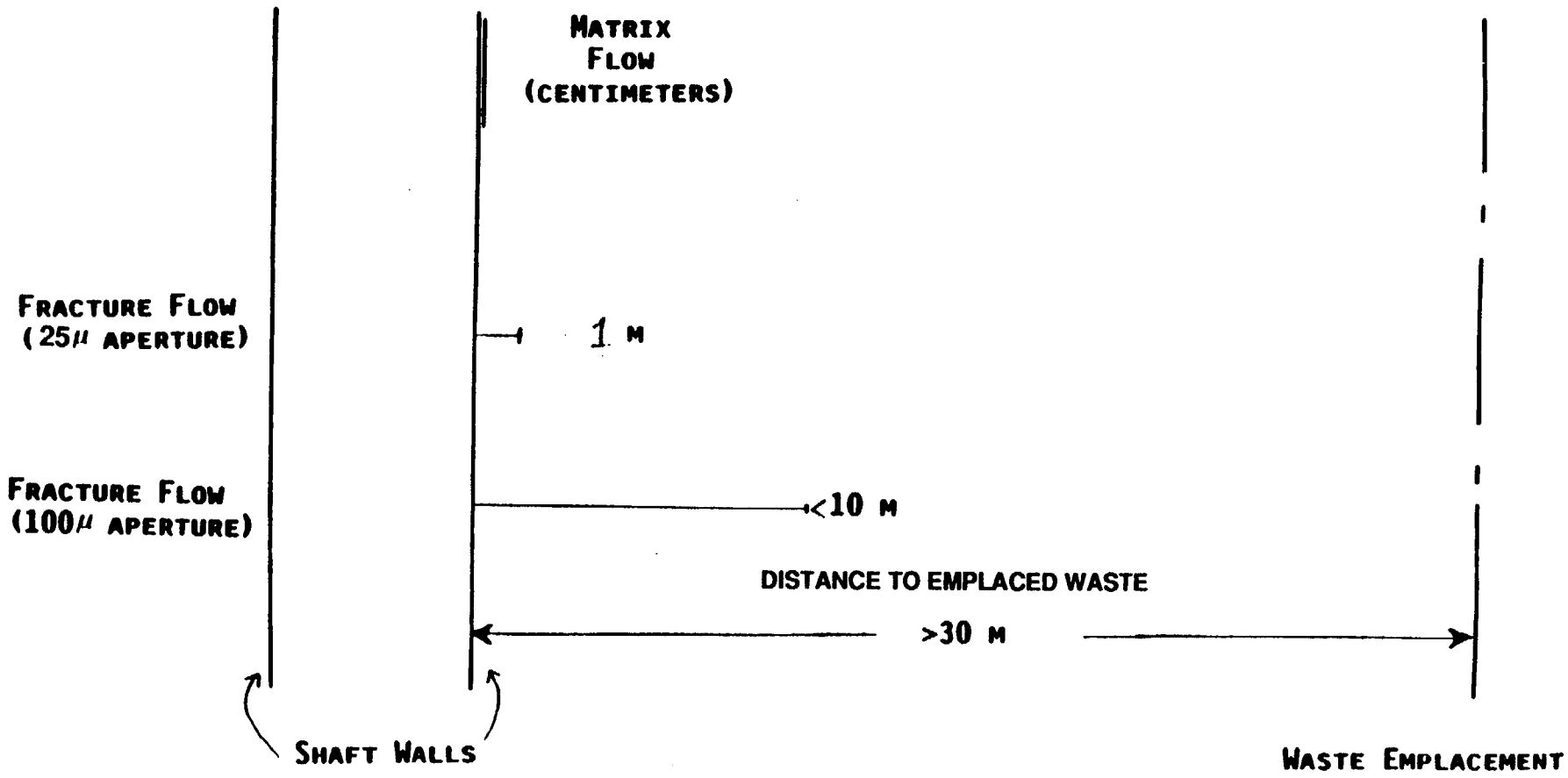
PRESENCE OF ESF DOES NOT PRECLUDE ABILITY OF SITE TO MEET TOTAL-SYSTEM PERFORMANCE OBJECTIVE

- CHANGES TO HYDROLOGIC PROPERTIES ARE LIMITED IN EXTENT
- CHANGES TO WATER FLUX ARE SMALL AND LIMITED IN EXTENT
- PENETRATIONS DO NOT CREATE PREFERENTIAL PATHWAYS FOR RELEASES
  - LOCALIZED EFFECTS ARE LATERALLY SEPARATED FROM EMPLACED WASTE
  - ESF DRAINS AWAY FROM WASTE
  - PENETRATIONS ARE TO BE SEALED

SURFACE-WATER INFLOW ANALYSES REALISTIC CASE-PMF



SCHEMATIC SHOWING PENETRATION DISTANCES FOR MATRIX AND FRACTURE FLOWS AT REPOSITORY HORIZON RELATIVE TO DISTANCE FROM EMPLACED WASTE



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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: MODELS OF WASTE PACKAGE BEHAVIOR IN A REPOSITORY ENVIRONMENT

PRESENTER: DR. THOMAS H. PIGFORD

PRESENTER'S TITLE AND ORGANIZATION: DEPARTMENT OF NUCLEAR ENGINEERING & LAWRENCE BERKELEY LAB, UNIVERSITY OF CALIFORNIA, BERKELEY, CA.

PRESENTER'S TELEPHONE NUMBER: (415) 642-6469

MAY 16-17, 1989

SCOPE OF PRESENTATION

- OBJECTIVES
- DEVELOPMENT OF MODELS
- RESULTS OF CURRENT WORK
- FUTURE ACTIVITIES

THE DESIGN OBJECTIVE

TO DESIGN A REPOSITORY THAT PERFORMS SUFFICIENTLY WELL WHEN MEASURED AGAINST CRITERIA FOR SATISFACTORY LONG-TERM PROTECTION OF PUBLIC HEALTH AND SAFETY

THE PURPOSE OF PERFORMANCE PREDICTIONS

- TO MAKE RELIABLE PREDICTIONS THAT PERFORMANCE WILL NOT FALL OUTSIDE THE CRITERIA FOR ACCEPTABILITY
- PREDICTING ALL DETAILS OF REPOSITORY PERFORMANCE IS NEITHER NECESSARY OR ACHIEVABLE

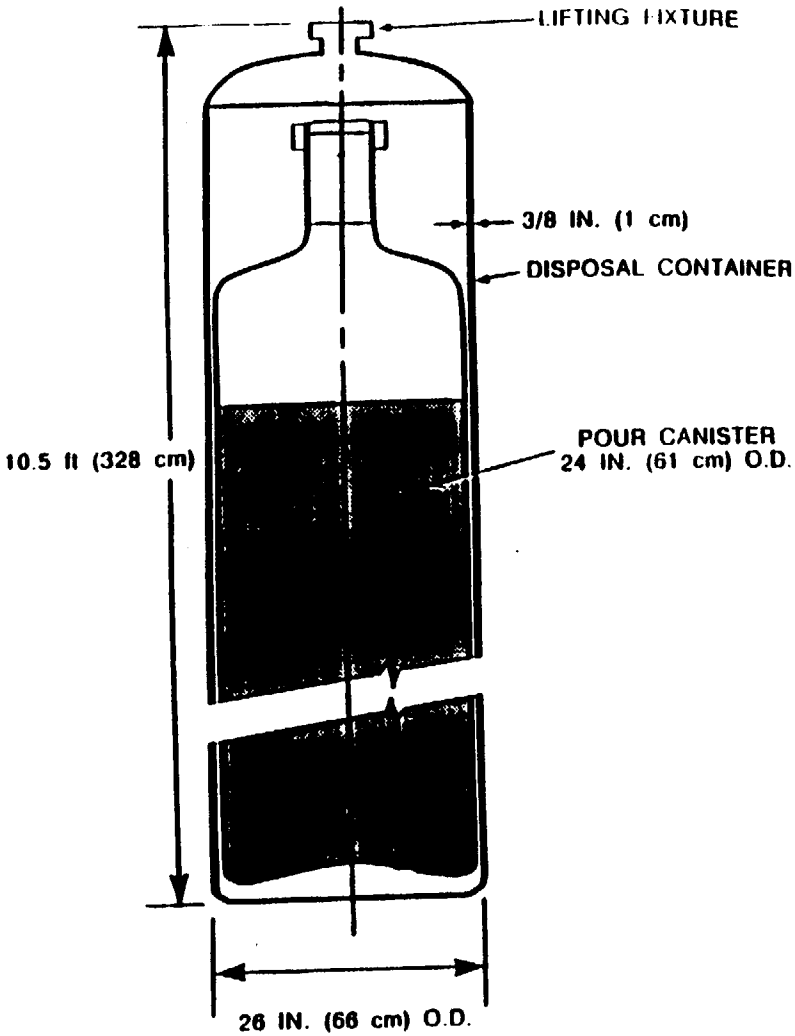
PREDICTIVE RELIABILTY

PREDICTIVE RELIABILTY IN DESIGN DEPENDS ON:

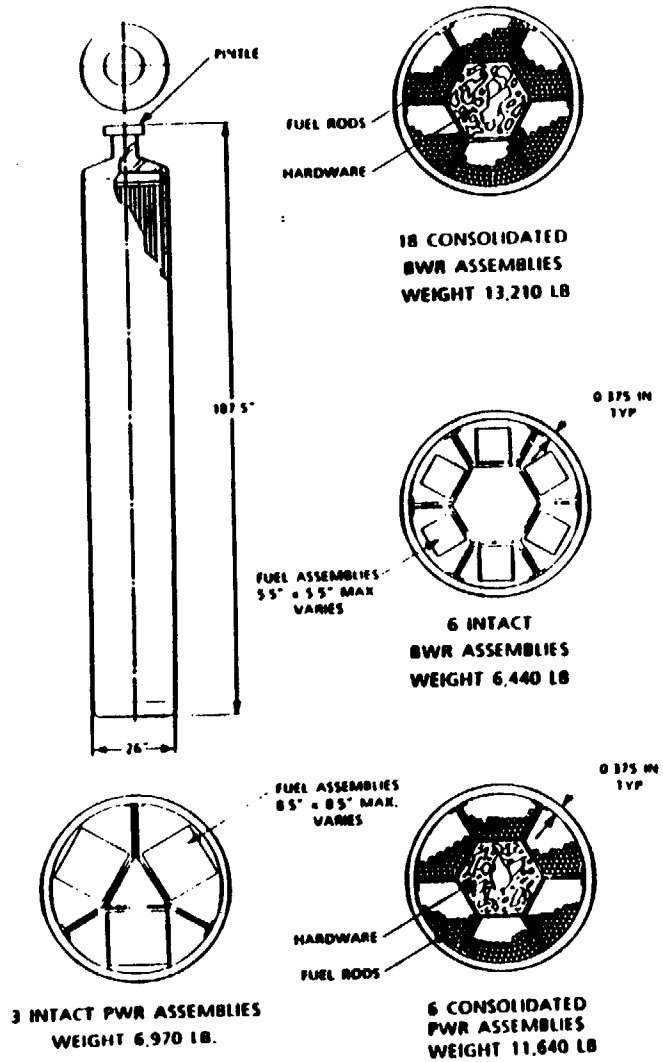
- CLEAR AND RELIABLE CRITERIA FOR ACCEPTABLE PERFORMANCE
- A THEORY THAT CAN RELIABLY PREDICT THE PERFORMANCE DOES NOT FALL OUTSIDE THE CRITERIA FOR ACCEPTABLE PERFORMANCE
- RELIABLE PARAMETER VALUES TO APPLY THE THEORY

CONCEPTUAL WASTE PACKAGE DESIGNS FOR HIGH-LEVEL WASTE AND SPENT NUCLEAR FUEL

HIGH-LEVEL WASTE CONTAINER



SPENT NUCLEAR FUEL CONTAINER



THREE GENERAL MODELS FOR WASTE PACKAGE RELEASES

1. DRY
2. WET-DRIP
3. WET-CONTINUOUS

1. DRY CASE FOR WASTE PACKAGE RELEASES

A. SOME CONTAINERS FAIL, ALLOWING RADIOACTIVE GASES TO ESCAPE
(e.g., ^{3}H, ^{14}C, ^{85}Kr, ^{129}I)

B. NO WATER ENTERS THE PENETRATIONS IN THE FAILED CONTAINERS. NO NON-VOLATILE RADIONUCLIDES ARE RELEASED

2. WET-DRIP CASE

- BOUNDING CALCULATIONS OF RADIONUCLIDE RELEASE RATES TO GROUND WATER FOR INDIVIDUAL WASTE PACKAGES AT YUCCA MOUNTAIN
- ASSUME NO CLADDING BARRIER
- ASSUME GROUND WATER ENTERS AND LEAVES DEFECTIVE WASTE PACKAGE
- BATHTUB AND FLOW-THROUGH MODELS (ASSUMING NO DIFFUSIVE PATHWAY TO SURROUNDING ROCK)

(a) BULK-FLOW SOLUBILITY-LIMITED (e.g., U, Pu, Np, Am)

$$\dot{m}_i = Q\frac{n_i}{n_e}N_e^*, \quad f_i = \frac{\dot{m}_i}{M_i}$$

<u>WHERE</u>

f_i IS THE FRACTIONAL RELEASE RATE OF SPECIES i
n_e IS THE CONCENTRATION OF ELEMENT CONTAINING SPECIES i IN WASTE
n_i IS THE CONCENTRATION OF ISOTOPE i IN WASTE
$\dot{m}_i$ IS THE RELEASE RATE OF SPECIES i
M_i IS THE 1,000-YEAR INVENTORY OF SPECIES i
N_e^* IS THE SOLUBILITY OF ELEMENT CONTAINING ISOTOPE i
Q IS THE VOLUMETRIC FLOW RATE OF GROUND WATER PER WASTE PACKAGE

2. WET-DRIP CASE

(CONTINUED)

(b) LIMITED BY WASTE-WATER REACTION RATE (e.g., SOLUBLE Tc-99)

$$\dot{m}_i = j_m A \frac{n_i}{n_e}, \quad f_i = \frac{\dot{m}_i}{M_i}$$

WHERE j_m IS THE RATE OF SOLID-SOLID ALTERATION OF THE WASTE MATRIX, (e.g., UO_2 (s) $\rightarrow U_3O_7$ (s)), PER UNIT AREA

A IS THE SURFACE AREA OF WASTE EXPOSED TO GROUND WATER

2. WET-DRIP CASE

(CONTINUED)

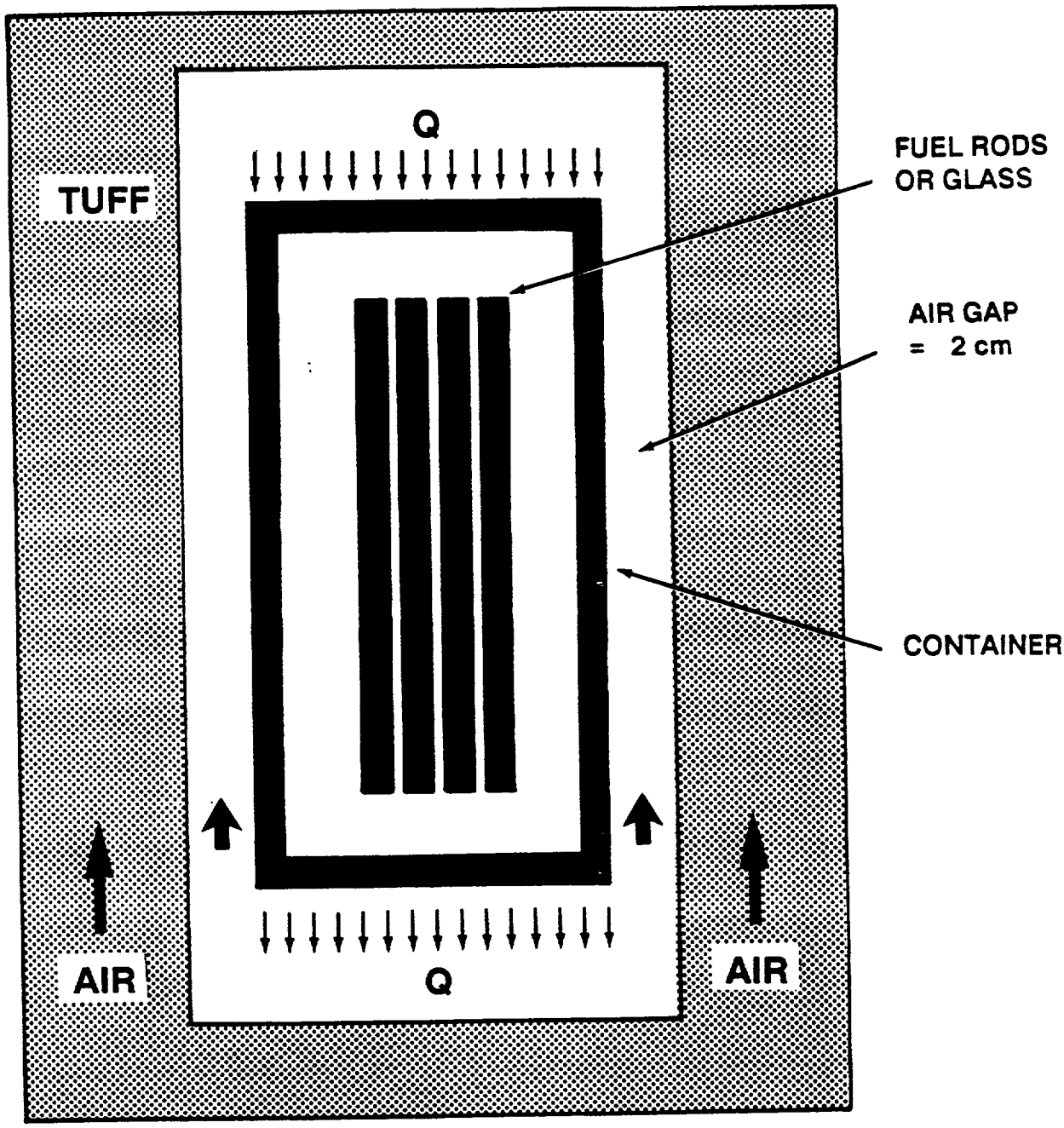
(c) READILY SOLUBLE SPECIES (e.g., Cs, I, not in UO_2 MATRIX)

$$\dot{m}_{is} = M_{is}\frac{d\psi}{dt}, \quad f_{is} = \frac{\dot{m}_{is}}{M_i}$$

WHERE

$\frac{d\psi}{dt}$ IS THE FRACTION OF SOLUBLE INVENTORY M_{is} EXPOSED TO WATER PER UNIT TIME

KEY PARAMETERS: M_{is}, M_i, $\frac{d\psi}{dt}$

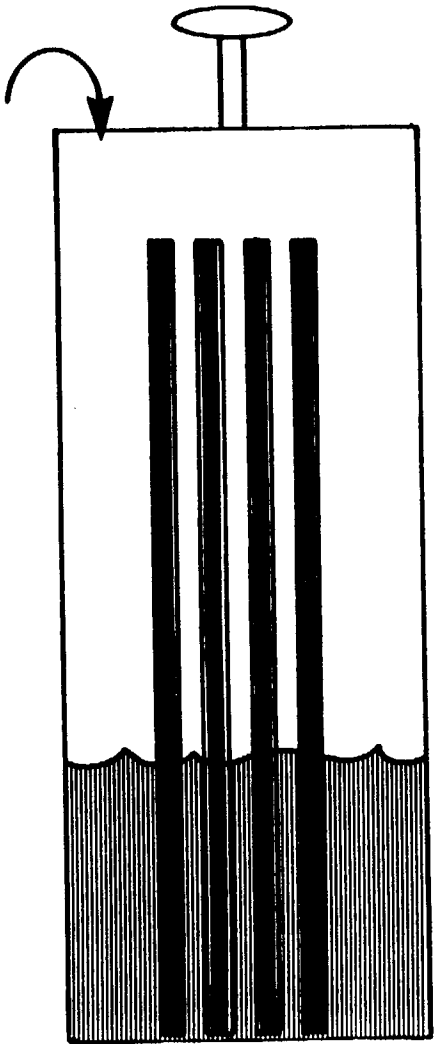


NWFRD5P A13/5 16, 17-89 9

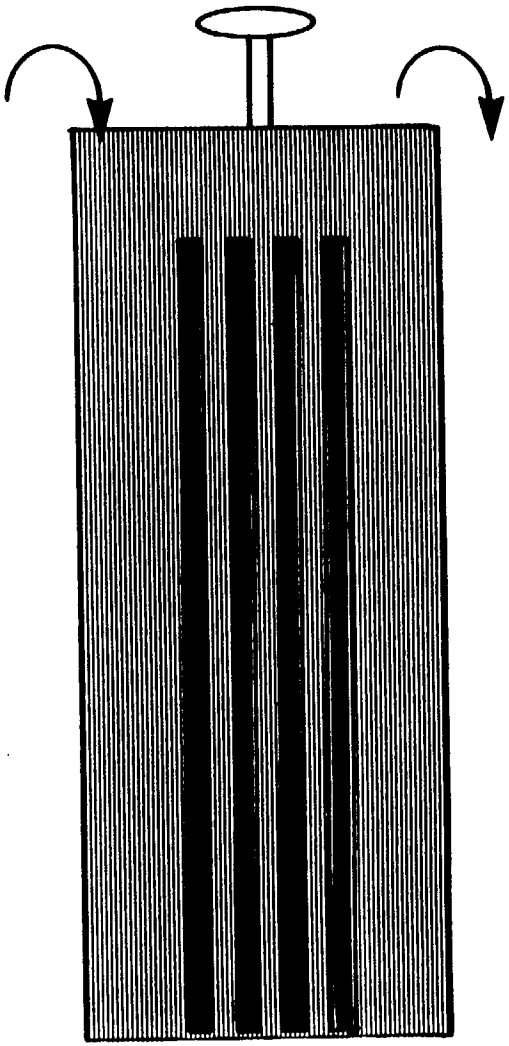
WASTE PACKAGE IN UNSATURATED TUFF
WET-DRIP CASE
(POST-THERMAL PERIOD)
$Q \geq 0$

WET-DRIP CASE

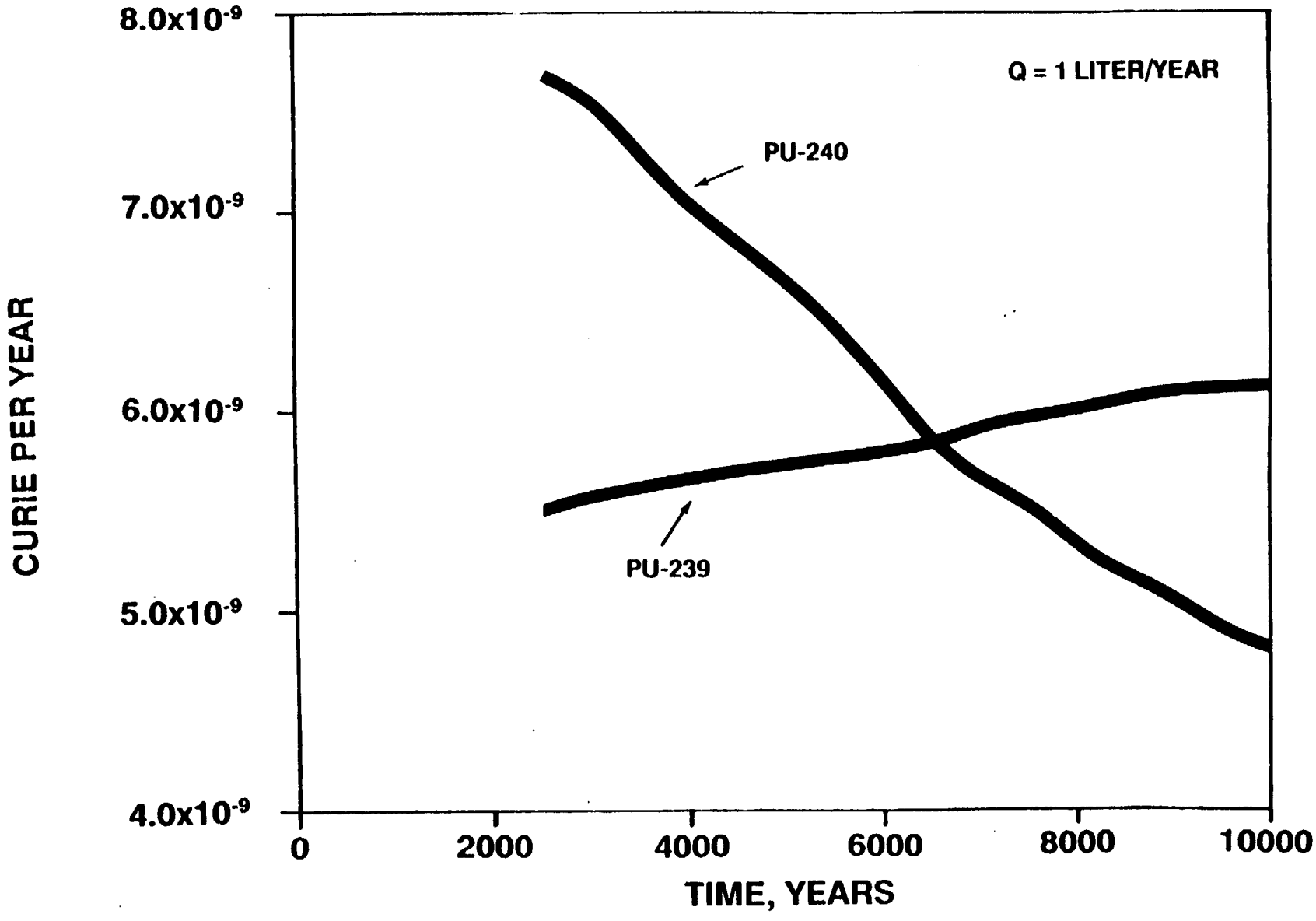
THE "BATHTUB" SCENARIO INVOLVES BREACHES THAT ALLOW WATER TO ENTER AND FILL THE PACKAGE, IMMERSING THE WASTE FORM



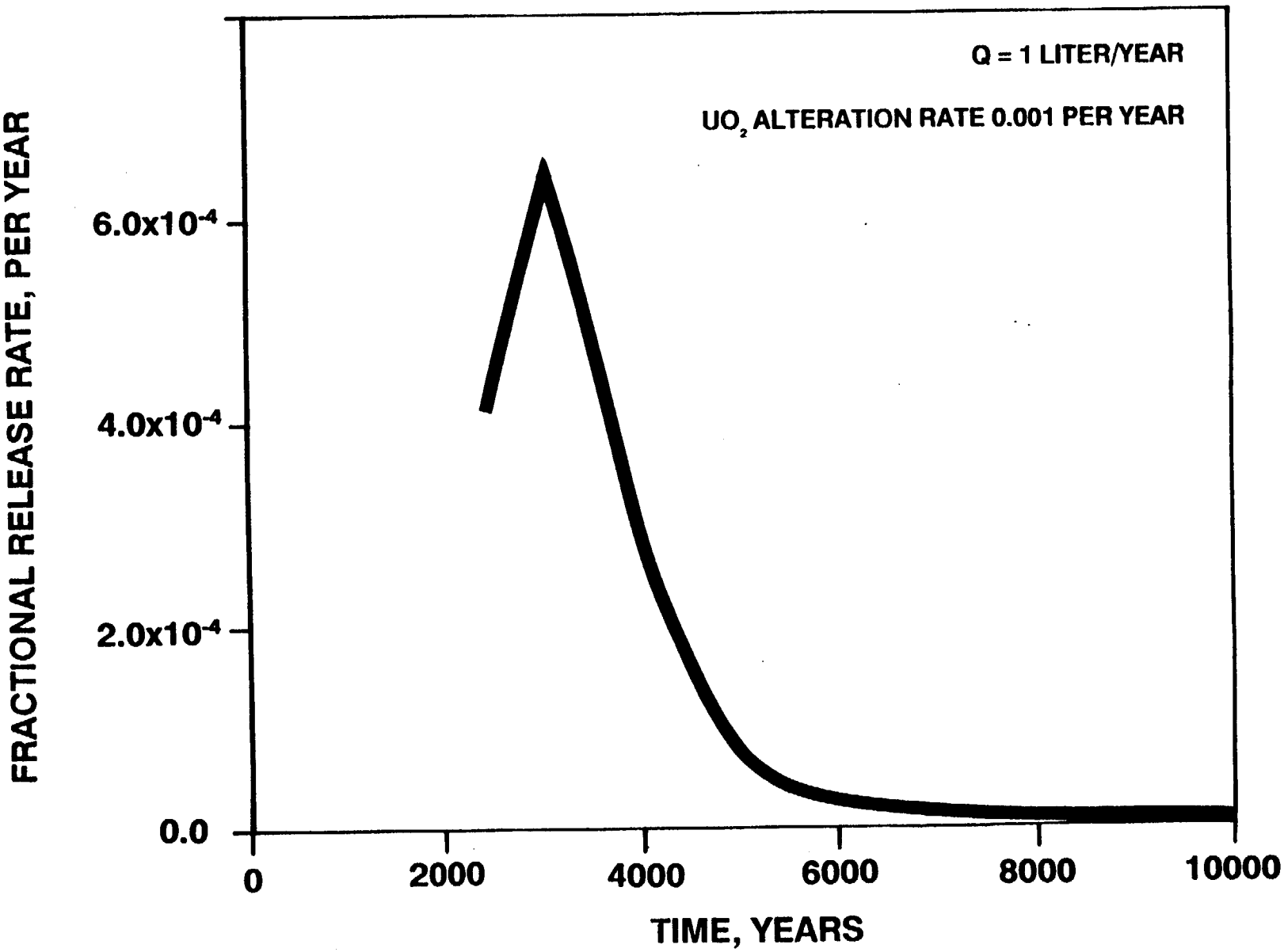
FILLING PACKAGE



FILLED PACKAGE



RELEASE RATE OF Pu-239 & Pu-240, BATHTUB MODEL
SOURCE: O'CONNELL, 1989



FRACTIONAL RELEASE RATE OF Tc-99 BATHTUB MODEL
SOURCE: O'CONNELL, 1989

3. WET-CONTINUOUS CASE

- DIFFUSIVE-ADVECTIVE MASS TRANSFER - DETAILED ANALYTIC SOLUTIONS
- PRESENT ANALYSES ASSUME WASTE CONTAINER AND FUEL CLADDING ARE NOT PRESENT
- ASSUMES A CONTINUOUS LIQUID DIFFUSION PATHWAY FROM THE WASTE TO THE TUFF

  (a) SATURATION CONCENTRATION OF SPECIES i AT WASTE SURFACE

  COMPLETE TIME-DEPENDENT ANALYTIC SOLUTIONS FOR SINGLE SPECIES OR DECAY CHAINS, FOR WASTE IN CONTACT WITH TUFF, OR SURROUNDED BY BACKFILL AND TUFF, NO ARBITRARY OR ADJUSTABLE PARAMETERS

(a) SATURATION CONCENTRATION OF SPECIES i AT WASTE SURFACE

(CONTINUED)

KEY PARAMETERS FOR THE LOW-FLOW AT YUCCA MOUNTAIN, ASSUMING GROUND WATER IN POROUS MEDIA ONLY

- D COEFFICIENT OF MOLECULAR DIFFUSION IN PORE WATER
- N^*_i ELEMENTAL SOLUBILITY FOR THE SPECIES
- R RADIUS OF SPHERICAL-EQUIVALENT WASTE SOLID
- n_i CONCENTRATION OF ELEMENT CONTAINING SPECIES i IN WASTE
- n_I CONCENTRATION OF ISOTOPE i IN WASTE
- $\dot{m}_I$ RELEASE RATE OF SPECIES i
- M_I 1,000-YEAR INVENTORY OF SPECIES i
- ϵ POROSITY
- λ DECAY CONSTANT
- K RETARDATION FACTOR DUE TO SORPTION
- ℓ THICKNESS OF BACKFILL, IF PRESENT
- S MOISTURE CONTENT

EXTENDED SOLUTIONS INCLUDE EFFECT OF TEMPERATURE CHANGES DUE TO REPOSITORY HEATING AND SUBSEQUENT COOLING.

IF GROUND WATER EXISTS IN THE FRACTURES AND IN POROUS ROCK, ADDITIONAL PARAMETERS ARE:

- FRACTURE SPACING
- FRACTURE APERTURE

GROUND WATER FLOW IS NOT A PARAMETER, UNLESS IT BECOMES MANY ORDERS OF MAGNITUDE GREATER THAN CURRENTLY ESTIMATED FOR YUCCA MOUNTAIN

3. WET-CONTINUOUS CASE

(CONTINUED)

(b) READILY SOLUBLE SPECIES (e.g., Cs, I, NOT IN UO_2 MATRIX)

COMPLETE TIME-DEPENDENT ANALYTIC SOLUTIONS FOR SINGLE SPECIES FOR WASTE IN CONTACT WITH TUFF, OR SURROUNDED BY BACKFILL AND TUFF, NO ARBITRARY OR ADJUSTABLE PARAMETERS

KEY PARAMETERS FOR THE LOW-FLOW AT YUCCA MOUNTAIN

- D COEFFICIENT OF MOLECULAR DIFFUSION IN PORE WATER
- ϵ POROSITY
- V VOLUME WITHIN WASTE PACKAGE THAT CAN BE FILLED WITH WATER
- λ DECAY CONSTANT
- K RETARDATION FACTOR DUE TO SORPTION
- ℓ BACKFILL THICKNESS, IF PRESENT
- S MOISTURE CONTENT (FRACTION)
- M_{is} INVENTORY OF SPECIES i IN READILY SOLUBLE FORM

(b) READILY SOLUBLE SPECIES

(CONTINUED)

EXTENDED SOLUTIONS INCLUDE EFFECT OF TEMPERATURE CHANGES DUE TO REPOSITORY HEATING AND SUBSEQUENT COOLING

3. WET-CONTINUOUS CASE

(CONTINUED)

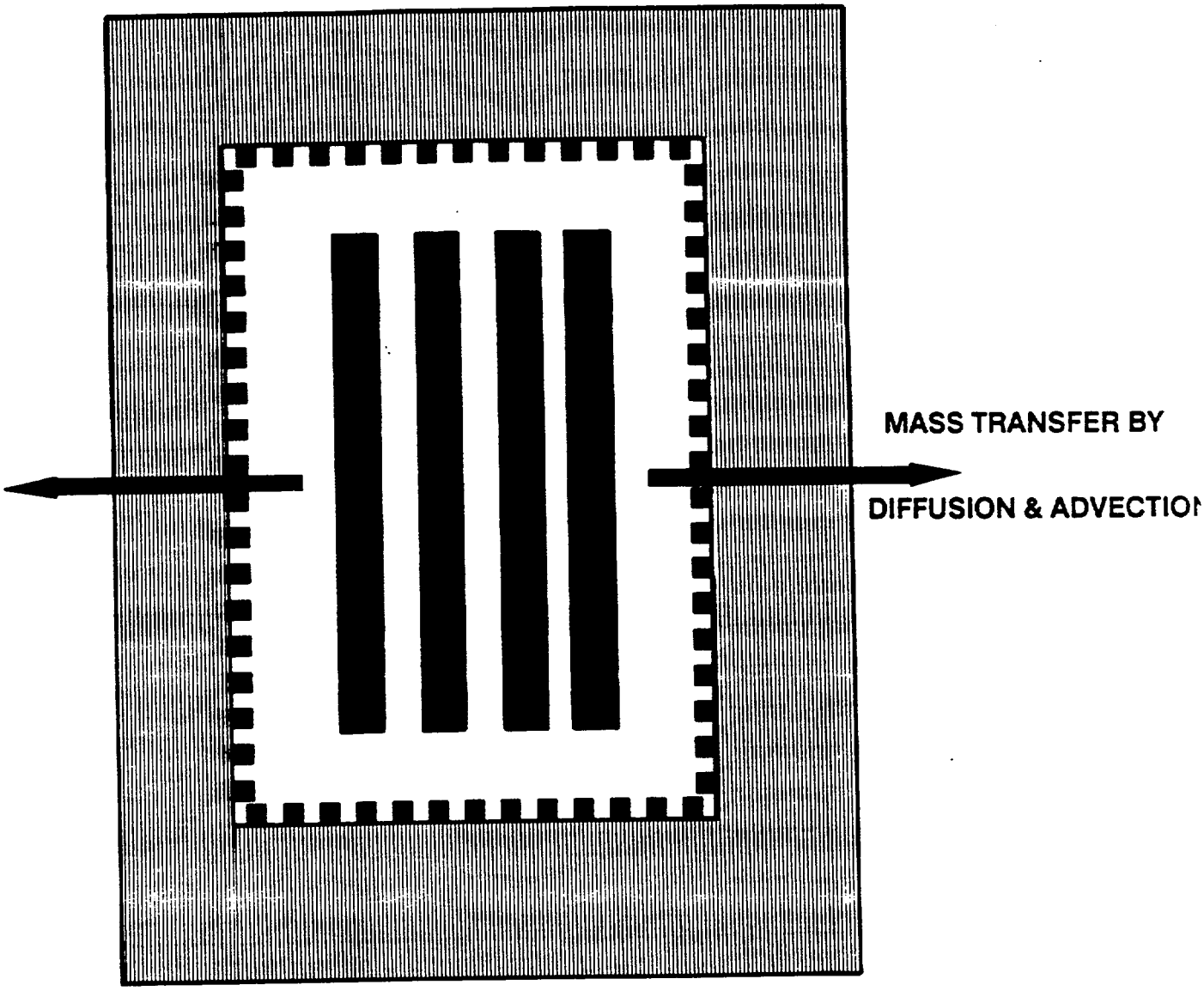
(c) DISSOLUTION OF SPECIES i CONGRUENT WITH THAT OF A DOMINANT LOW-SOLUBILITY SPECIES m

$$f_i = \frac{\dot{m}_i}{M_i} = f_m = \frac{\dot{m}_m}{M_m}, \quad \dot{m}_i = \dot{m}_m \left(\frac{M_i}{M_m}\right)$$

KEY PARAMETERS FOR $\dot{m}_m$ GIVEN IN 3(a)

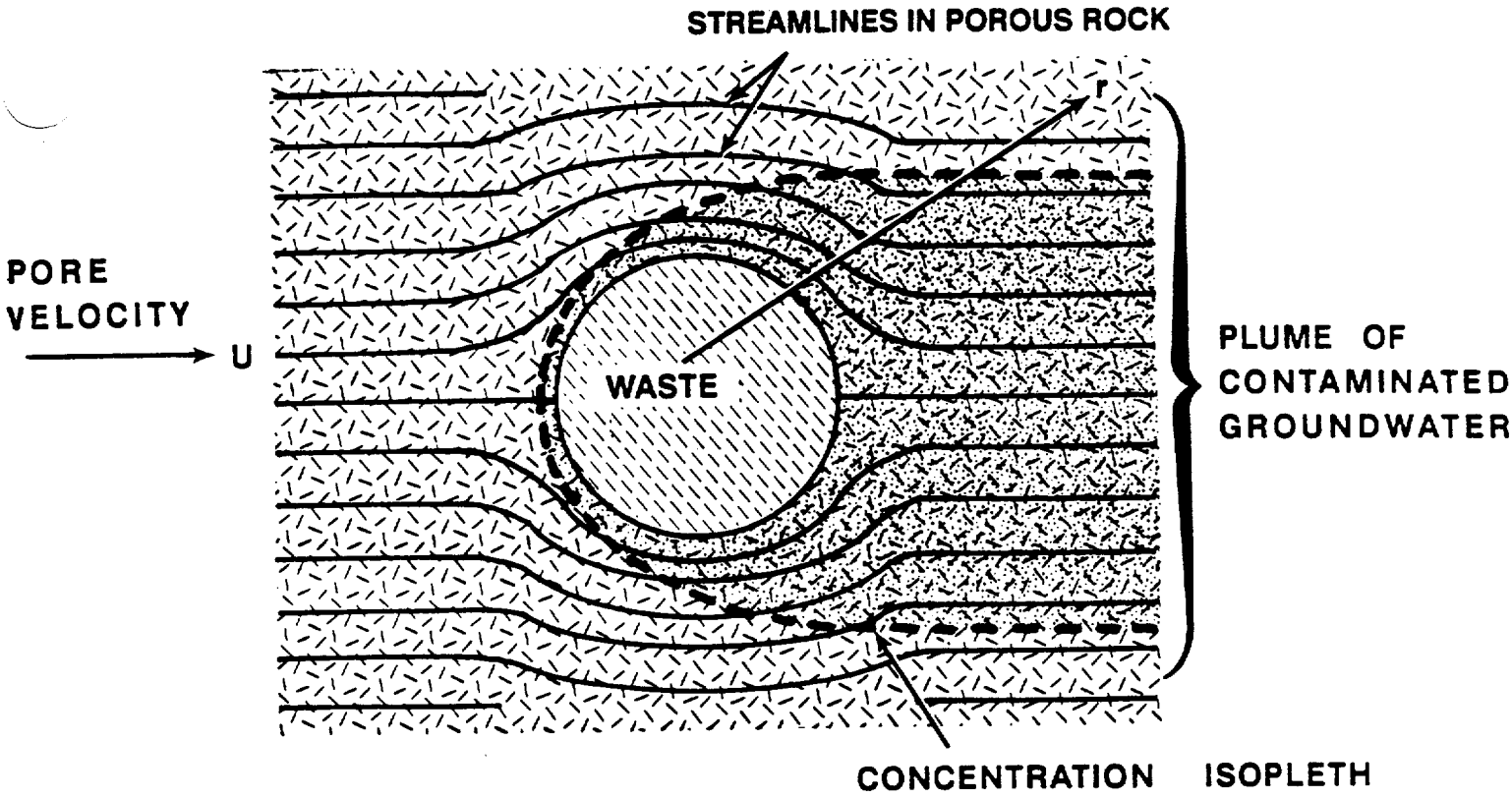
(d) DISSOLUTION OF SPECIES i CONGRUENT WITH THE RATE OF ALTERATION OF THE WASTE MATRIX

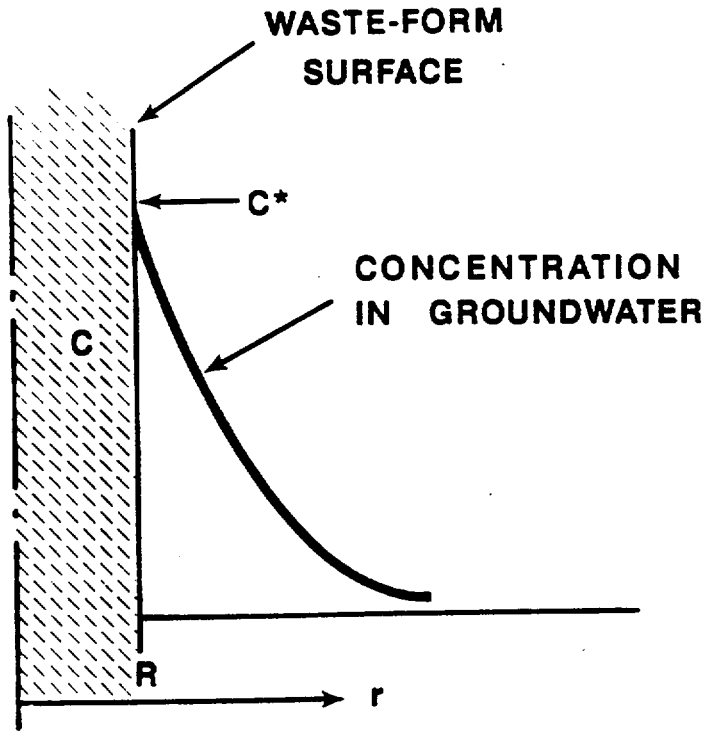
$$\dot{m}_i = j_m A \frac{n_i}{n_m}, \quad f_i = \frac{\dot{m}_i}{M_i}$$



WET-CONTINUOUS CASE
A WASTE PACKAGE IN SATURATED TUFF

NWFRD5P.A13/5-16, 17-89





VELOCITY AND CONCENTRATION PROFILES
FOR GROUNDWATER FLOWING
AROUND A WASTE CYLINDER

3. WET-CONTINUOUS CASE
MASS TRANSFER BY DIFFUSION AND ADVECTION
(NO RADIOACTIVE DECAY)

$$f_j = \frac{8\, N_j^*\, D^{\frac{1}{2}}\, \epsilon\, V^{\frac{1}{2}}\, (1 + R/L)}{(\pi R)^{\frac{3}{2}}\, n_j}, \quad \frac{VR}{D} > 4$$

f_j = FRACTIONAL DISSOLUTION RATE OF SPECIES j

N_j^* = SATURATION CONCENTRATION

D = DIFFUSION COEFFICIENT IN GROUND WATER

ε = POROSITY

V = GROUND WATER PORE VELOCITY

R = CYLINDER RADIUS

L = CYLINDER LENGTH

n_j = CONCENTRATION IN WASTE SOLID

NOTATION FOR FIGURES

d DIAMETER

D DIFFUSION COEFFICIENT

f_j FRACTIONAL DISSOLUTION RATE OF SPECIES j

h MASS-TRANSFER COEFFICIENT

j_0 FORWARD REACTION RATE

K RETARDATION COEFFICIENT

r RADIUS

t TIME

V GROUND WATER PORE VELOCITY

α $\frac{\text{BACKFILL PERMEABILITY}}{\text{ROCK PERMEABILITY}}$

β $\frac{\text{ROCK POROSITY}}{\text{BACKFILL POROSITY}}$

ε POROSITY

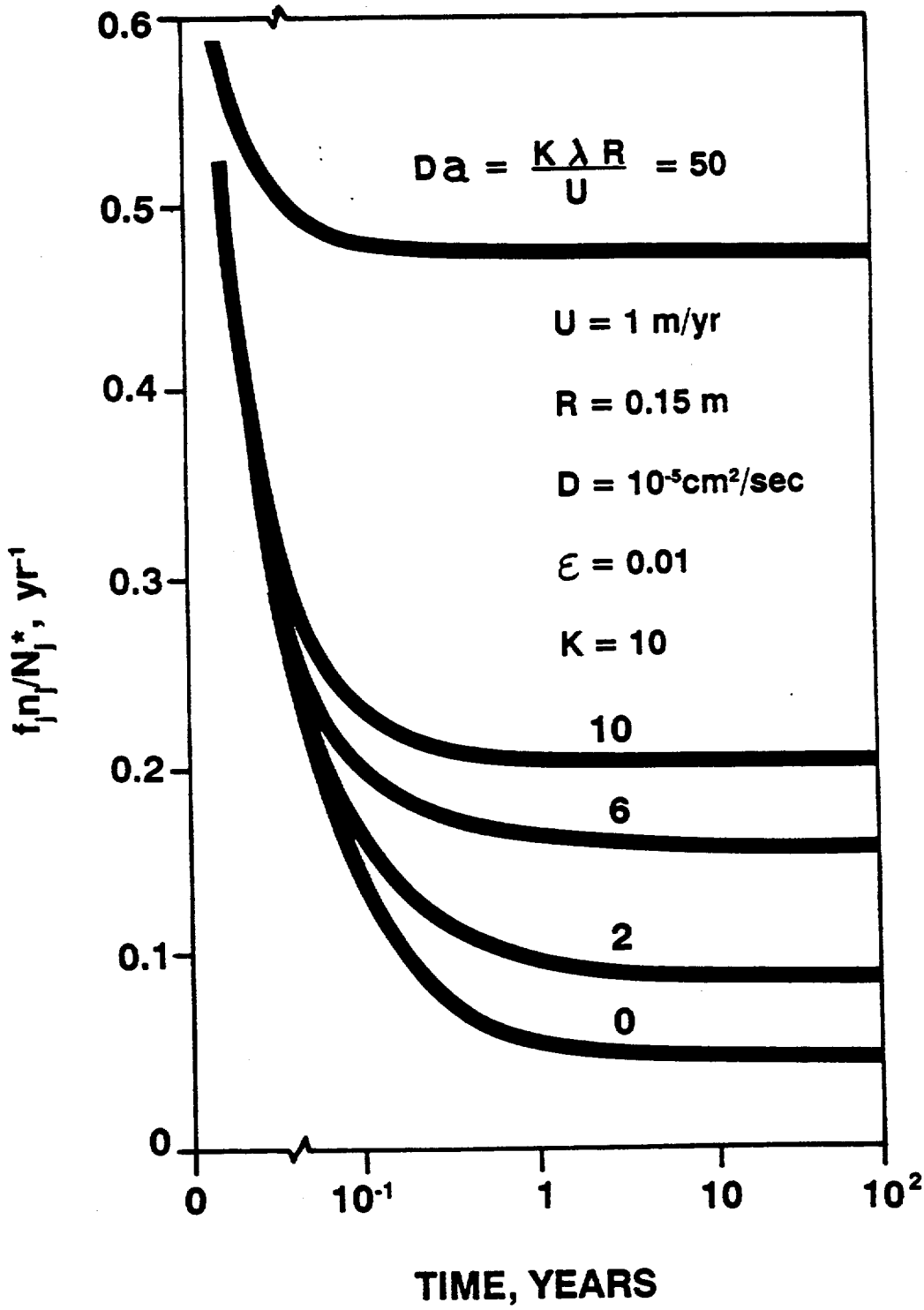
λ RADIOACTIVE DECAY CONSTANT

NOTATION FOR FIGURES

(CONTINUED)

PECLET NUMBER	$Pe = \frac{Vr}{D}$
DAMKÖHLER NUMBER	$Da = \frac{\lambda Kr}{V}$
THIELE MODULUS	$\Lambda = \left(\frac{\lambda d^2 K}{D}\right)^{1/2}$
FOURIER MODULUS	$T = \frac{Dt}{Kd^2}$
SHERWOOD NUMBER	$Sh = \frac{hd}{D\varepsilon}$
REACTION-RATE MODULUS	$R = \frac{j_o r}{\varepsilon D N^*}$

NORMALIZED SOLUBILITY-LIMITED RELEASE RATE AS A FUNCTION OF TIME FLOW ACROSS A WASTE CYLINDER



3. WET-CONTINUOUS CASE MASS TRANSFER BY DIFFUSION (NO RADIOACTIVE DECAY)

$$f_j = \frac{\beta\, \epsilon D N_j^*}{n_j}, \quad \text{as } V \rightarrow 0$$

SPHERE: $\beta = \dfrac{3}{R^2}$

PROLATE SPHEROID: $\beta = \dfrac{3e}{b^2 \ln\left(\coth\frac{\alpha_s}{2}\right)}$

e = ECCENTRICITY

b = SEMI-MINOR AXIS

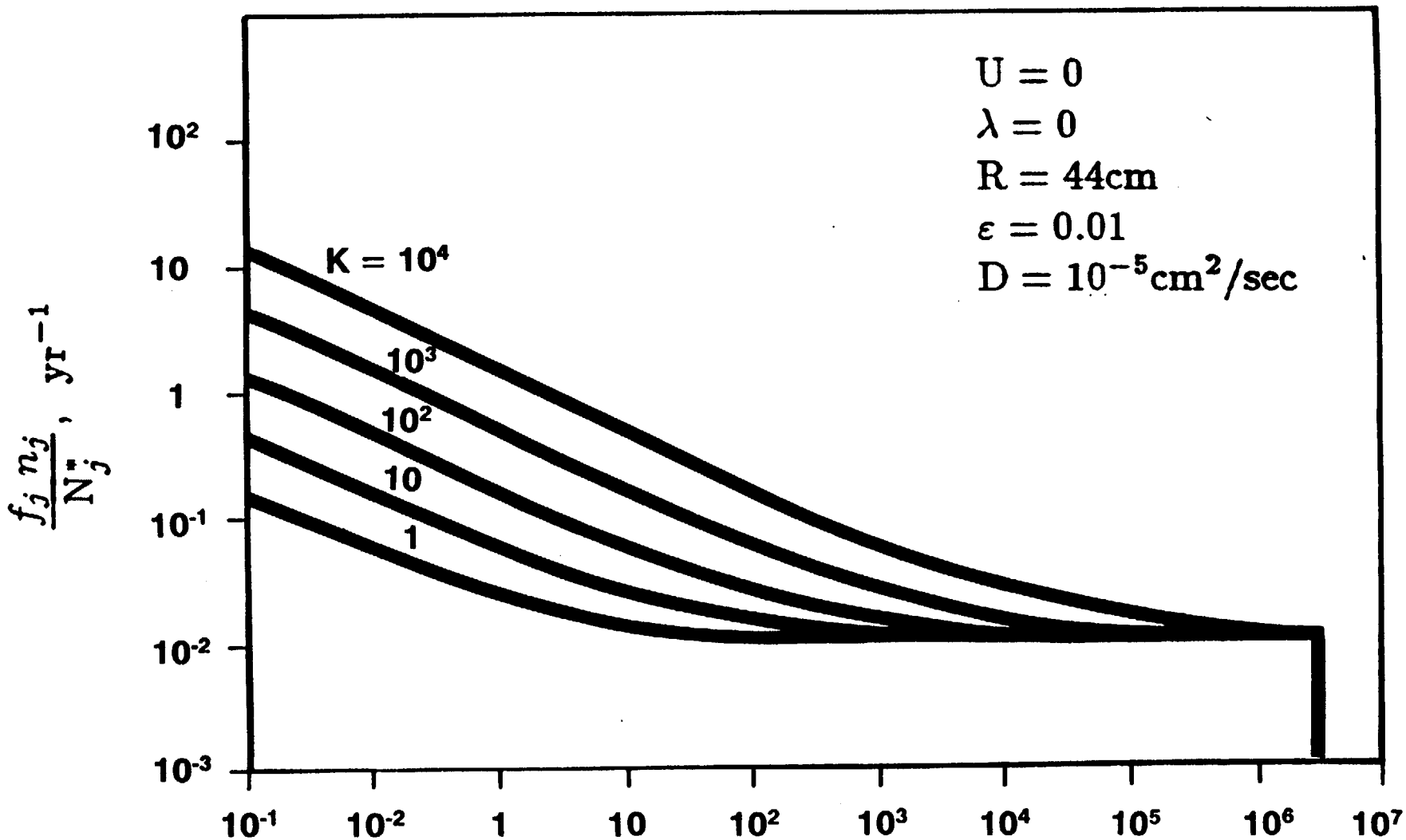
$$\alpha_s = \cosh^{-1}\left(\frac{1}{e}\right)$$

TIME FOR 99% OF STEADY STATE:

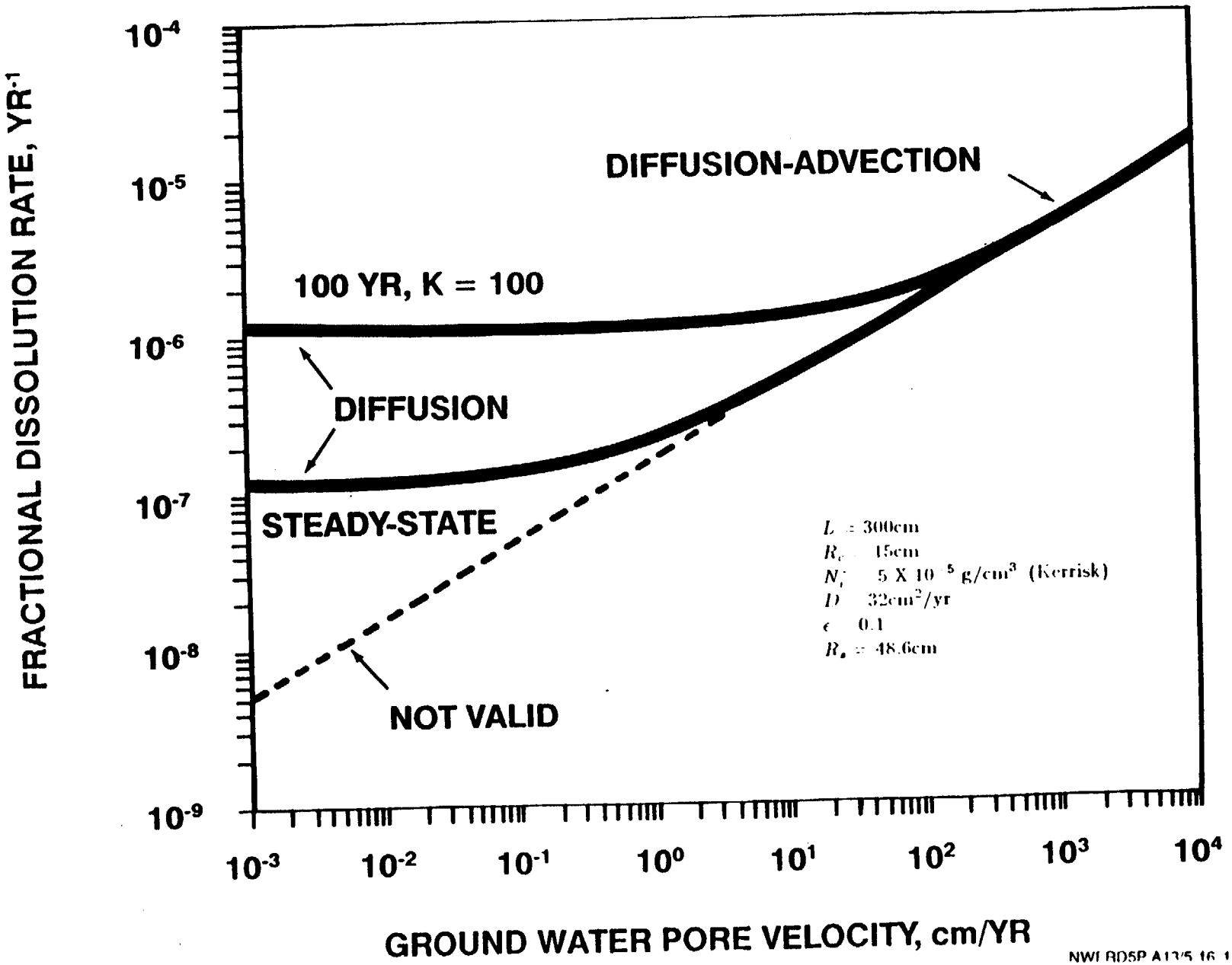
$$t = \frac{10^4\, K b^2}{\pi D}\left[\sinh \alpha_s \ln\left(\coth\frac{\alpha_s}{2}\right)\right]^2$$

K = RETARDATION FACTOR

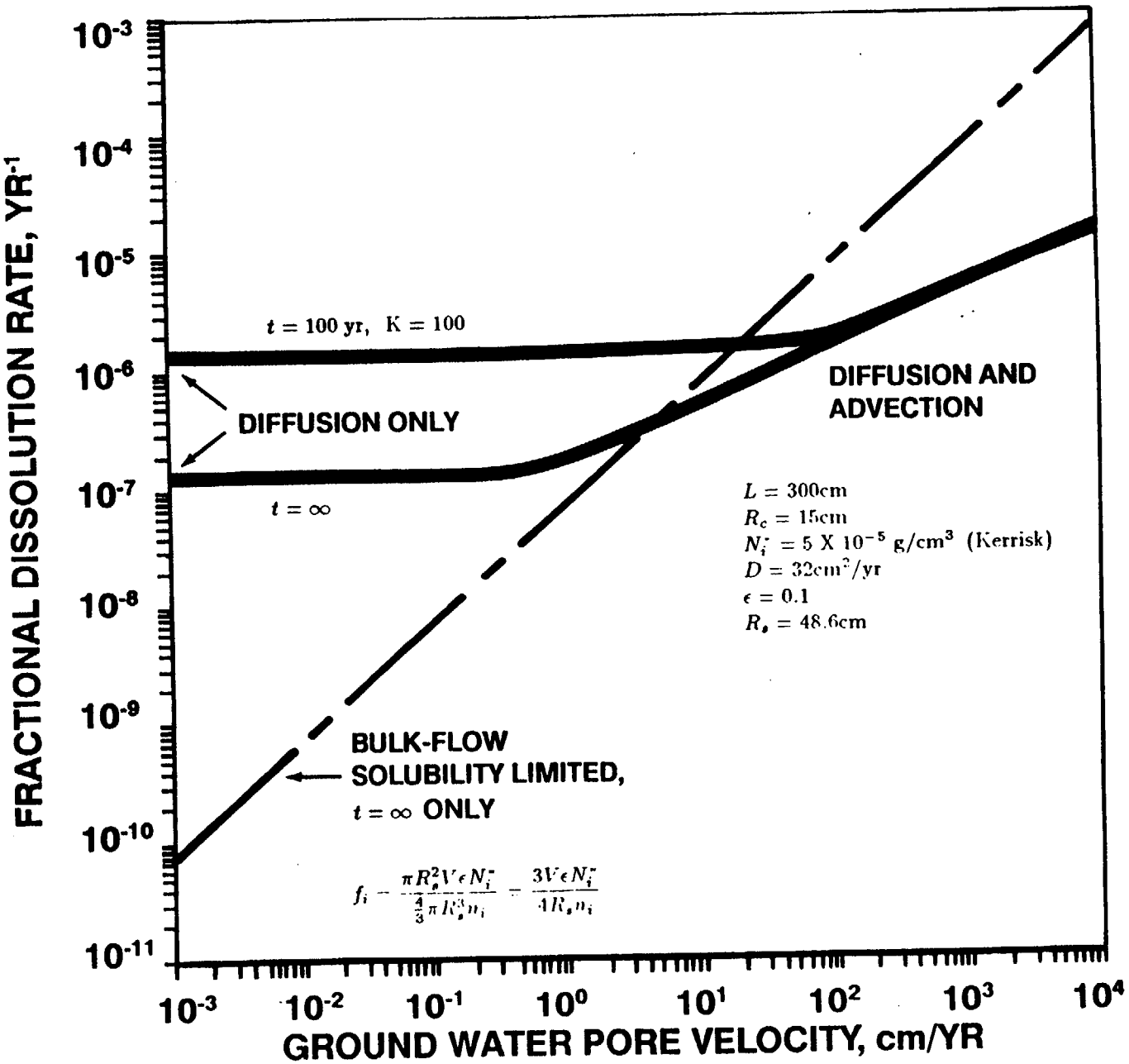
NORMALIZED MASS-TRANSFER RATE AS A FUNCTION OF TIME AND RETARDATION COEFFICIENT (K); DIFFUSION FROM SPHERICAL WASTE FORM



RELEASE RATE AS A FUNCTION OF GROUND WATER VELOCITY
DIFFUSIVE-ADVECTIVE MASS TRANSFER
(UO_2 IN AN OXIDIZING ENVIRONMENT)



COMPARISON OF WET-DRIP AND WET-CONTINUOUS CASES FRACTIONAL RELEASE RATES FOR UO_2 IN AN OXIDIZING ENVIRONMENT



WET-CONTINUOUS CASE, LOW-FLOW RELEASE RATES FOR DEFENSE WASTE BOROSILICATE GLASS

ELEMENT	CONCENTRATION IN WASTE[a] (g/cm^3)	SATURATION CONCENTRATION[b] (g/m^3)	FRACTIONAL RELEASE RATE[c] (PER YEAR)
Si	7.6×10^{-1}	3.2×10^{2}	7.6×10^{-7}
U	5.4×10^{-2}	4.7×10^{-2}	1.6×10^{-9}
Np	5.3×10^{-5}	3.0×10^{-4}	1.0×10^{-8}
Pu	3.0×10^{-4}	3.8×10^{-10}	2.3×10^{-15}
Am	4.1×10^{-7}	1.5×10^{-3}	6.6×10^{-6}
Cs	2.0×10^{-3}	6.2×10^{-1}	5.6×10^{-7}

NOTES:

A. DATA FROM BRUTON, 1987; WASTE DENSITY = 3 g/cm^3

B. DATA FROM BRUTON, 1987, AT 90 C; EXCEPT Cs SOLUBILITY FROM APTED, 1989

C. WASTE CYLINDER 0.3m RADIUS, 2.5m LONG; PORSITY = 0.16; DIFFUSION COEFFICIENT 10^{4} cm^2/s; LOW-FLOW STEADY STATE MASS TRANSFER ANALYSIS

EVOLUTION OF SOLUBILITY DATA FOR SPENT FUEL SOLUBILITY (MOLES/L) AT 25 C

ELEMENT	EA 1986	SCP 1988	LLNL 1989
Am	1×10^{-8}	1×10^{-6}	1.6×10^{-10}
Np	3×10^{-3}	1×10^{-3}	6.3×10^{-6} to 10^{-9}
Pu	1.8×10^{-6}	1×10^{-5}	4×10^{-13} to 1.6×10^{-4} NOTE a. 5×10^{-5} to 2×10^{-6} NOTE b.
U	2.1×10^{-4}	4×10^{-3}	6.3×10^{-5} NOTE c.

NOTES:

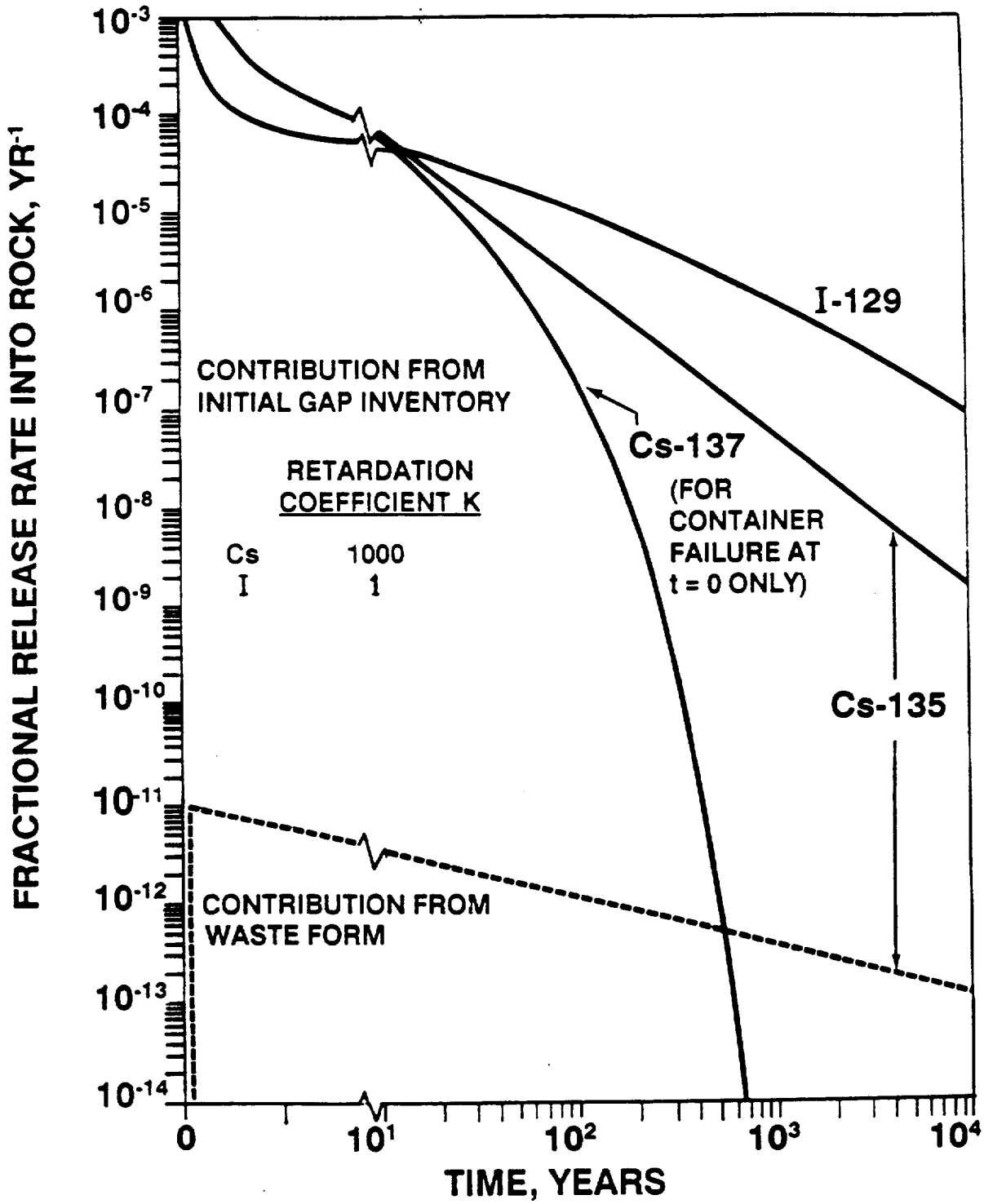
A. AS PuO_2

B. AS AMORPHOUS $Pu(OH)_4$

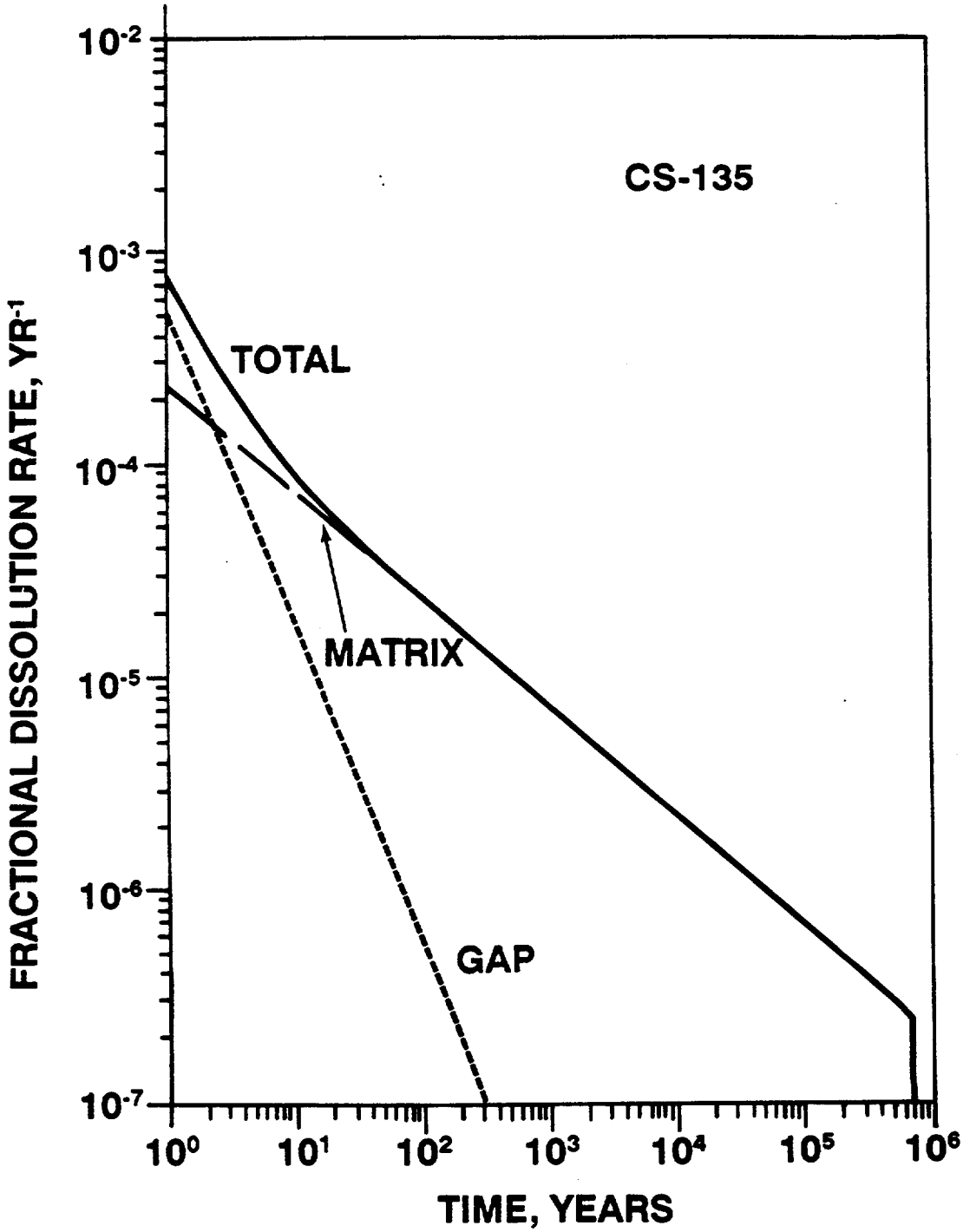
C. IN EQUILIBRIUM WITH ATMOSPHERIC OXYGEN

FRACTIONAL RELEASE RATES FROM SPENT FUEL INTO ROCK AS A FUNCTION OF TIME (10cm OF VOID WATER, 1% OF TOTAL CESIUM AND IODINE IS IN GAP, D = 0.12 M^2/YR, NON-OXIDIZING ENVIRONMENT)

NWI-RD5P A13/5 16, 17-89 30

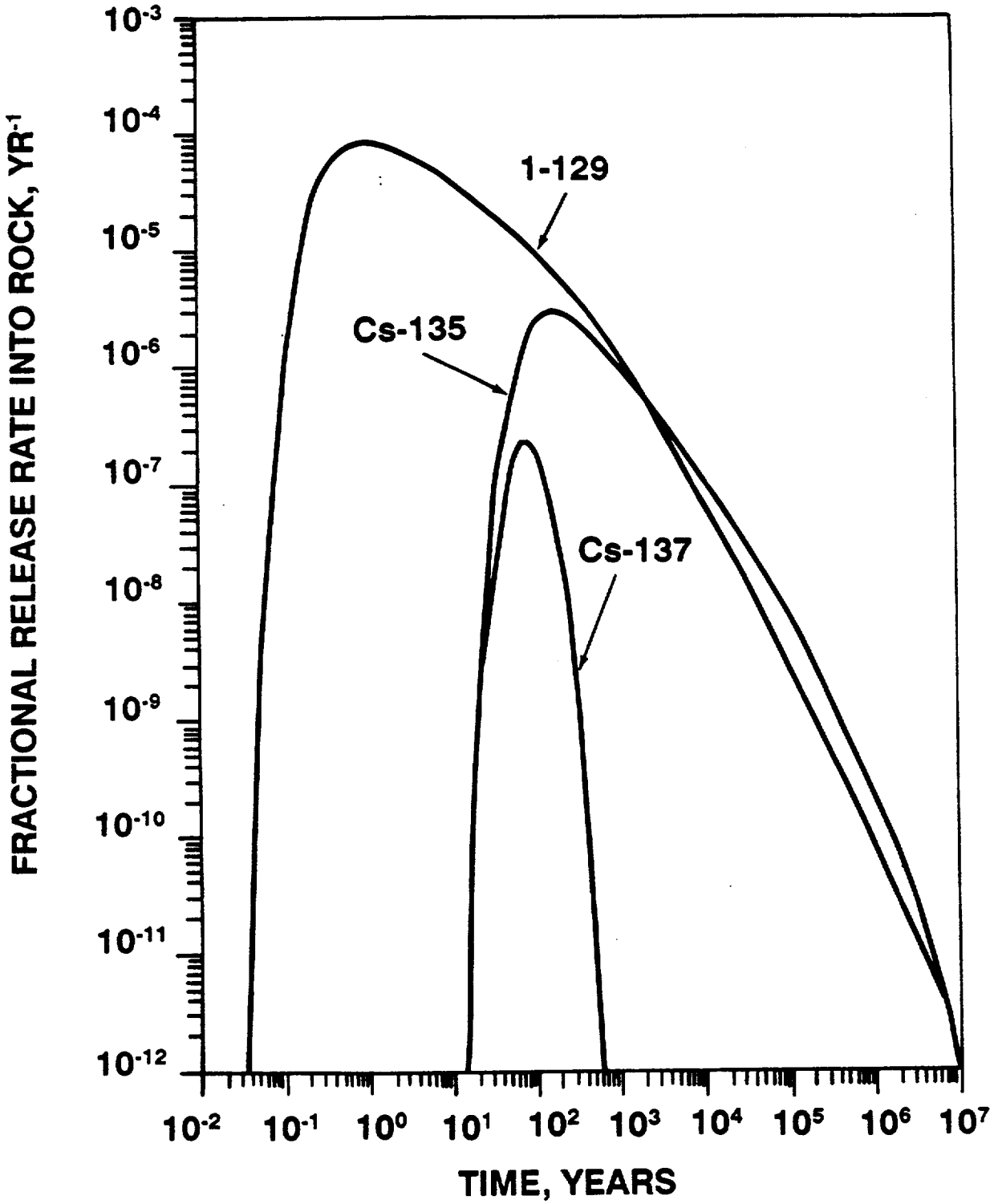


FRACTIONAL RELEASE RATES FROM SPENT FUEL INTO ROCK AS A FUNCTION OF TIME (10cm OF VOID WATER, 1% OF TOTAL CESIUM AND IODINE IS IN GAP, D = 0.12 M^2/YR, OXIDIZING ENVIRONMENT)



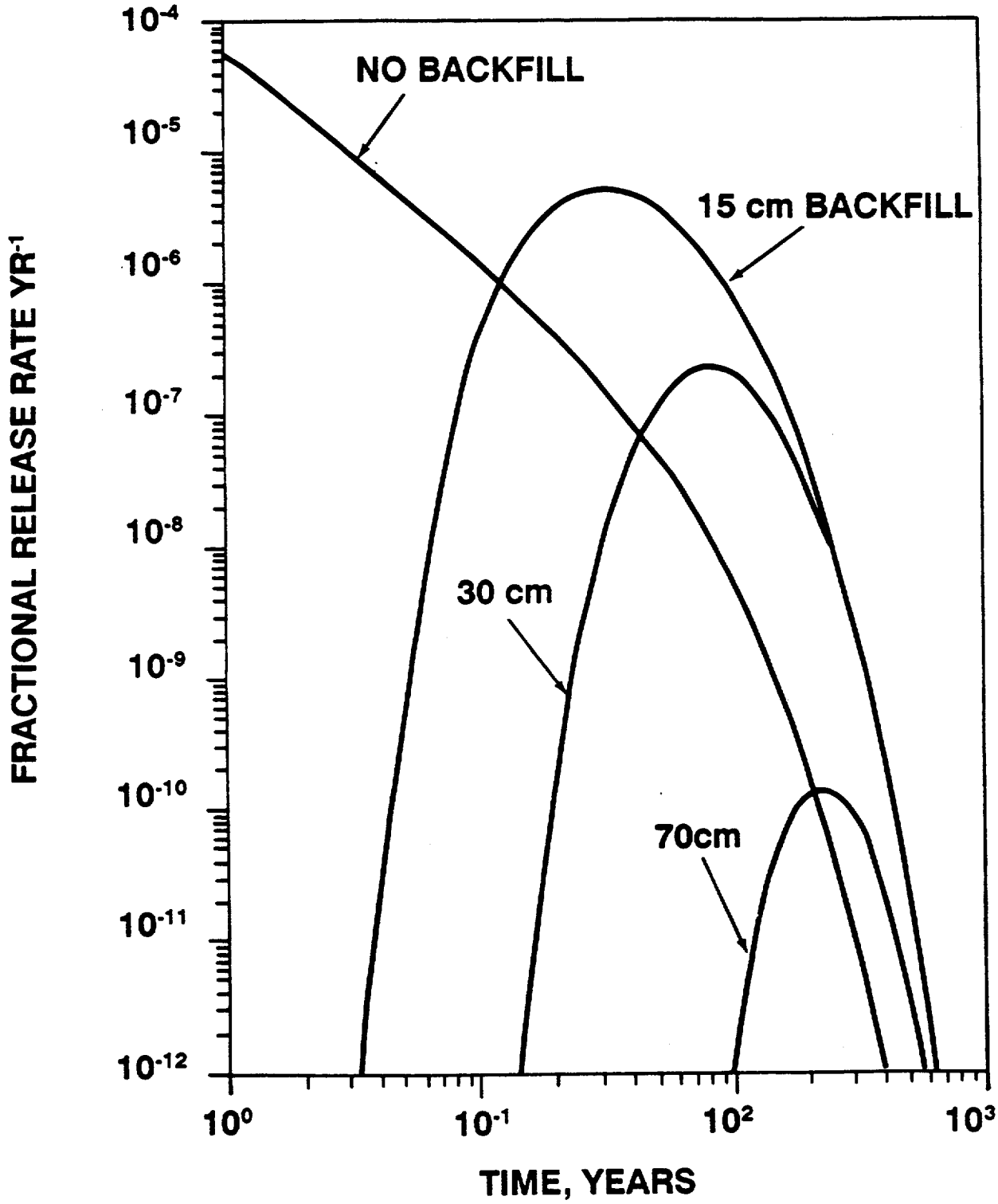
NWFRD5P.A13/5-16, 17-89 31

RELEASE RATES OF SOLUBLE SPECIES THROUGH 0.3m OF BACKFILL



NWFRD5P A13/5-16, 17-89 32

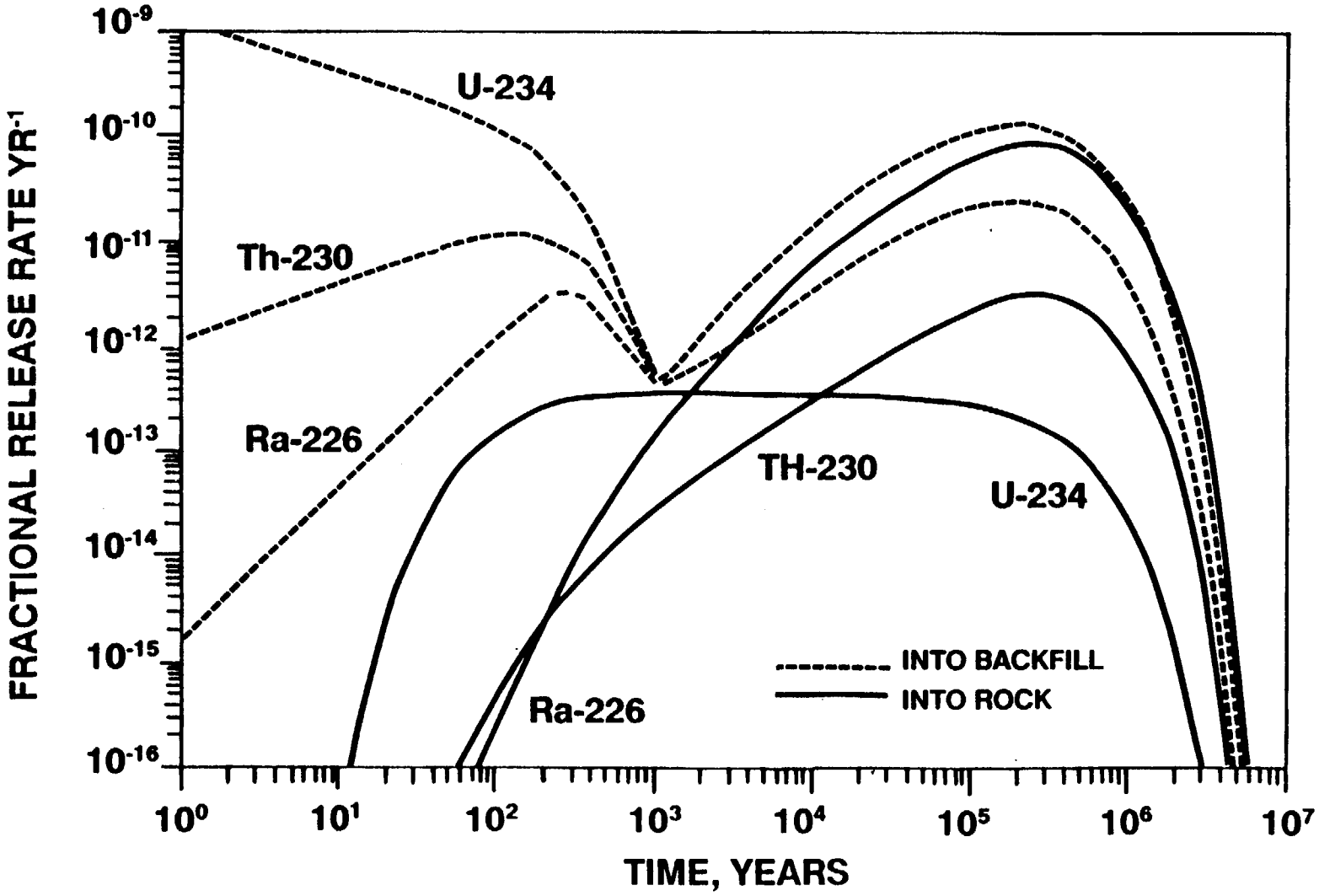
RELEASE RATES OF SOLUBLE Cs-137 SPECIES AS A FUNCTION OF BACKFILL THICKNESS



OTHER USUAL ASSUMPTIONS IN MASS-TRANSFER THEORY

1. EFFECT OF A LIQUID-FILLED ANNULUS BETWEEN WASTE & ROCK
2. EFFECT OF FLOW DIRECTION AND GEOMETRY
3. HYDRODYNAMIC DISPERSION
4. EFFECT OF RADIOACTIVE DECAY
5. LOCAL SORPTION EQUILIBRIUM
6. LINEAR SORPTION: CONSTANT DISTRIBUTION COEFFICIENT, CONSTANT RETARDATION COEFFICIENT
7. SURFACE DIFFUSION
8. INTERFERENCE FROM OTHER WASTE PACKAGES
9. POROUS OR FRACTURED ROCK
10. CONSTANT TEMPERATURE
11. CONSTANT AND UNIFORM CHEMICAL ENVIRONMENT
12. NO RADIOACTIVE DECAY PRECURSOR

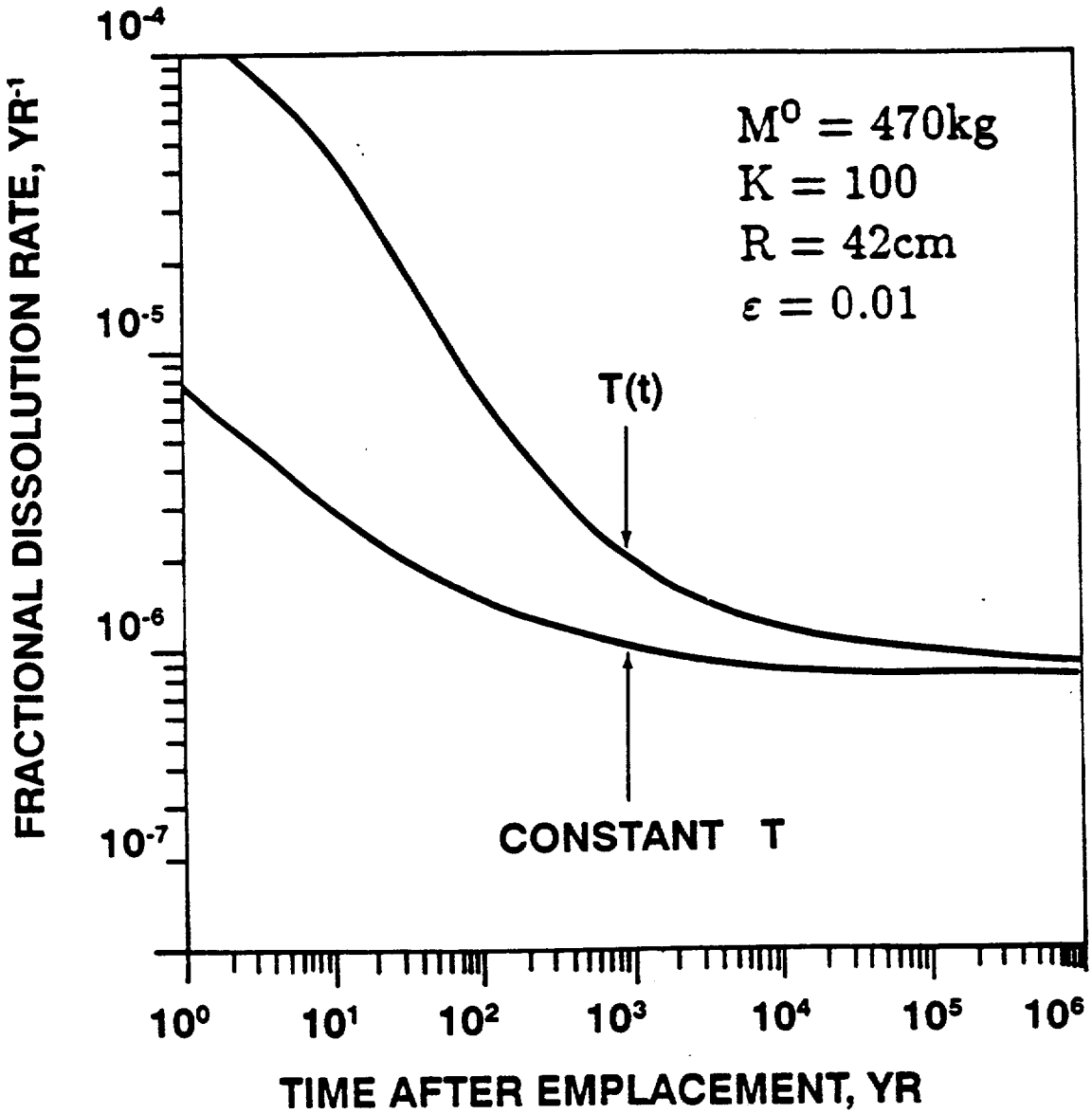
FRACTIONAL RELEASE RATES OF A RADIONUCLIDE DECAY CHAIN, NORMALIZED TO 1000 YEAR INVENTORIES



NOTE: Th-230 AND Ra-226 ASSUMED TO BE RELEASED CONGRUENTLY WITH U-234

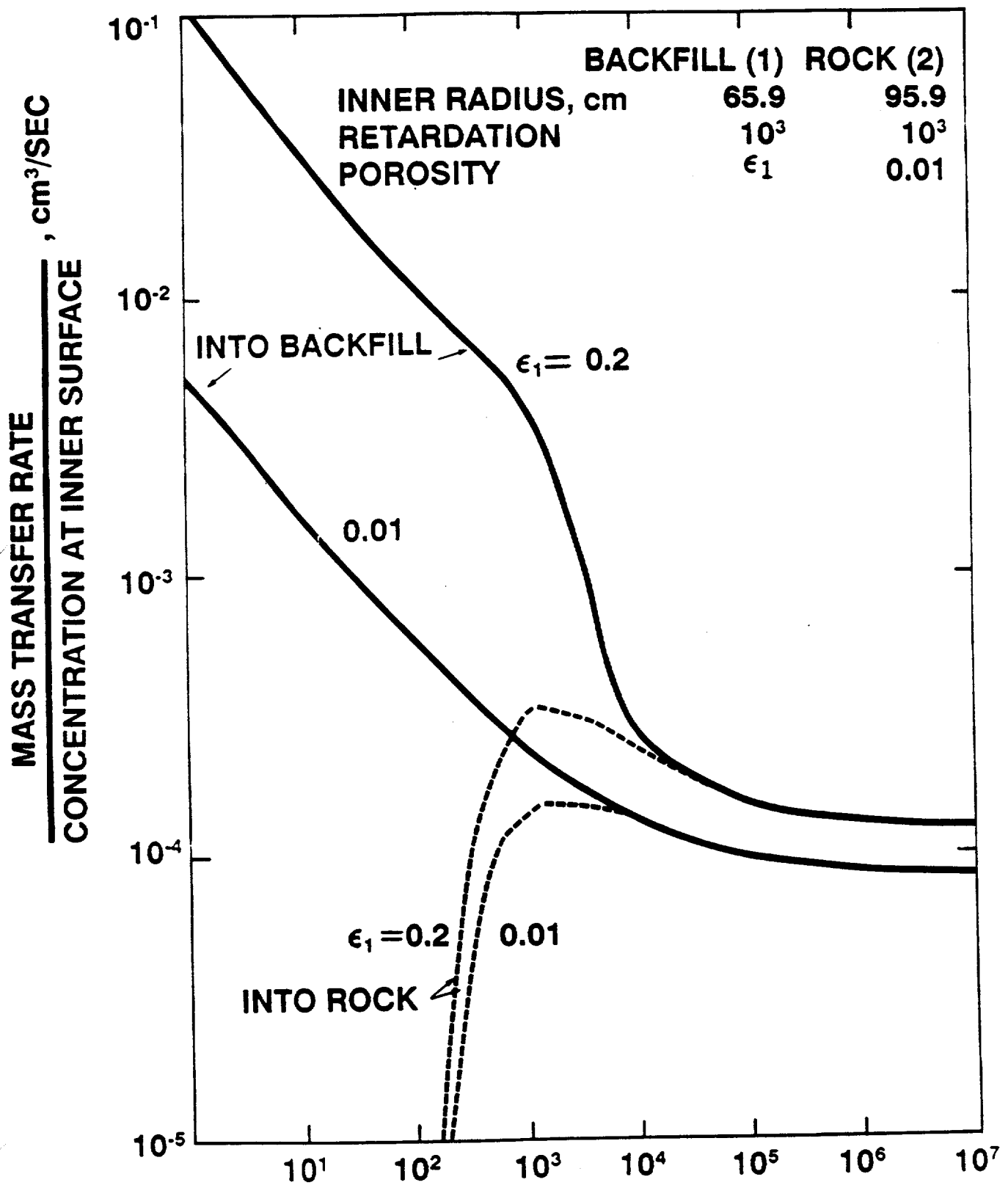
NWFRD5P A13/5 16, 17-89

FRACTIONAL DISSOLUTION RATE FOR SILICA NORMALIZED TO INITIAL INVENTORY - EFFECT OF REPOSITORY HEATING



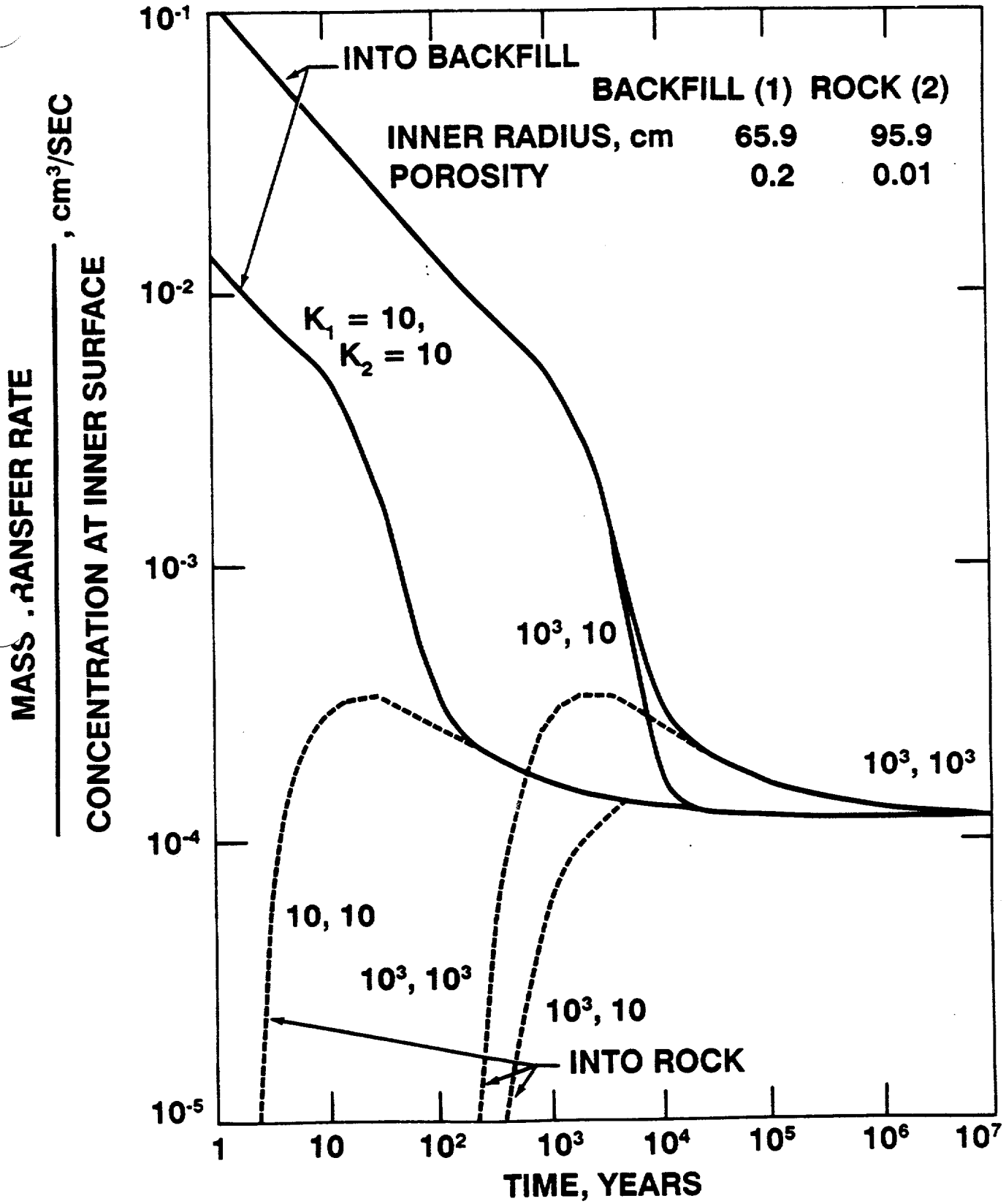
NWFRD5P.A13/5-16, 17-89

EFFECT OF BACKFILL POROSITY (ϵ)
(NO RADIOACTIVE DECAY)



NWI RD5P A13/5-16, 17-89

EFFECT OF RETARDATION (K) IN BACKFILL AND ROCK (NO RADIOACTIVE DECAY)



NWFRD5P A13/5-16, 17-89

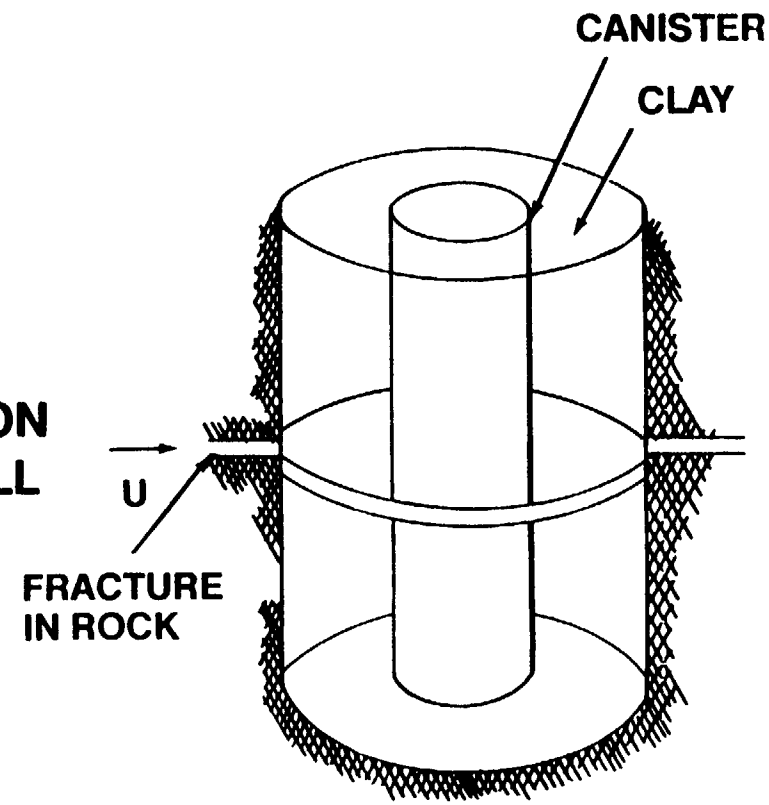
TRANSPORT OF RADIONUCLIDES IN THE BACKFILL SURROUNDING A WASTE FORM IN FISSURED ROCK

BACKGROUND

- IN MOST KINDS OF ROCK, THERE ARE NUMEROUS FRACTURES
- FRACTURES HAVE LARGER PERMEABILITY THAN ROCK

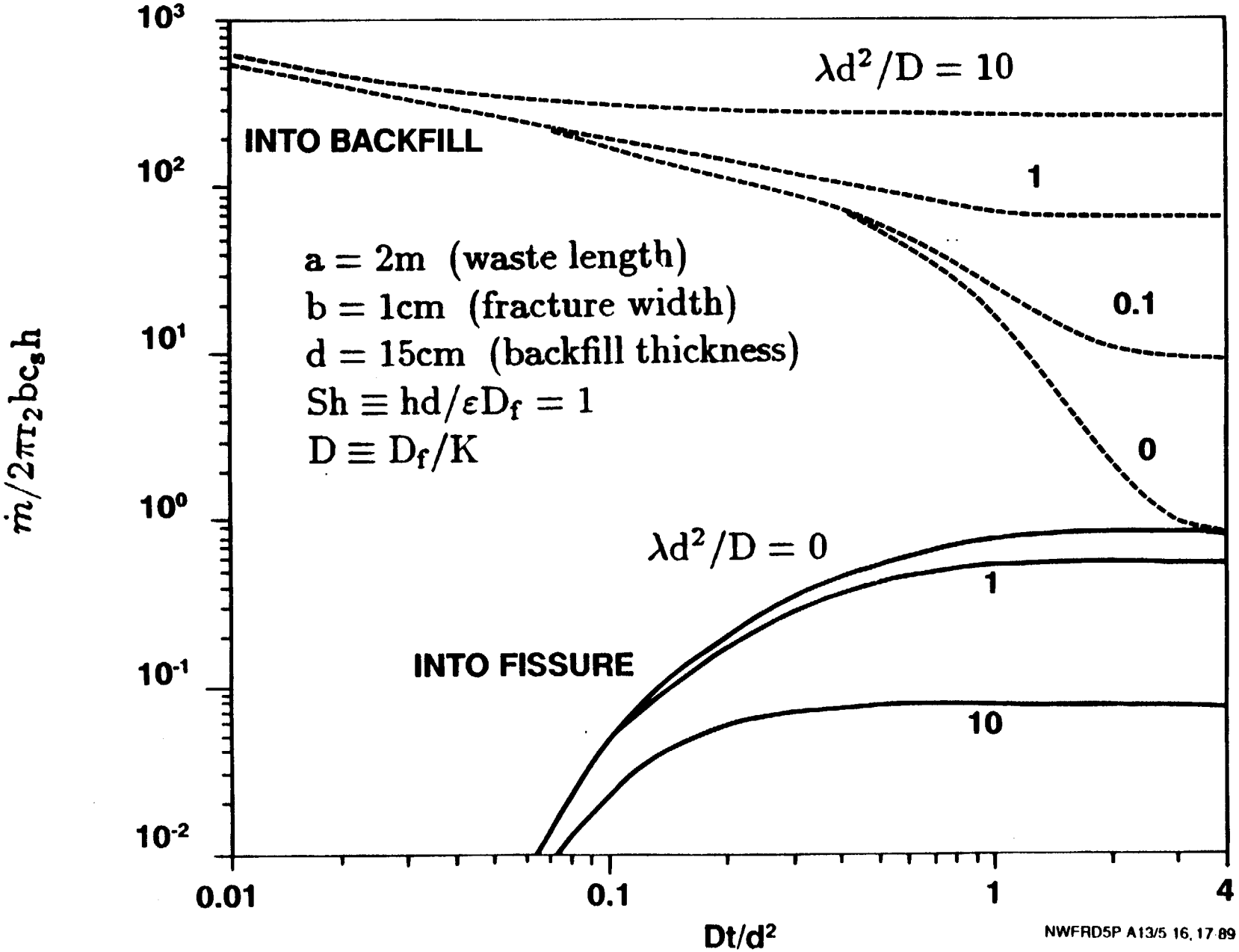
ASSUMPTION

- WATER-SATURATED BACKFILL
- NO CANISTER
- CONSTANT SPACING FRACTURE AND PERPENDICULAR TO WASTE FORM
- CONSTANT SURFACE CONCENTRATION
- NO GROUNDWATER FLOW IN BACKFILL
- COMPLETELY IMPERVIOUS ROCK



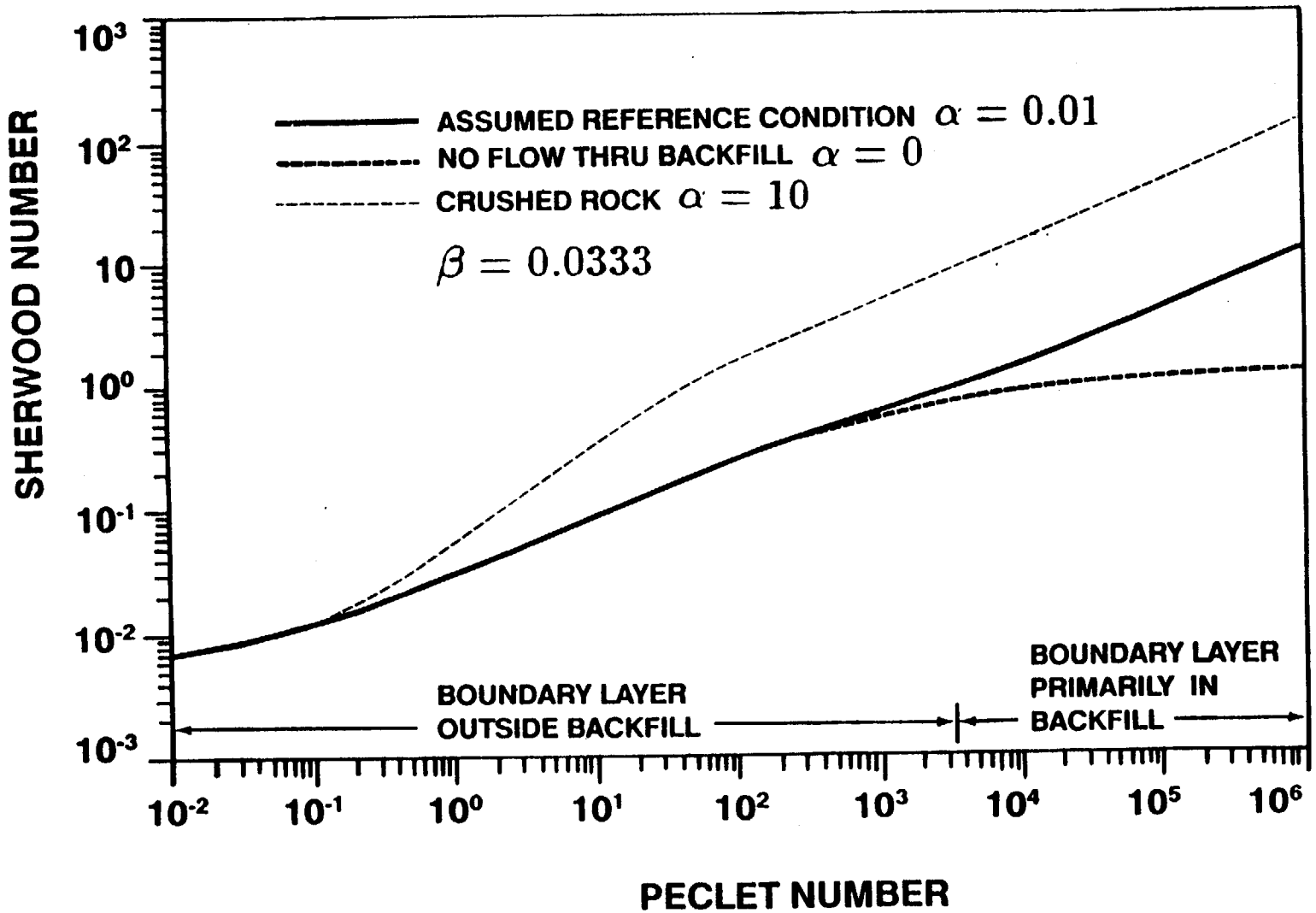
NWFRD5P A13/5:16, 17 89

RELEASE INTO BACKFILL AND INTO FISSURED ROCK



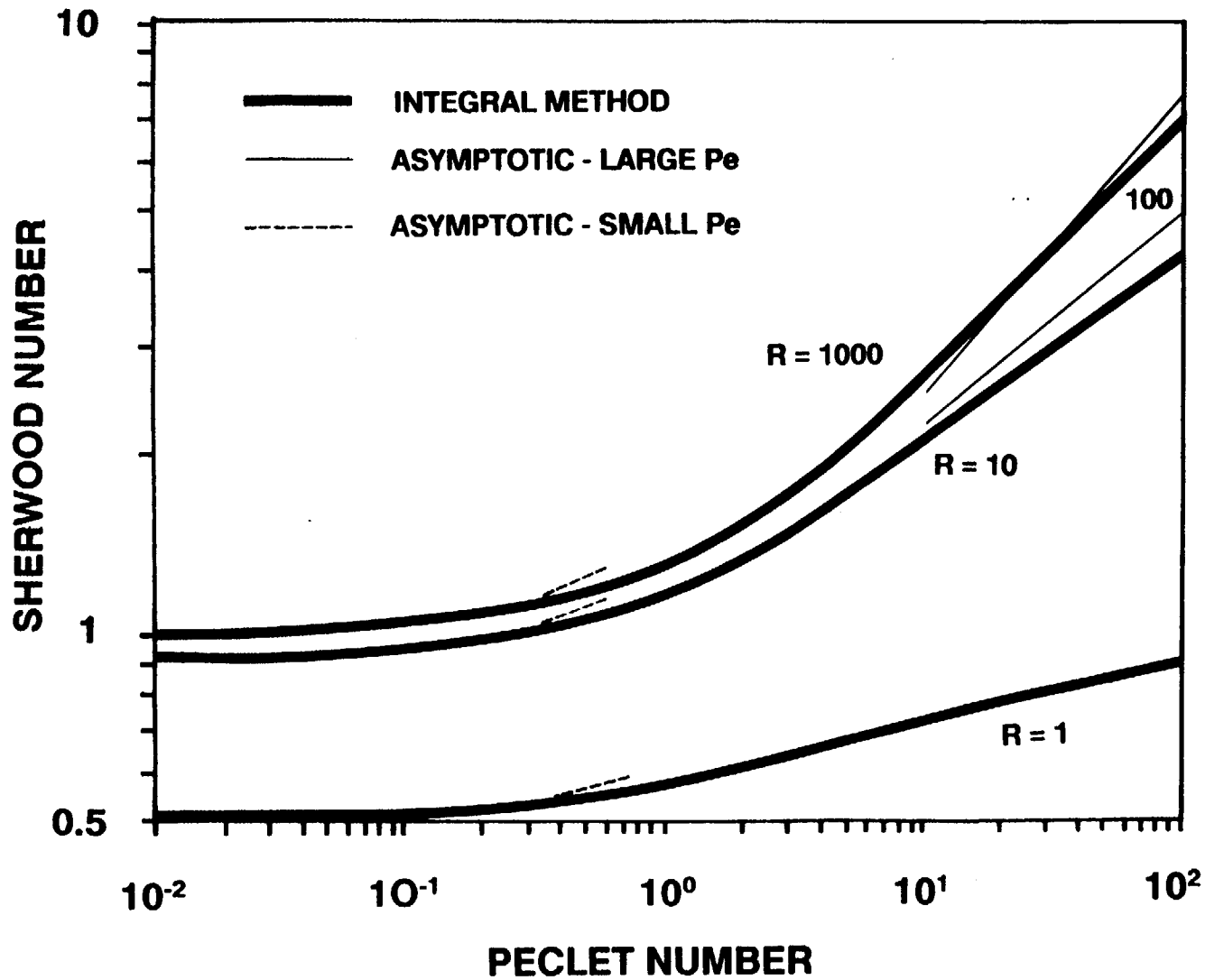
NWFRD5P A13/5 16, 17 89

EFFECT OF FLOW THROUGH BACKFILL ON RELEASE RATE (RELEASE RATE IS PROPORTIONAL TO SHERWOOD NUMBER)



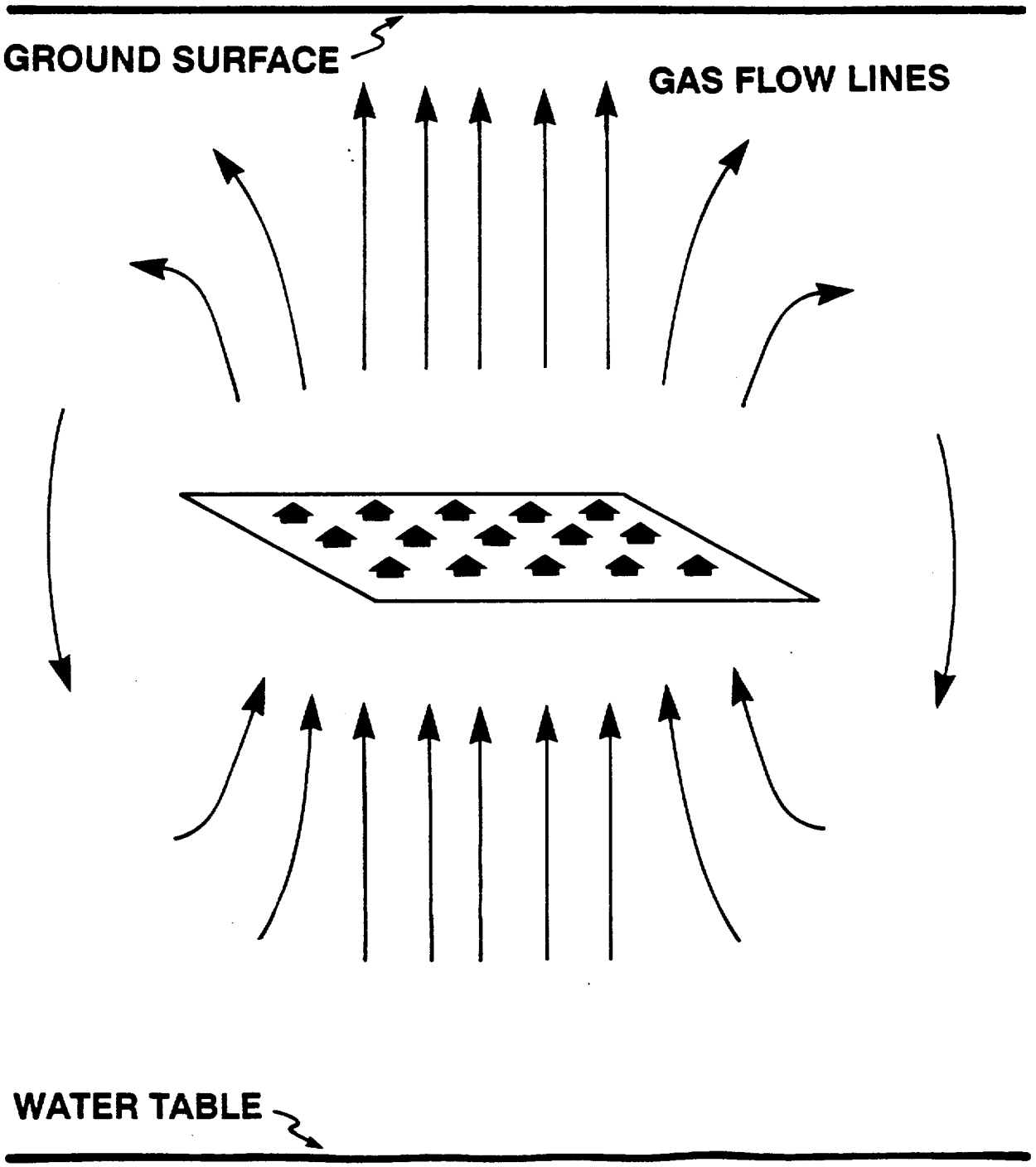
NWFRD5P.A13/5-16, 17-89

EFFECT OF FLOW RATE AND REACTION RATE ON RELEASE RATE (RELEASE RATE IS PROPORTIONAL TO THE SHERWOOD NUMBER)



NWFRD5P.A13/5-16, 17-89

YUCCA MOUNTAIN HLW REPOSITORY
GAS FLOW FIELD

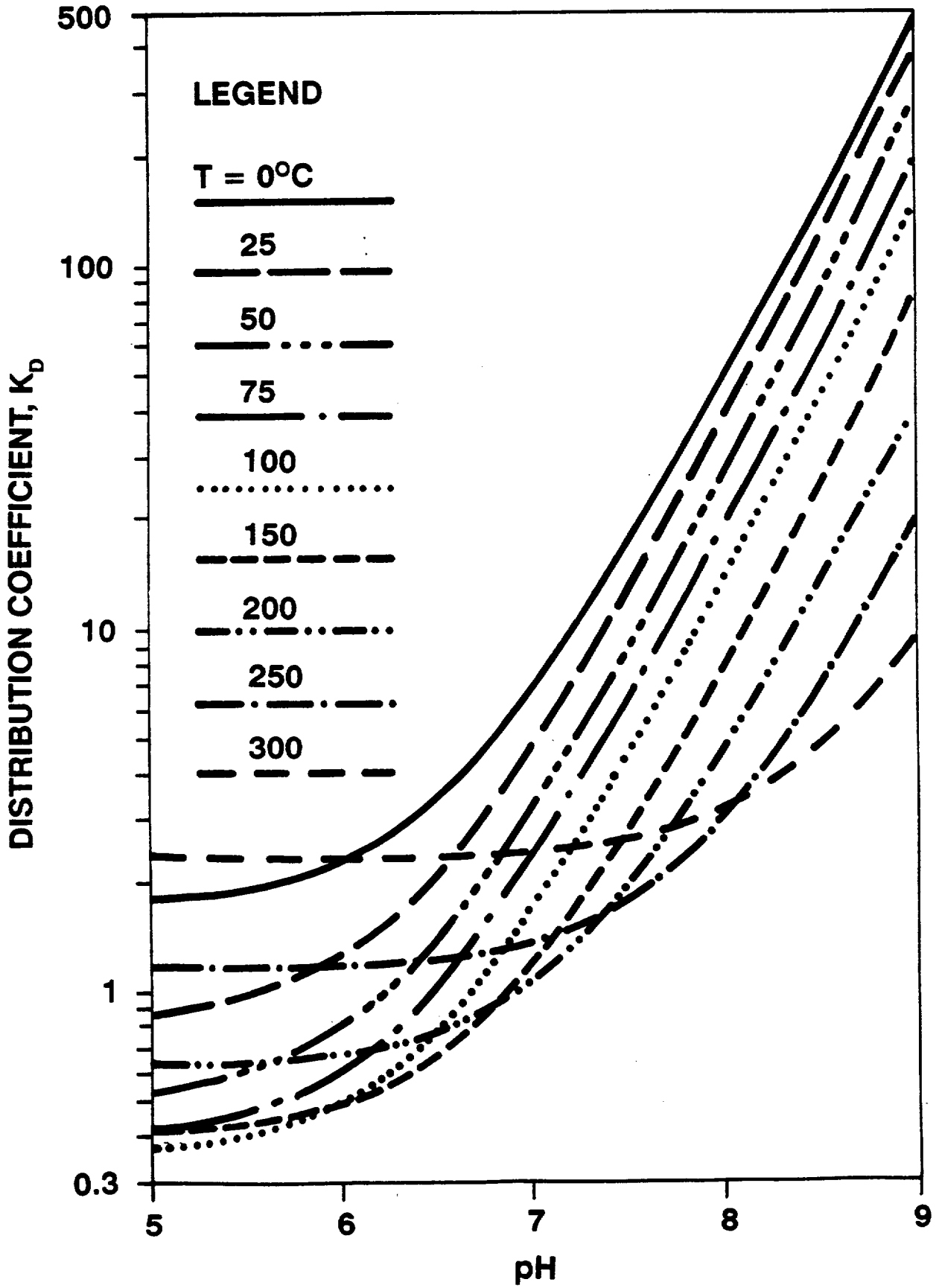


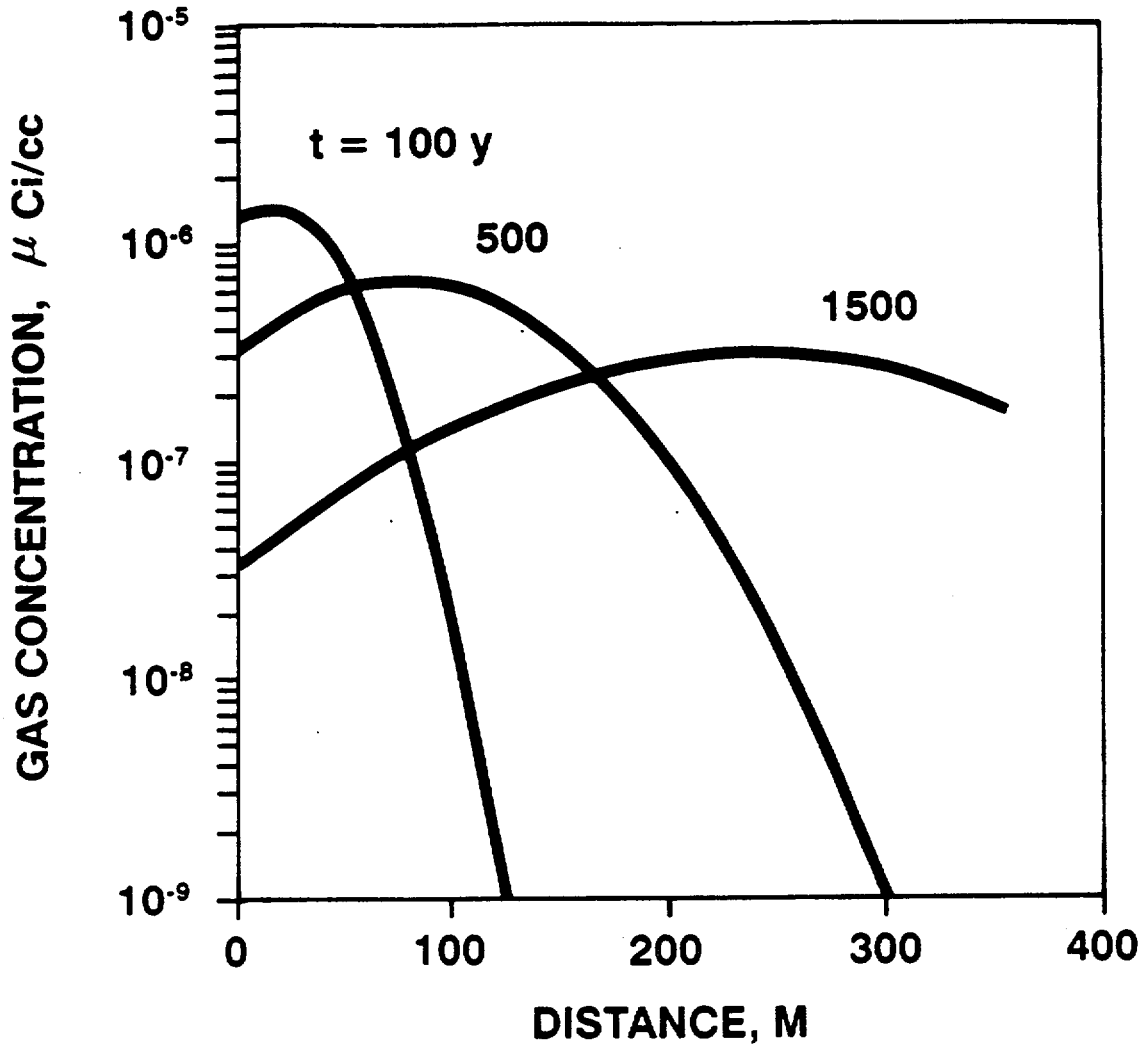
NWFRD5P.A13/5-16, 17-89

MODEL FEATURES

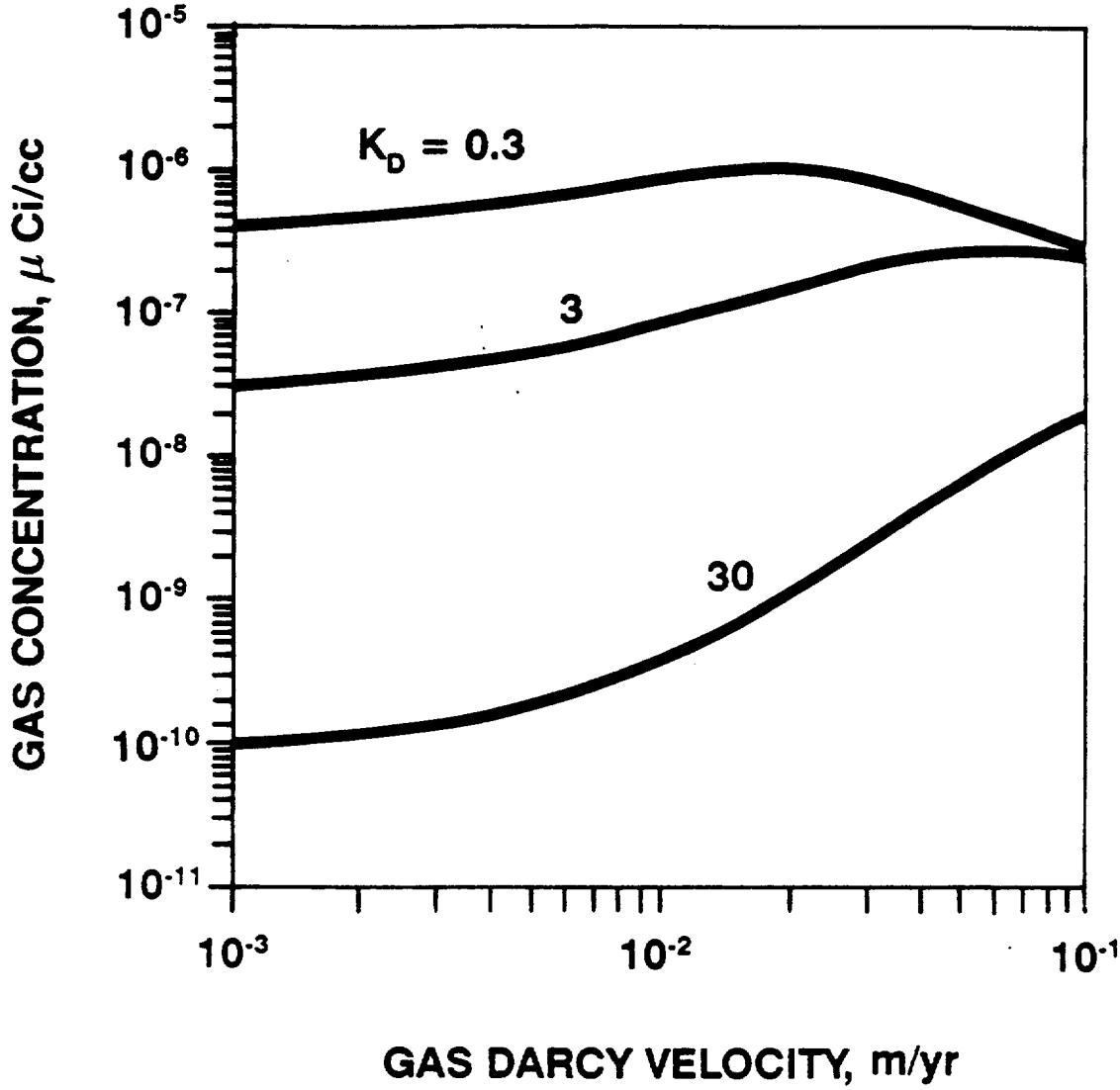
- ^{14}C IS RELEASED AS GASEOUS $^{14}CO_2$ AT THE REPOSITORY HORIZON
- $^{14}CO_2$ IS ADVECTED UPWARD THROUGH A FRACTURE
- SOME OF THE $^{14}CO_2$ DISSOLVES INTO THE PORE WATER OF THE ADJACENT WET-ROCK MATRIX
- EQUILIBRIUM IS MAINTAINED AT THE FRACTURE INTERFACE BETWEEN $^{14}CO_2$ IN THE GAS PHASE AND DISSOLVED ^{14}C IN THE LIQUID PHASE
- THE DISSOLVED ^{14}C DIFFUSES TRANSVERSLY IN THE WET-ROCK MATRIX

DISTRIBUTION COEFFICIENT FOR CO_2 ABSORPTION IN GROUND WATER

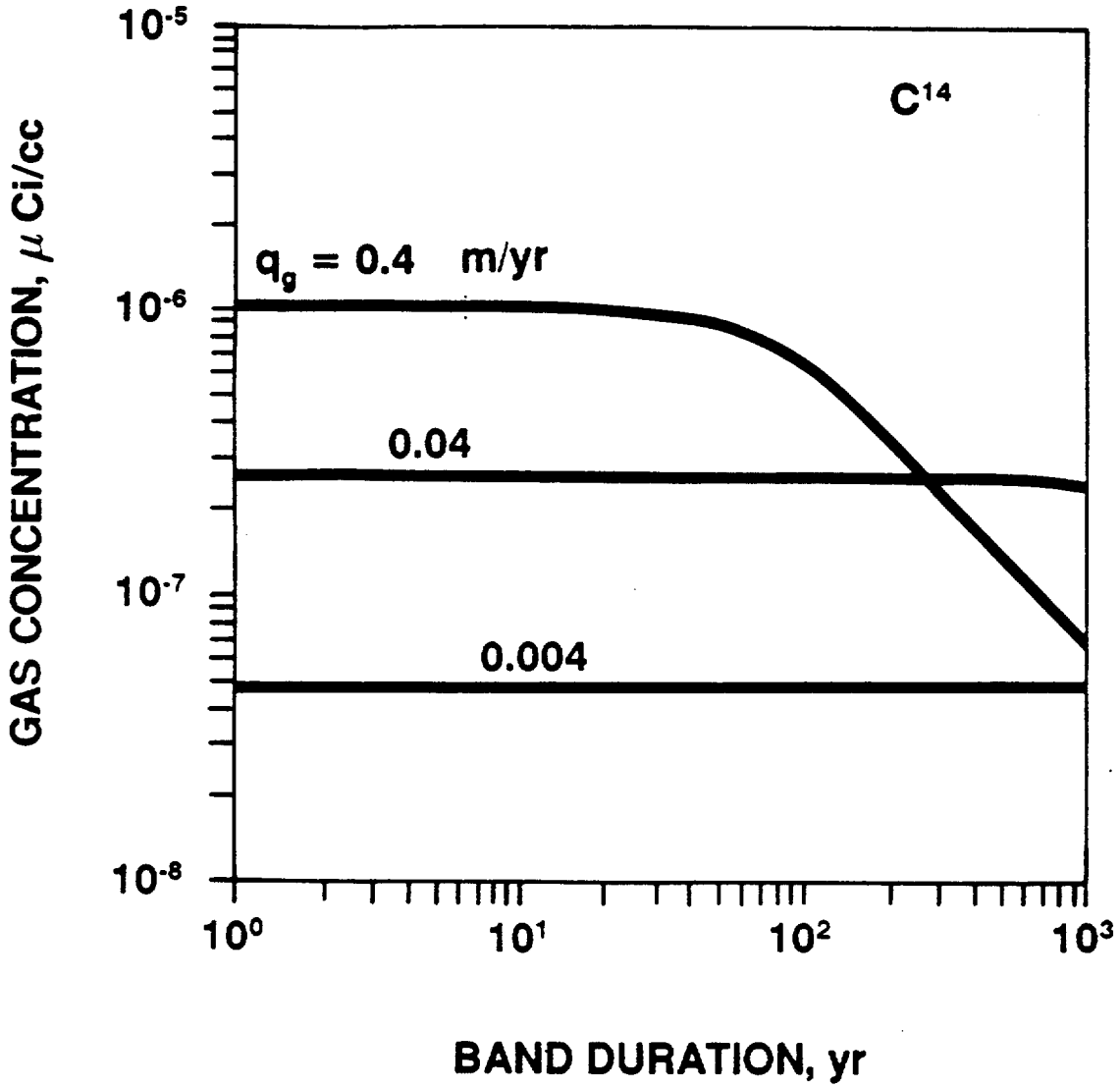




$^{14}CO_2$ CONCENTRATION VS. DISTANCE FOR IMPULSE RELEASE FROM INFINITE PLANE SOURCE (0.$\bar{0}$4 m/yr)

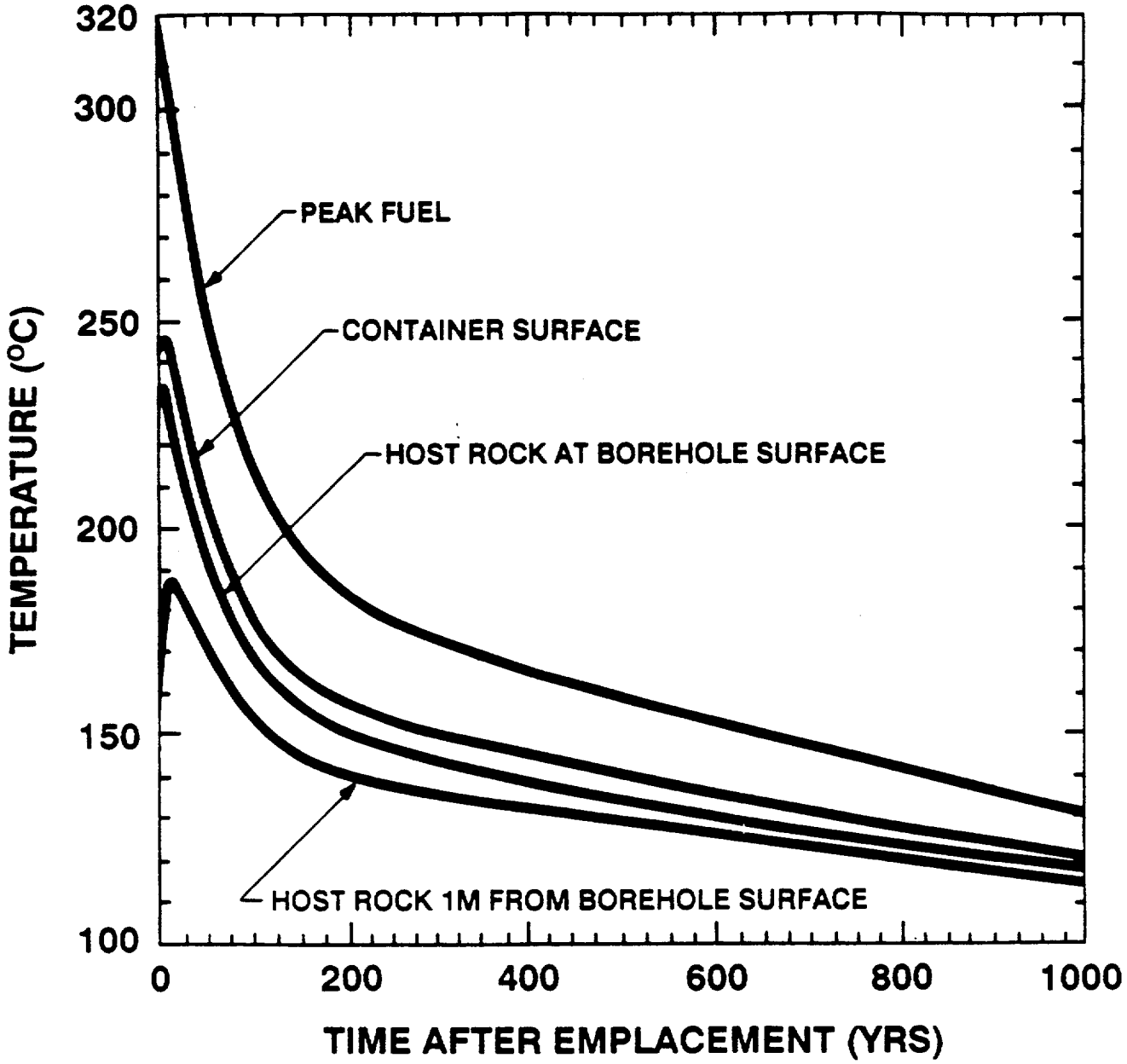


PEAK SURFACE CONCENTRATION OF $^{14}CO_2$ (Z = 350M) VS. GAS DARCY VELOCITY FOR BAND (1000 yr) RELEASE FROM INFINITE PLANE SOURCE



PEAK SURFACE CONCENTRATION OF $^{14}CO_2$ (Z = 350M) VS. BAND - RELEASE DURATION FOR INFINITE PLANE SOURCE

CALCULATED TEMPERATURE FOR REFERENCE WASTE PACKAGE IN TUFF



NWFRD5P.A13/5-16,17-89

WASTE FORM - SPENT FUEL (PRESSURIZED WATER REACTOR)

LOCAL POWER DENSITY - 57.0 KW/ACRE

AREAL POWER DENSITY - 48.4 KM/ACRE

AVERAGE PACKAGE POWER AT BURIAL - 3.3 KW

(10 YRS OUT OF REACTOR)

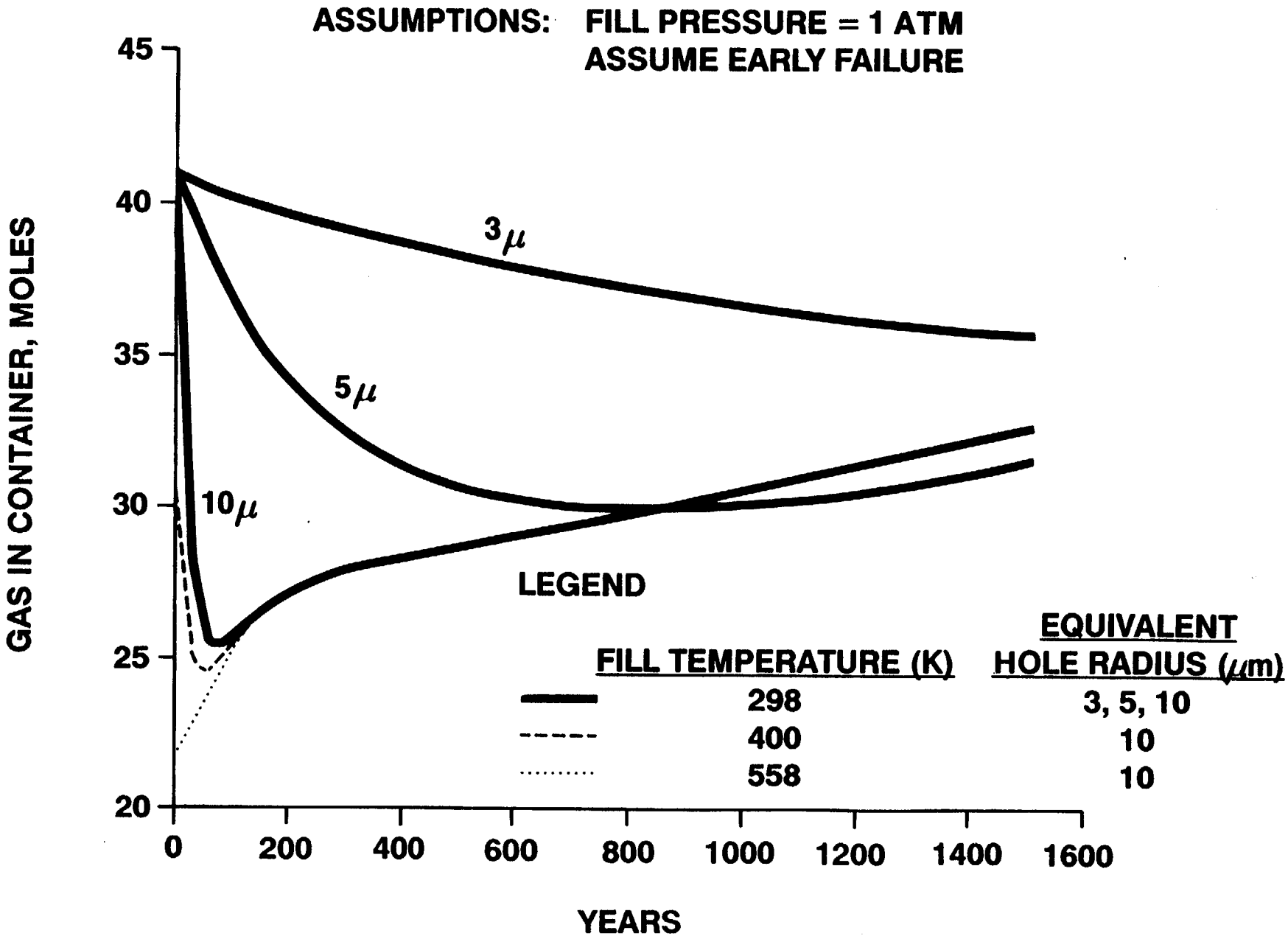
CONTAINER DIAMETER -0.7 M

PACKAGE SPACING - 5M

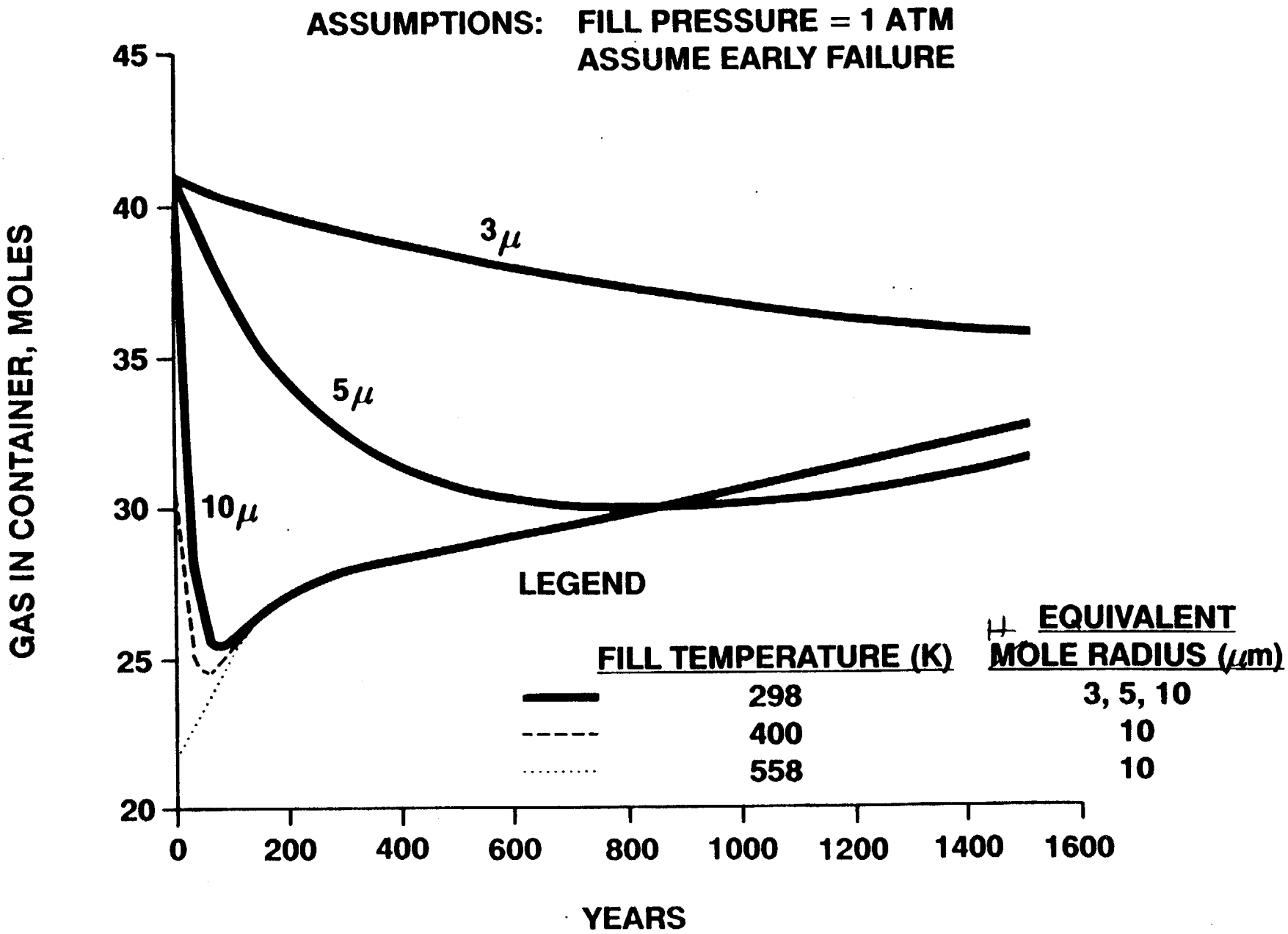
DRIFT SPACING - 46.86 M

DIRECTORY NO. - P57V3.3A
(DOE-SCP, 1988 p. 7-14)

GAS IN A WASTE CONTAINER, RESULT OF WASTE COOLING AND FLOW THROUGH PENETRATIONS



GAS IN A WASTE CONTAINER, RESULT OF WASTE COOLING AND FLOW THROUGH PENETRATIONS



FURTHER WORK NEEDED

FOCUS

1. REFINE AND VALIDATE PRESENT PREDICTIVE CAPABILITY

   - METHODOLOGY
   - DATA BASE FOR PARAMETERS

2. EVALUATE GASEOUS RELEASES: $^{14}CO_2$, ^{3}H, ^{85}Kr, ^{129}I

3. ASSESS THE PREDICTION OF LOWER RELEASE RATES FROM MORE REALISTIC MODELS

4. EVALUATE ADDITIONAL PHENOMENA THAT CAN AFFECT RELEASE RATES

SPECIFIC EXAMPLES OF FURTHER WORK NEEDED

1. REFINE AND VALIDATE PRESENT PREDICTIVE CAPABILITY

   - DEVELOP PROGRAM-WIDE UNDERSTANDING OF PRESENT CAPABILITY AND OF DATA NEEDS VIA TIG'S NEW TEST PROBLEMS

   - COMPLETE DOCUMENTATION OF PRESENT CAPABILITY

   - APPLY ADDITIONAL SUBMODELS ALREADY DEVELOPED

   - REFINE DATA AND ANALYSES ON EFFECTIVE SATURATION CONCENTRATIONS, INCLUDING EFFECT OF AIR INFLOW THROUGH FAILED CONTAINERS

   - MEASURE LIQUID DIFFUSION COEFFICIENTS AND CONNECTED POROSITY IN TUFF

   - PERFORM EXPERIMENTS TO VALIDATE THE THEORY UNDERLYING THE PREDICTIVE MODELS

SPECIFIC EXAMPLES OF FURTHER WORK NEEDED

2. EVALUATE GASEOUS RELEASES

- DETERMINE THE TIME-DEPENDENT SOURCE AND AMOUNT OF $^{14}CO_2$, ^{3}H, ^{85}Kr, ^{129}I THAT CAN BE MOBILIZED WITHIN A FAILED WASTE PACKAGE AND THE RATE OF ESCAPE THROUGH PENETRATIONS

- EVALUATE THE SPACE-TIME-DEPENDENT RETARDATION COEFFICIENT FOR CARBON DIOXIDE, AS AFFECTED BY TEMPERATURE, pH, LOCAL MOISTURE CONTENT IN TUFF, CALCITE, AND GROUND-WATER EVAPORATION

- EVALUATE THE SPACE-TIME-DEPENDENT FLOW RATE OF AIR IN THE HEATED REPOSITORY

- DETERMINE THE EXTENT TO WHICH THE PEAK CONCENTRATIONS OF GASEOUS EFFLUENTS AT THE SUBSURFACE ARE AFFECTED BY THEIR RATE OF RELEASE AT THE REPOSITORY HORIZON

SPECIFIC EXAMPLES OF FURTHER WORK NEEDED

3. INVESTIGATE MORE REALISTIC MODELS THAT ARE EXPECTED TO PREDICT LOWER RELEASE RATES TO GROUND WATER

- DEVELOP A MODEL FOR THE TIME OF CONTAINER FAILURE BY LOCALIZED PENETRATIONS AND THE SIZE, GEOMETRY, AND GROWTH OF THOSE PENETRATIONS

- DETRMINE THE FLOW OF GROUND WATER THROUGH THE SMALL PENETRATIONS IN A FAILED CONTAINER

- DETERMINE THE RATE OF DIFFUSION AND CONVECTION OF DISSOLVED RADIONUCLIDES OUT OF CONTAINER PENETRATIONS

- DETERMINE THE EFFECT OF TRANSPORT BARRIERS DUE TO SMALL PENETRATIONS IN DEFECTIVE FUEL CLADDING

- DETERMINE THE EFFECT OF UNCONNECTED POROSITY IN UNSATURATED TUFF ON DIFFUSIVE TRANSPORT

- DETERMINE THE TRANSPORT THROUGH RUBBLE IN THE CONTAINER-ROCK ANNULUS

SPECIFIC EXAMPLES OF FURTHER WORK NEEDED

4. EVALUATE THE EFFECT OF ADDITIONAL PHENOMENA THAT CAN AFFECT RELEASE RATES

- AIR INLEAKAGE THROUGH FAILED CONTAINERS
  - EFFECT ON SATURATION CONCENTRATIONS
  - OXIDATION OF ZIRCALOY CLADDING
  - OXIDATION OF URANIUM DIOXIDE
  - MOBILIZATION OF GASEOUS SPECIES

- ALPHA RADIOLYSIS
  - CAN RESULT IN HIGHER OXIDATIONS STATES AND INCREASED SATURATION CONCENTRATION
  - A REDOX FRONT NEAR THE WASTE SURFACE AND AN INCREASED CONCENTRATION GRADIENT AT THE WASTE SURFACE CAN INCREASE RELEASE RATE INTO GROUND WATER

- DIFFUSIVE-ADVECTIVE MASS TRANSFER FROM WASTE SOLID TO WATER INSIDE A WASTE CONTAINER
  - POTENTIALLY IMPORTANT IF VOID SPACE INSIDE CONTAINER IS FILLED WITH LOW-POROSITY MATERIAL

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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: PASS PROGRAM

PRESENTER: DR. M. J. APTED

PRESENTER'S TITLE AND ORGANIZATION:
DEPUTY MANAGER
PASS PROGRAM
BATTELLE PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

PRESENTER'S TELEPHONE NUMBER: (509) 376-4601

MAY 16-17, 1989

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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: PASS PROGRAM

PRESENTER: DR. M. J. APTED

PRESENTER'S TITLE AND ORGANIZATION:
DEPUTY MANAGER
PASS PROGRAM
BATTELLE PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

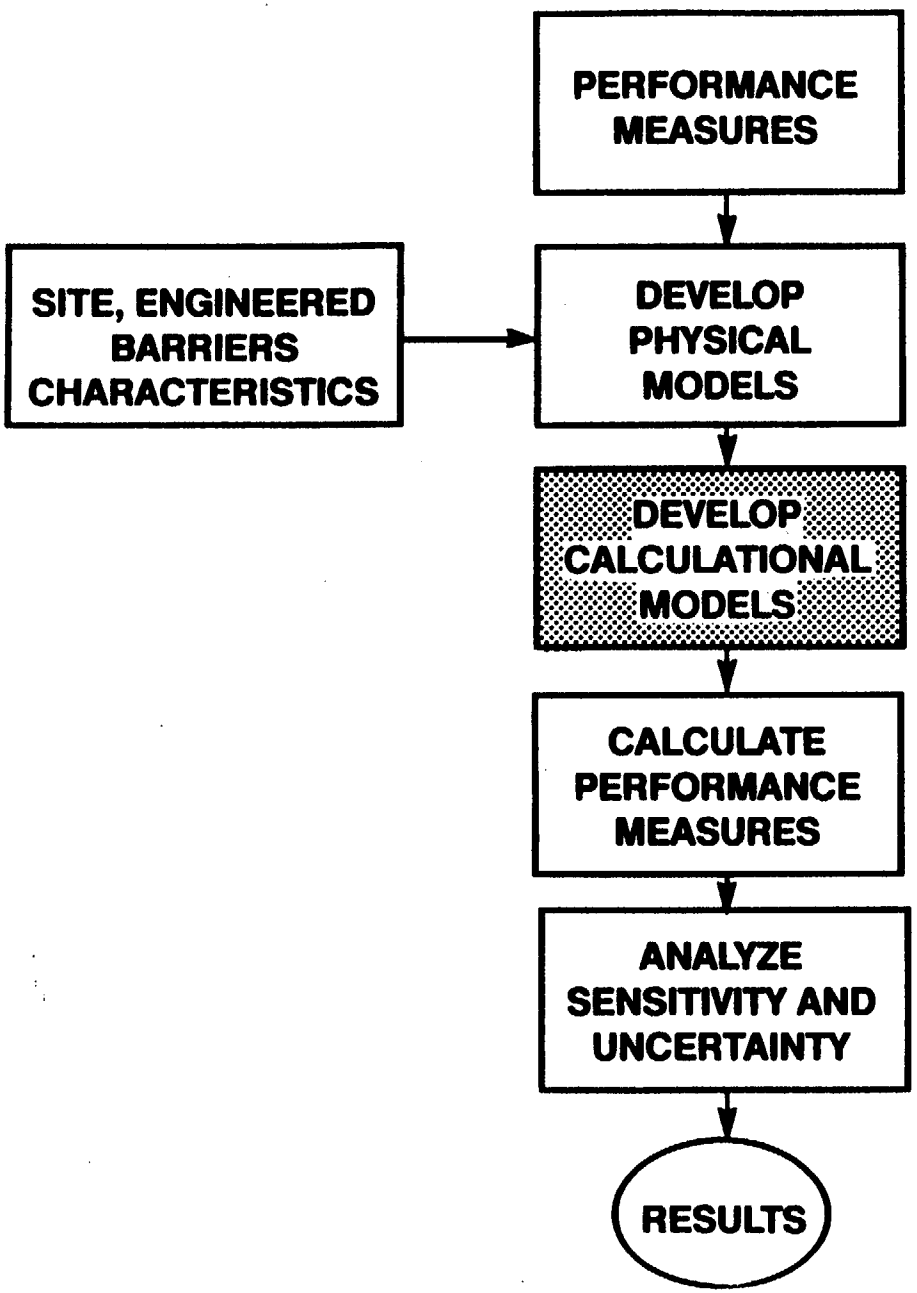
PRESENTER'S TELEPHONE NUMBER: (509) 376-4601

MAY 16-17, 1989

SCOPE OF PRESENTATION

- STRUCTURE OF AREST CODE
- TYPICAL RESULTS
- BENCHMARKING
- FUTURE ACTIVITIES

PERFORMANCE ASSESSMENT PROCESS



ANALYTIC REPOSITORY SOURCE-TERM (AREST) CODE

- INTEGRATES PROCESS SUBMODELS
  - NEAR-FIELD ENVIRONMENT
  - CONTAINMENT
  - RELEASE
- CALCULATES ENGINEERED BARRIER SYSTEM (EBS) PERFORMANCE
- CAPABLE OF PROBABILISTIC ANALYSES

APPROACH TO AREST SUBSYSTEM MODELING

DIVIDE THE ASSESSMENT INTO FOUR SEPARATE PARTS:

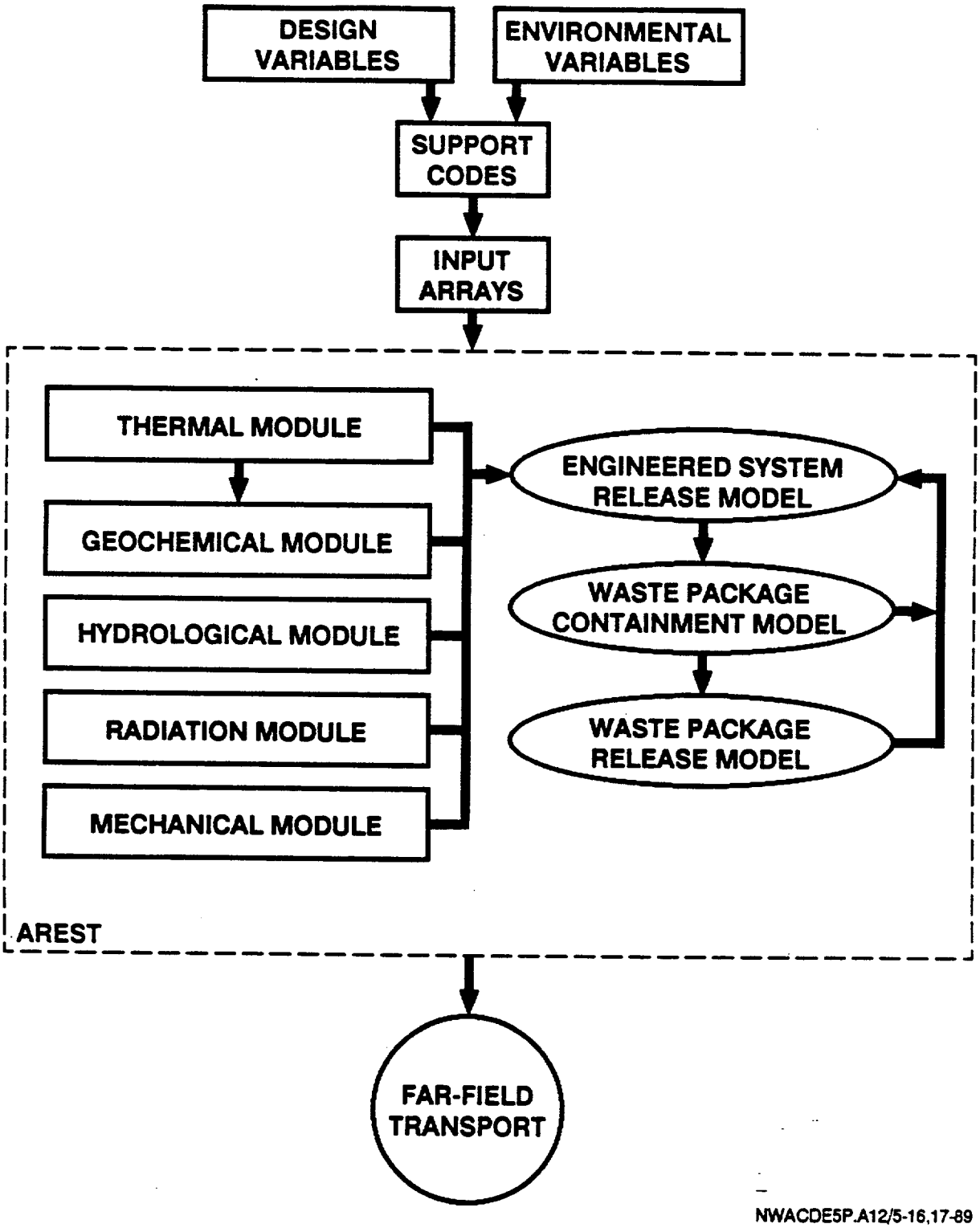
1) OBTAIN INPUT DATA, INCLUDING WASTE PACKAGE DESIGN, REPOSITORY LOGISTICS, AND SITE CHARACTERIZATION

2) USE DETAILED-THERMAL-MECHANICAL-HYDROLOGICAL CODES ("SUPPORT CODES") TO ANALYZE AND TABULATE THE EVOLUTION OF THE NEAR-FIELD ENVIRONMENT OVER TIME AND SPACE

3) DEVELOP MODULAR, MATERIAL-SPECIFIC MODELS AFFECTING THE CONTAINMENT, RELEASE, AND MASS TRANSFER INTO THE HOST ROCK OF RADIONUCLIDES FROM INDIVIDUAL WASTE PACKAGES

4) INTEGRATE THE BEHAVIOR OF INDIVIDUAL WASTE PACKAGES TO PROVIDE A PROBABILISTIC ASSESSMENT OF THE OVERALL CONTAINMENT AND RELEASE PERFORMANCE OF THE EBS

SUPPORT CODE/AREST MODEL INTERFACE

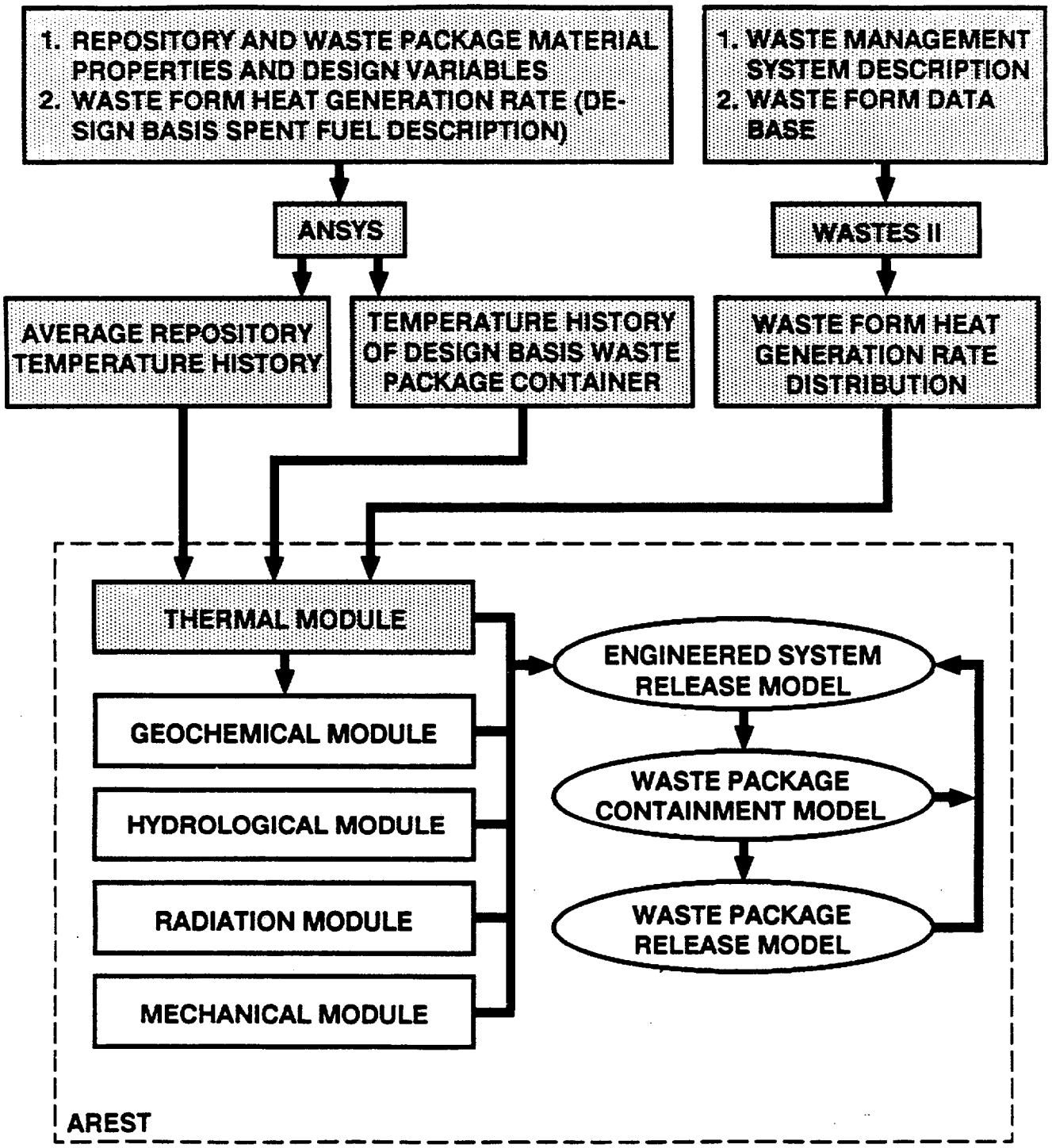


NWACDE5P.A12/5-16,17-89

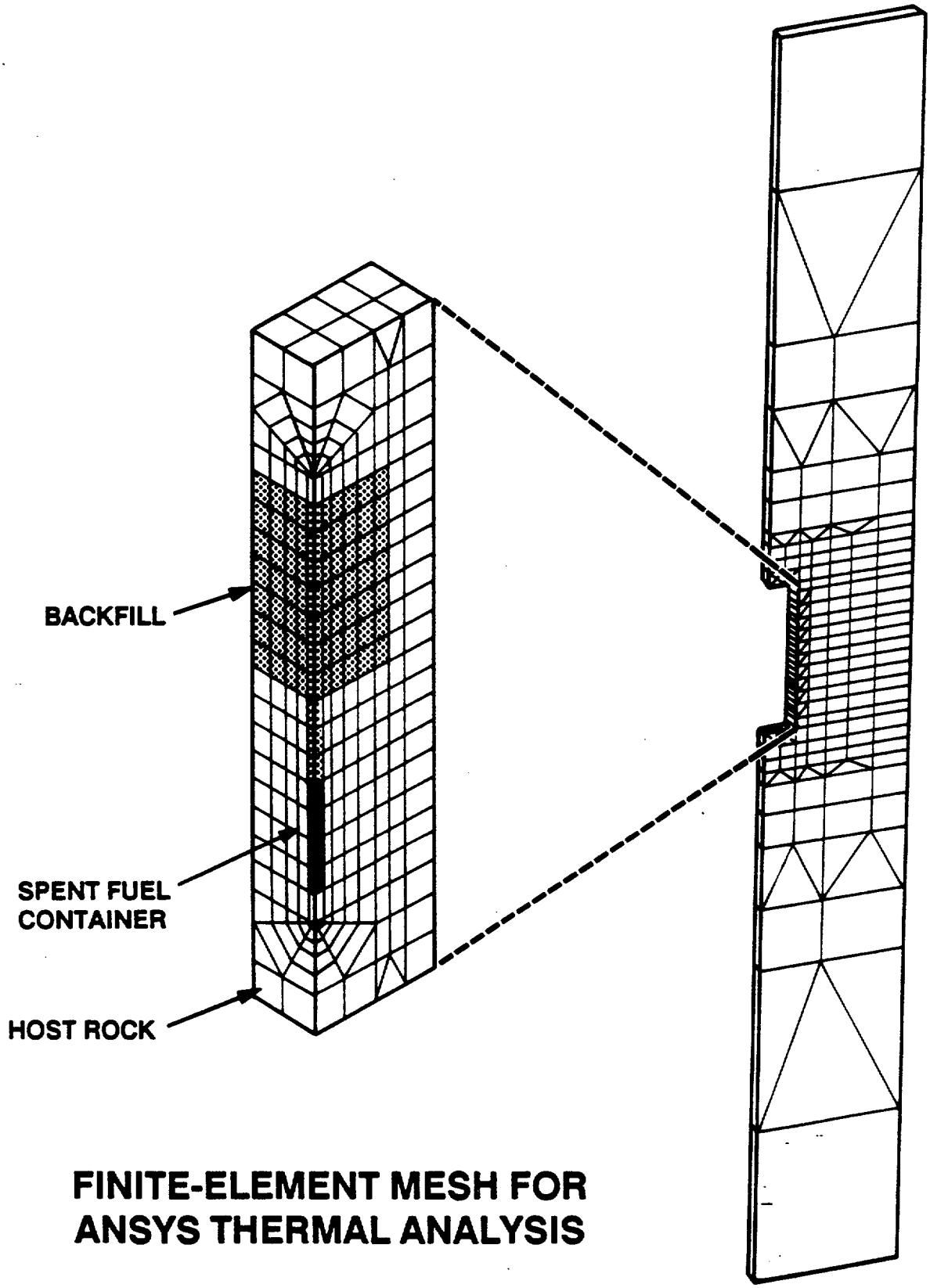
TECHNIQUES FOR BUILDING A SUBSYSTEM MODEL

- MODULAR STRUCTURE
- SIMPLIFY DETAILED PROCESS MODELS
  - ALGORITHMS
  - TABULATIONS
- SELECT TEMPERATURE AS PRIME PARAMETER
- EVALUATE IMPORTANCE OF COUPLED PROCESSES
- SIMPLIFY GEOMETRY

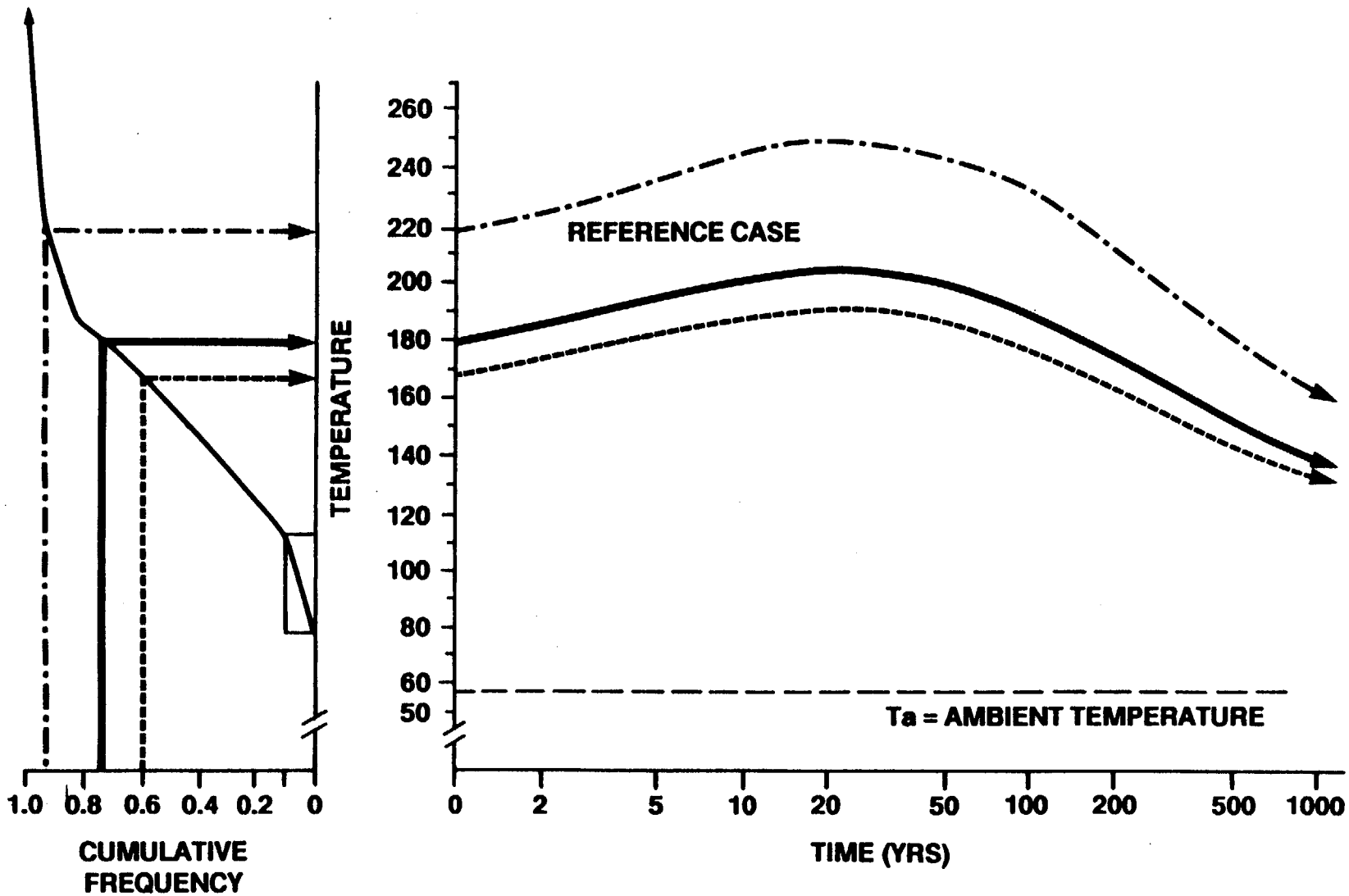
EXAMPLE 1: DERIVATION OF AREST THERMAL MODULE



NWACDE5P.A12/5-16.17-89

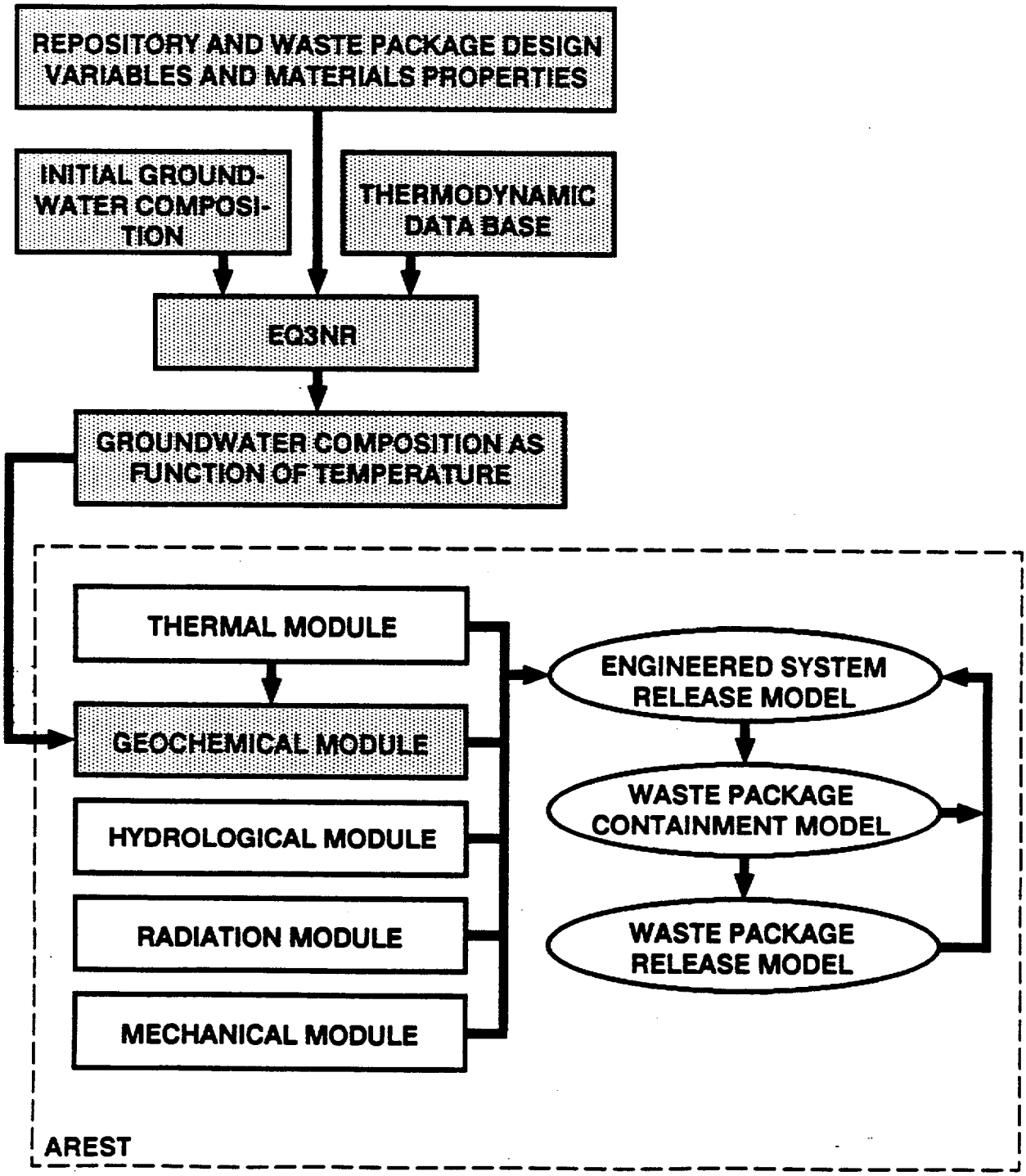


FINITE-ELEMENT MESH FOR ANSYS THERMAL ANALYSIS



DERIVATION OF TEMPERATURE PROFILES

EXAMPLE 2: DERIVATION OF AREST GEOCHEMICAL MODULE

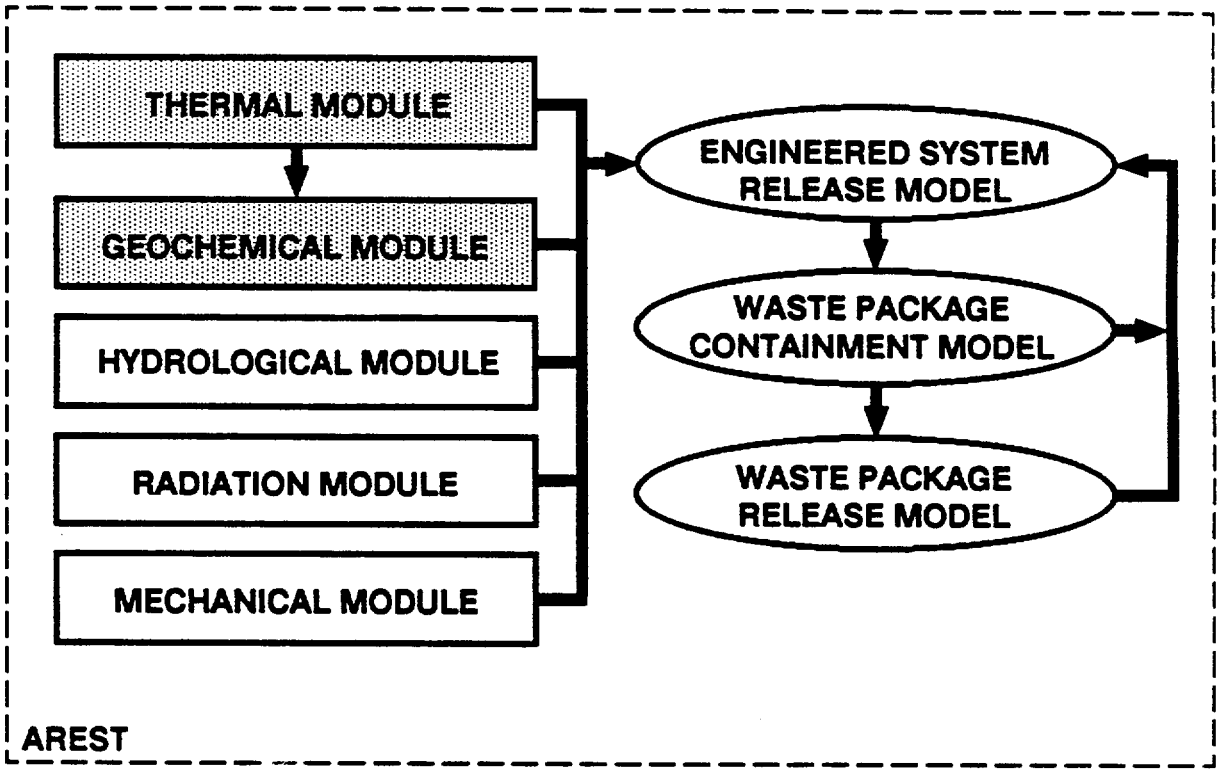


NWACDE5P.A12/5-16.17-89

EXAMPLE 2: TABULATED GROUNDWATER COMPOSITION

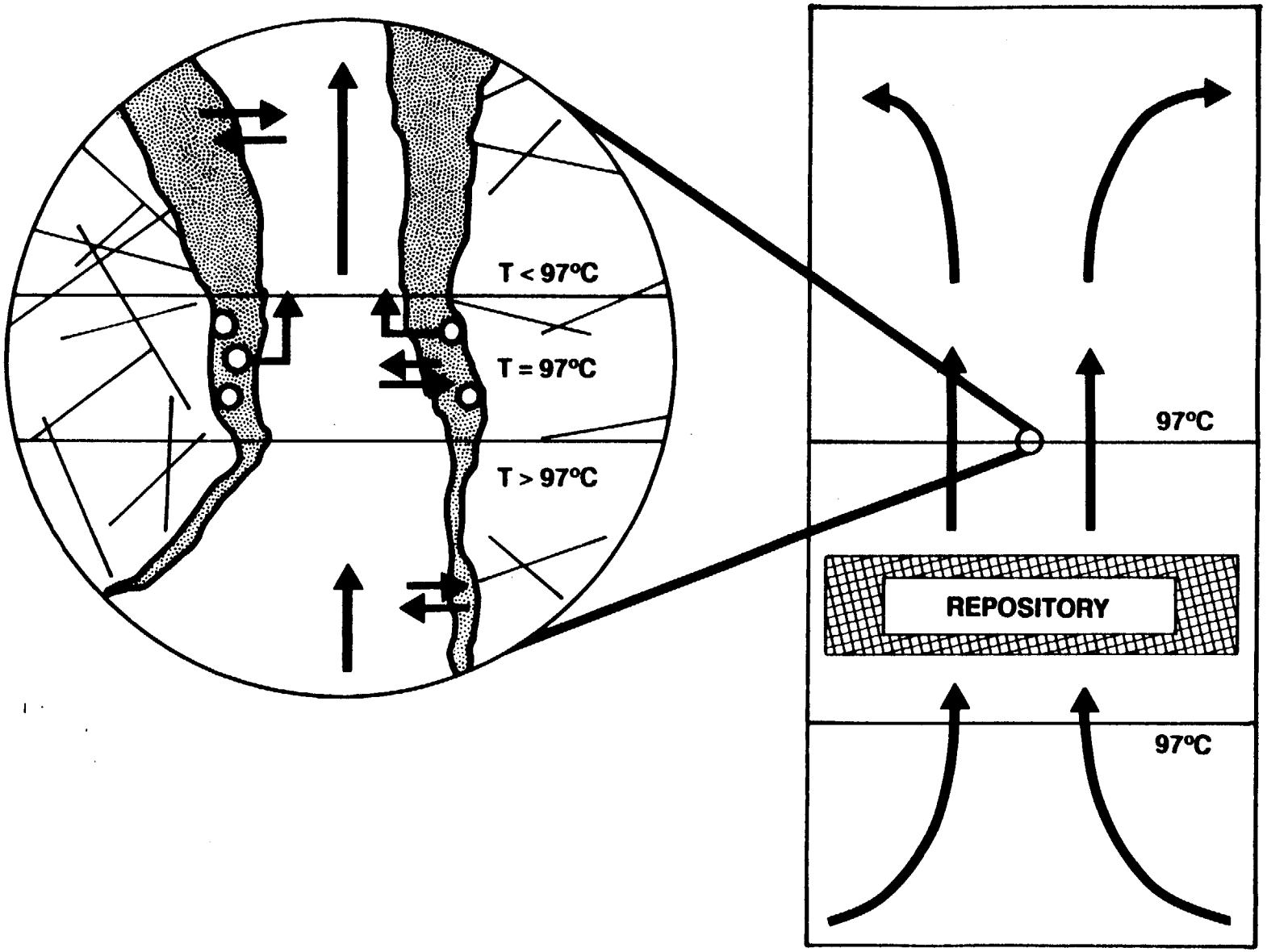
SPECIES	CONCENTRATION (mol/kg)		
T (°C)	55	60	65
pH (T)	7.45	7.42	7.40
Eh (V)	-0.345	-0.346	-0.347
ρ	1.023	1.020	1.019
Na^+	0.1398D-01	0.1466D-01	0.1571D-01
Cl^-	0.1038D-01	0.1083D-01	0.1083D-01
$Al(OH)_4^-$	0.9431D-03	0.1617D-02	0.2661D-02
SiO_2 (aq)	0.1445D-02	0.1439D-02	0.1436D-02
HCO_3^-	0.1431D-02	0.1025D-02	0.1430D-02
F	0.1025D-02	0.1025D-02	0.1025D-02
$H_3SiO_4^-$	0.1071D-03	0.1123D-03	0.1154D-03
Ca_2	0.5102D-04	0.5089D-04	0.5078D-04
HS^-	0.4149D-04	0.4143D-04	0.4130D-04
H_2CO_3	0.1977D-04	0.2053D-04	0.2185D.04
CO_3^{2-}	0.1877D-04	0.1860D-04	0.1797D-04
OH^-	0.1084D-04	0.1366D-04	0.1669D-04
NaCl	0.1070D-04	0.1092D-04	0.1146D-04
NaF	0.2406D-05	0.2703D-05	0.3092D-05
$NaCO_3^-$	0.1783D-05	0.1899D-05	0.2006D-05
H_2S (aq)	0.1313D-05	0.1272D-05	0.1272D-05
$CaHCO_3$	0.9615D-06	0.9783D-06	0.9941D-06
$CaCO_3$	0.8683D-06	0.9057D-06	0.9150D-06
CaF^+	0.7761D-06	0.8480D-06	0.9232D-06
SO_4^{2-}	0.1775D-06	0.2713D-06	0.3997D-06

EXAMPLE 3: EVALUATE IMPORTANCE OF THERMAL-CHEMICAL COUPLING

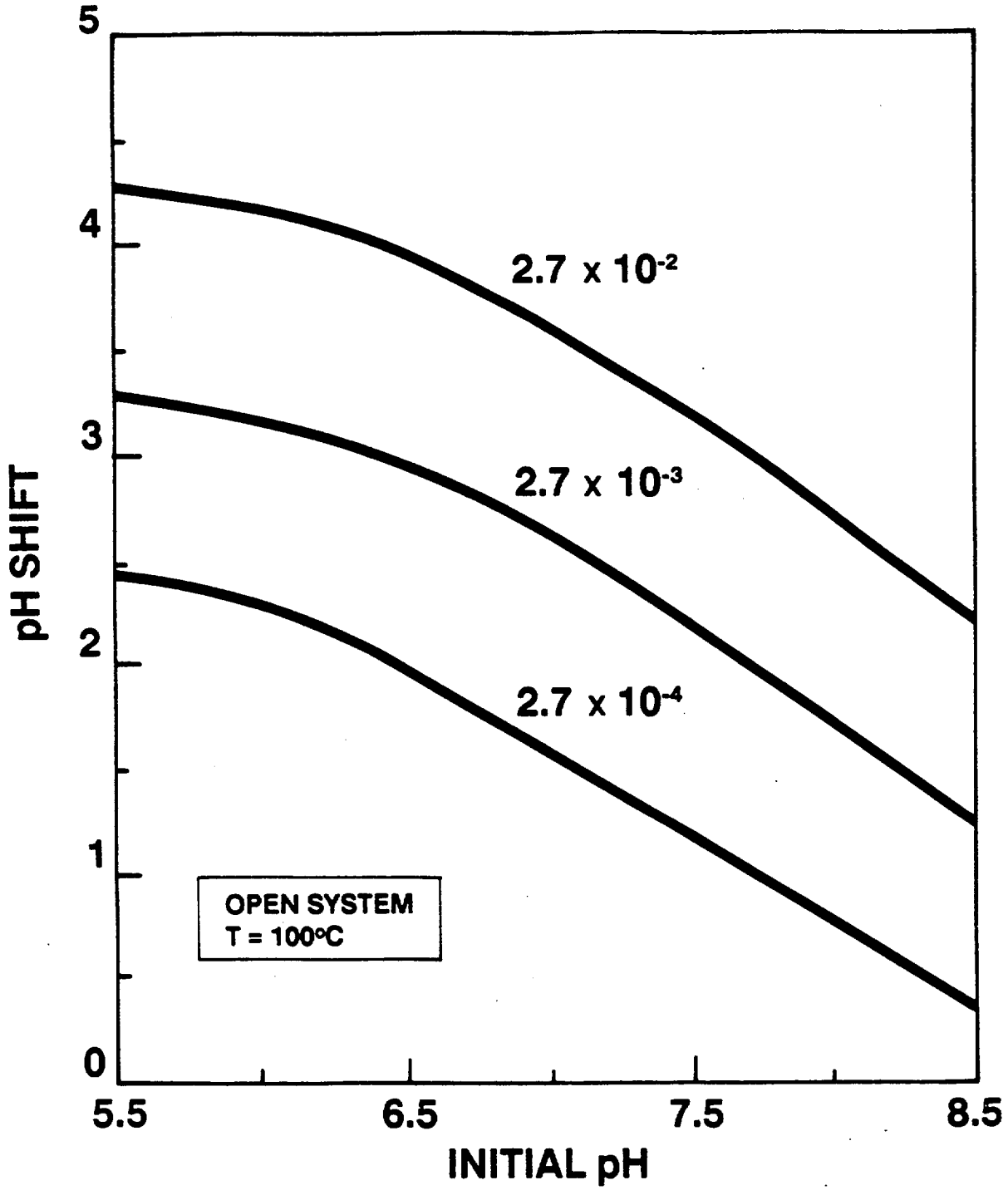


NWACDE5P.A12/5-16.17 89 13

SCHEMATIC OF BOILING FRONT AND ITS EFFECT ON GROUNDWATER CHEMISTRY

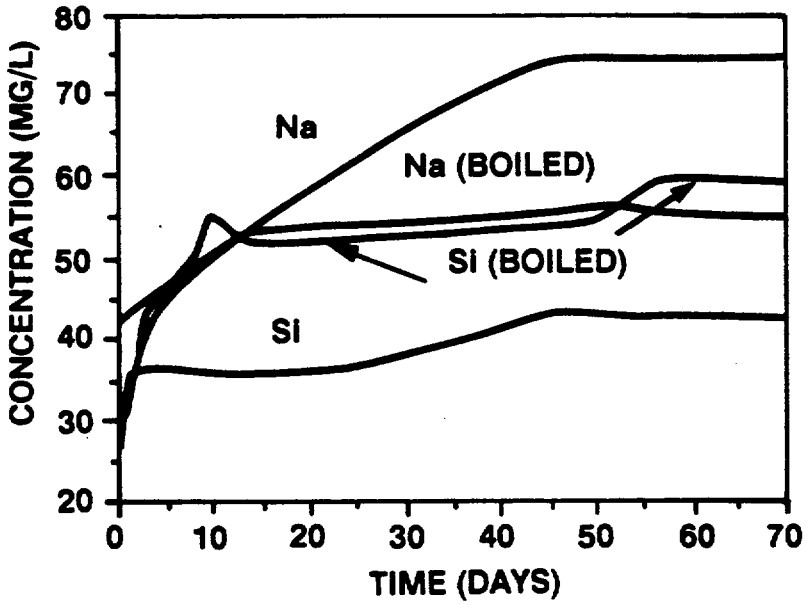


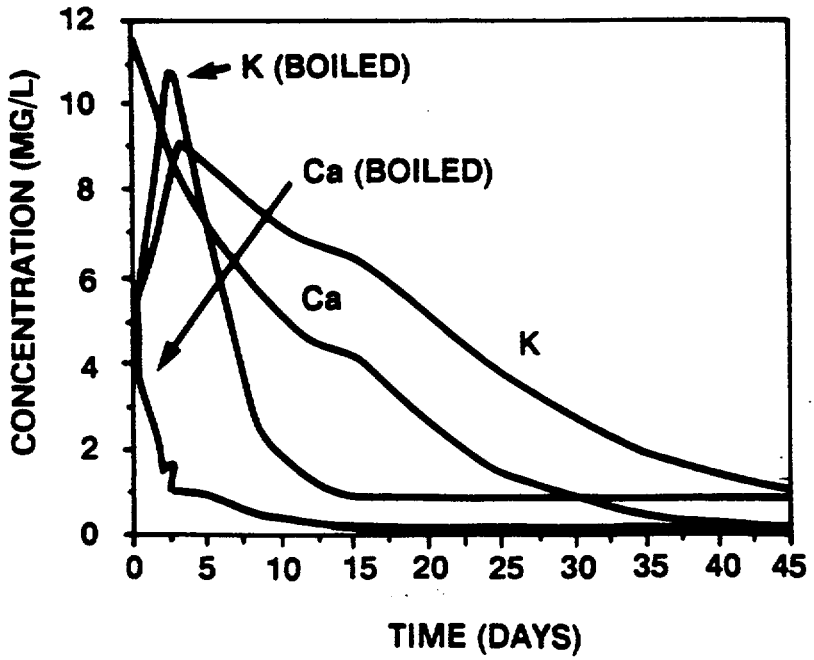
EFFECT OF BOILING ON pH OF GROUNDWATER CALCULATED WITH EQ 3/6



NWAPT5P.A12/5-17-89

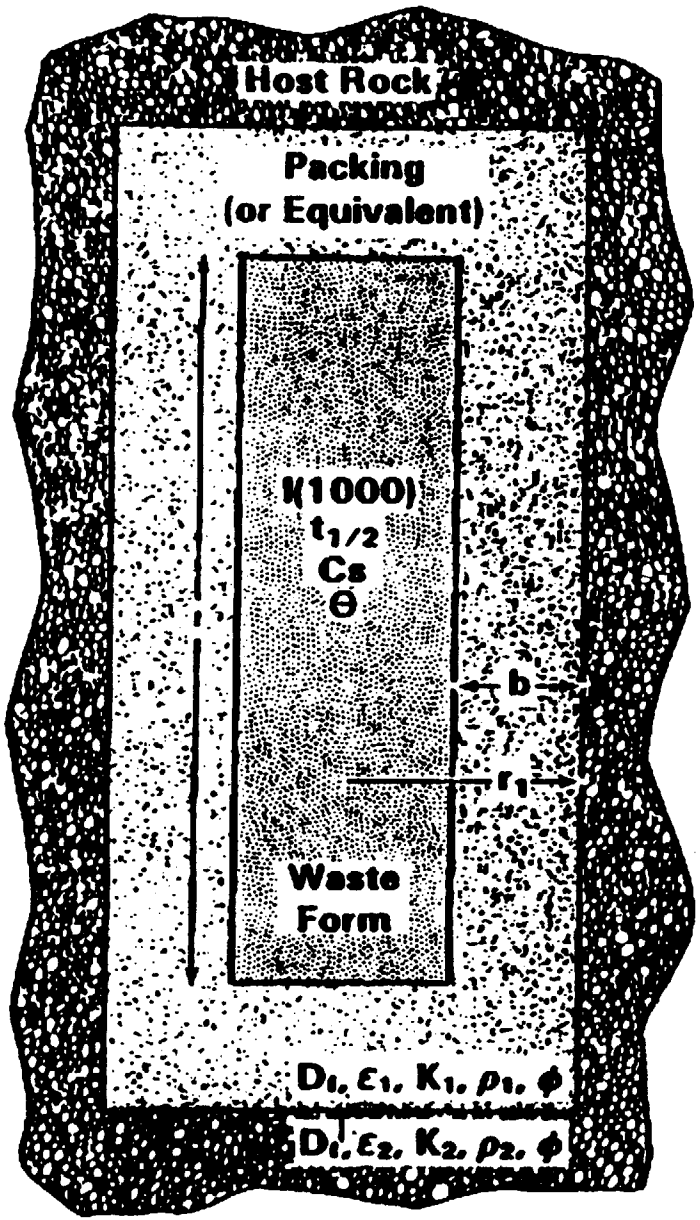
EFFECT OF BOILING ON GROUNDWATER COMPOSITION



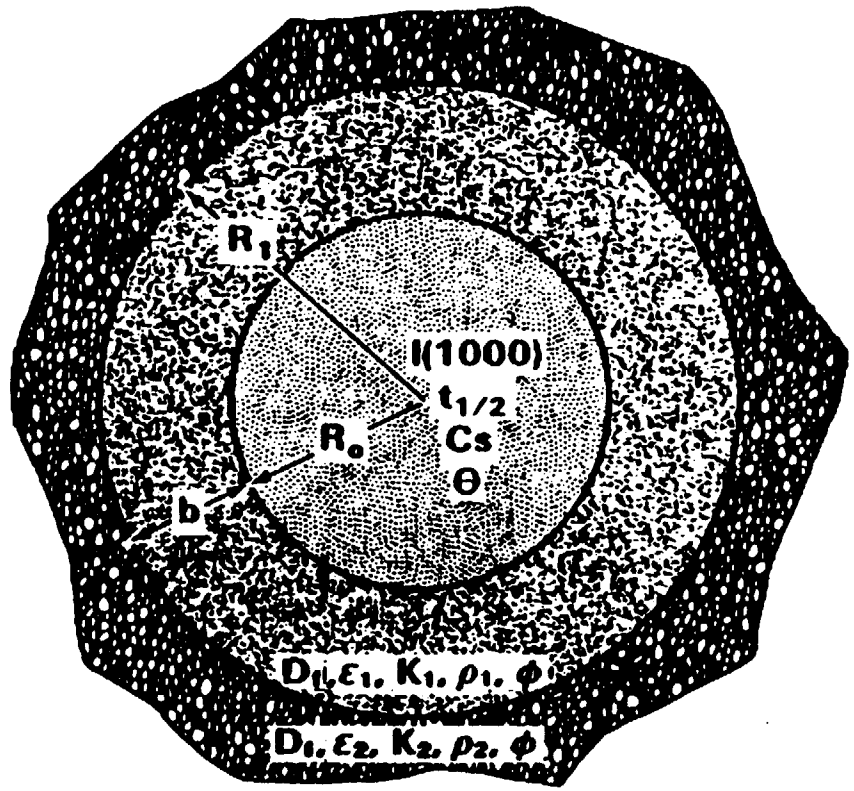


NWAPT5P.A12/5-17-89

EXAMPLE 4: SIMPLIFY WASTE PACKAGE GEOMETRY

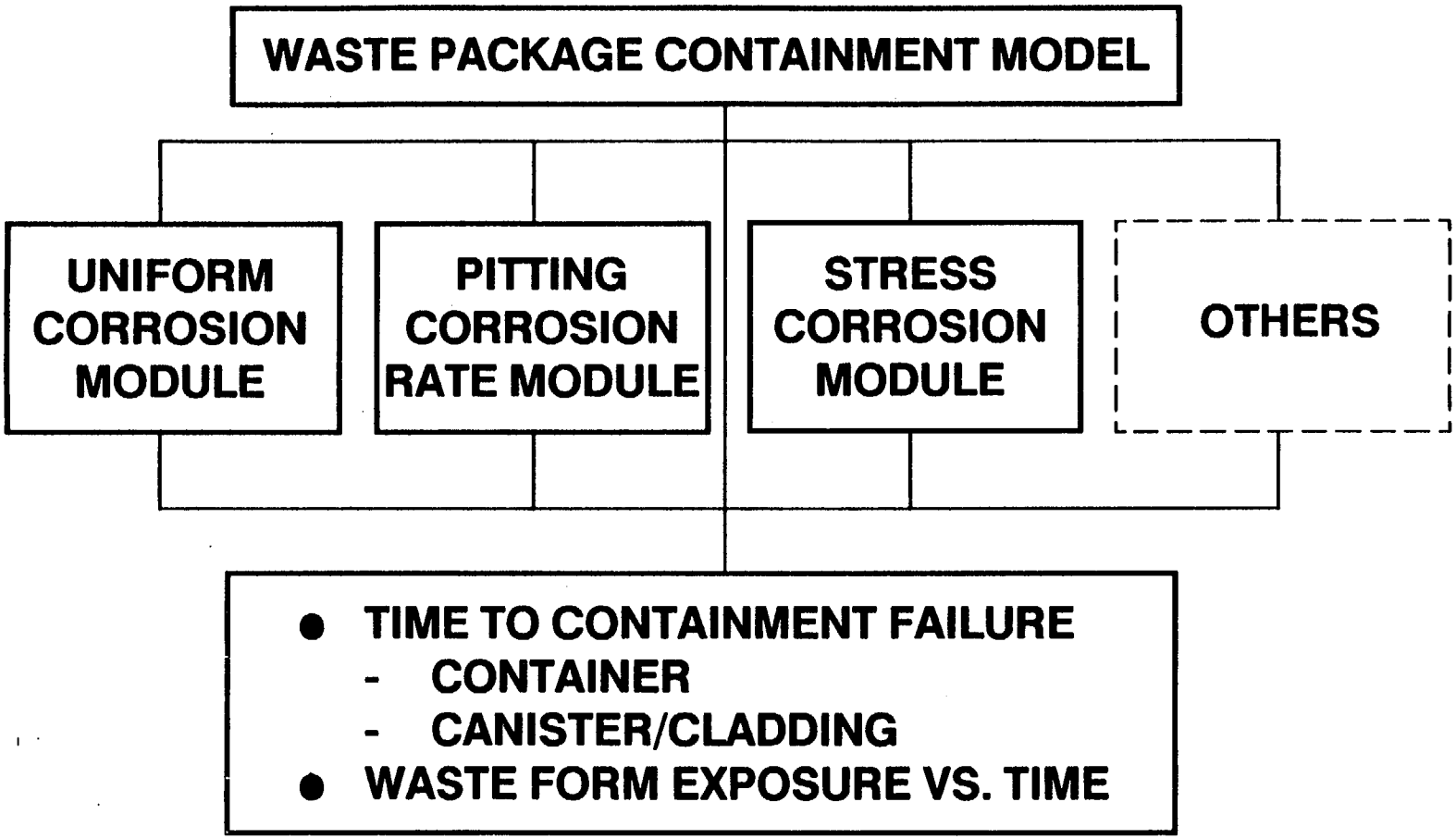


Actual Cylinder

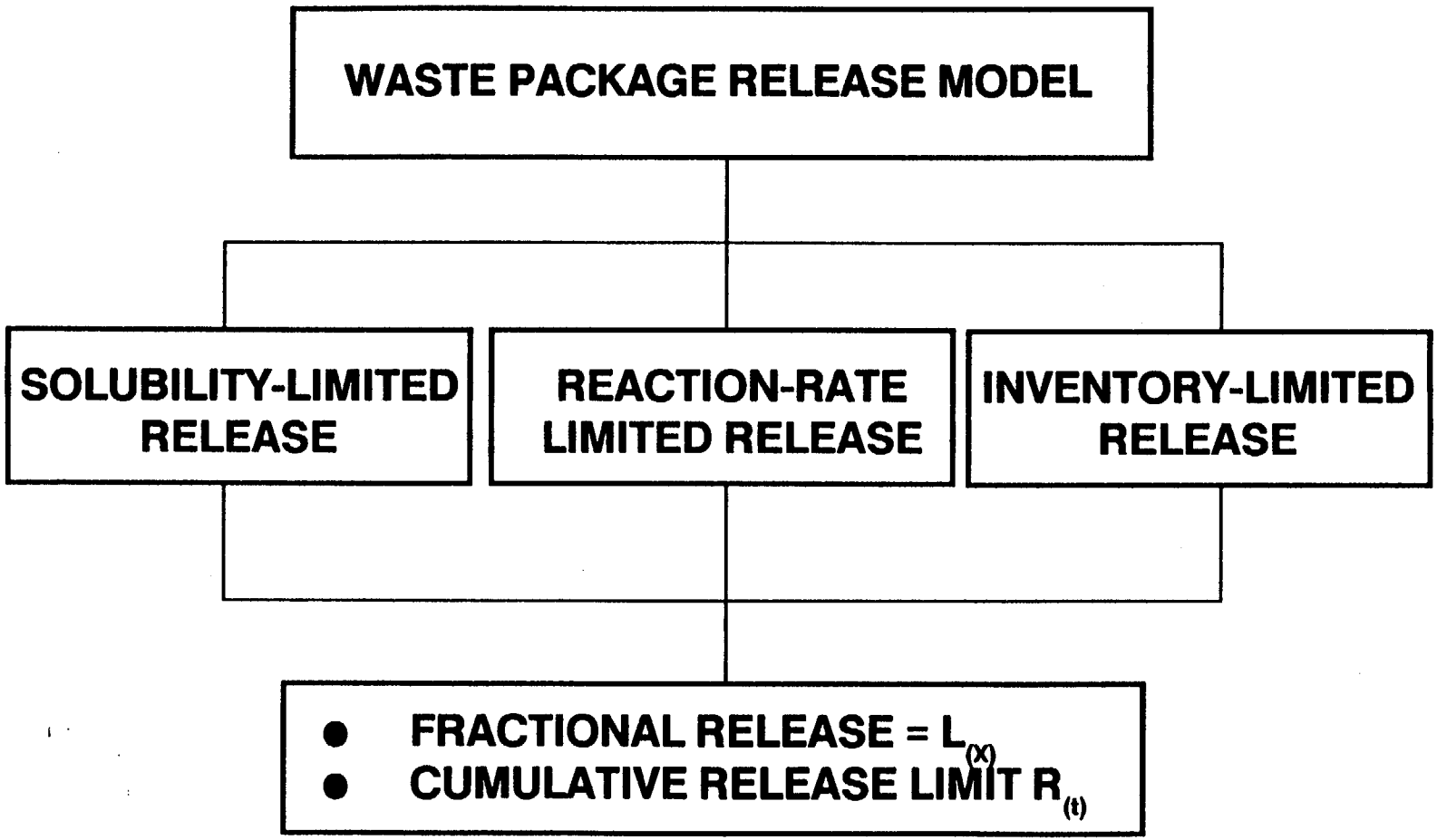


Equivalent Sphere

AREST: WASTE PACKAGE CONTAINMENT MODEL



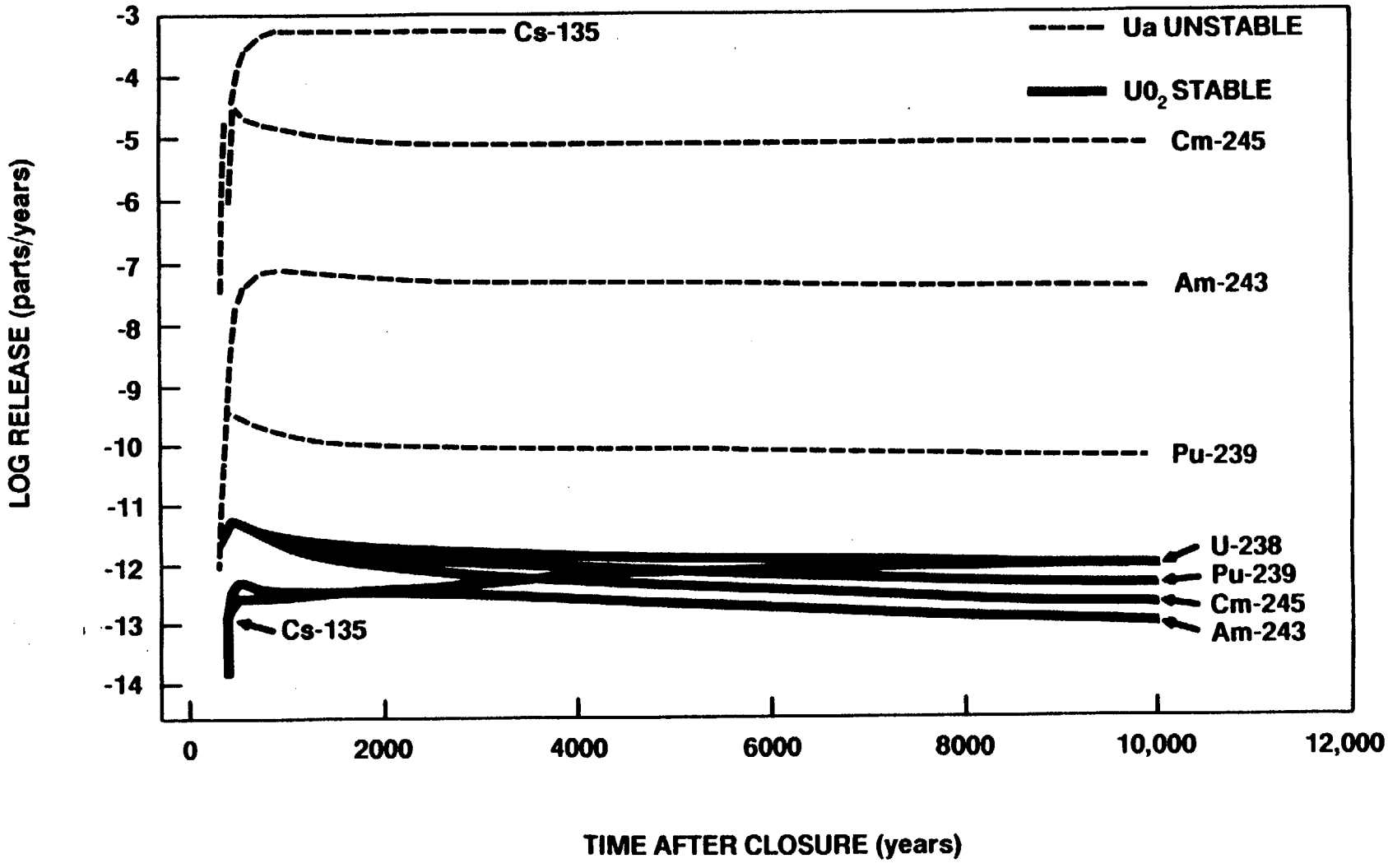
AREST: WASTE PACKAGE RELEASE MODEL



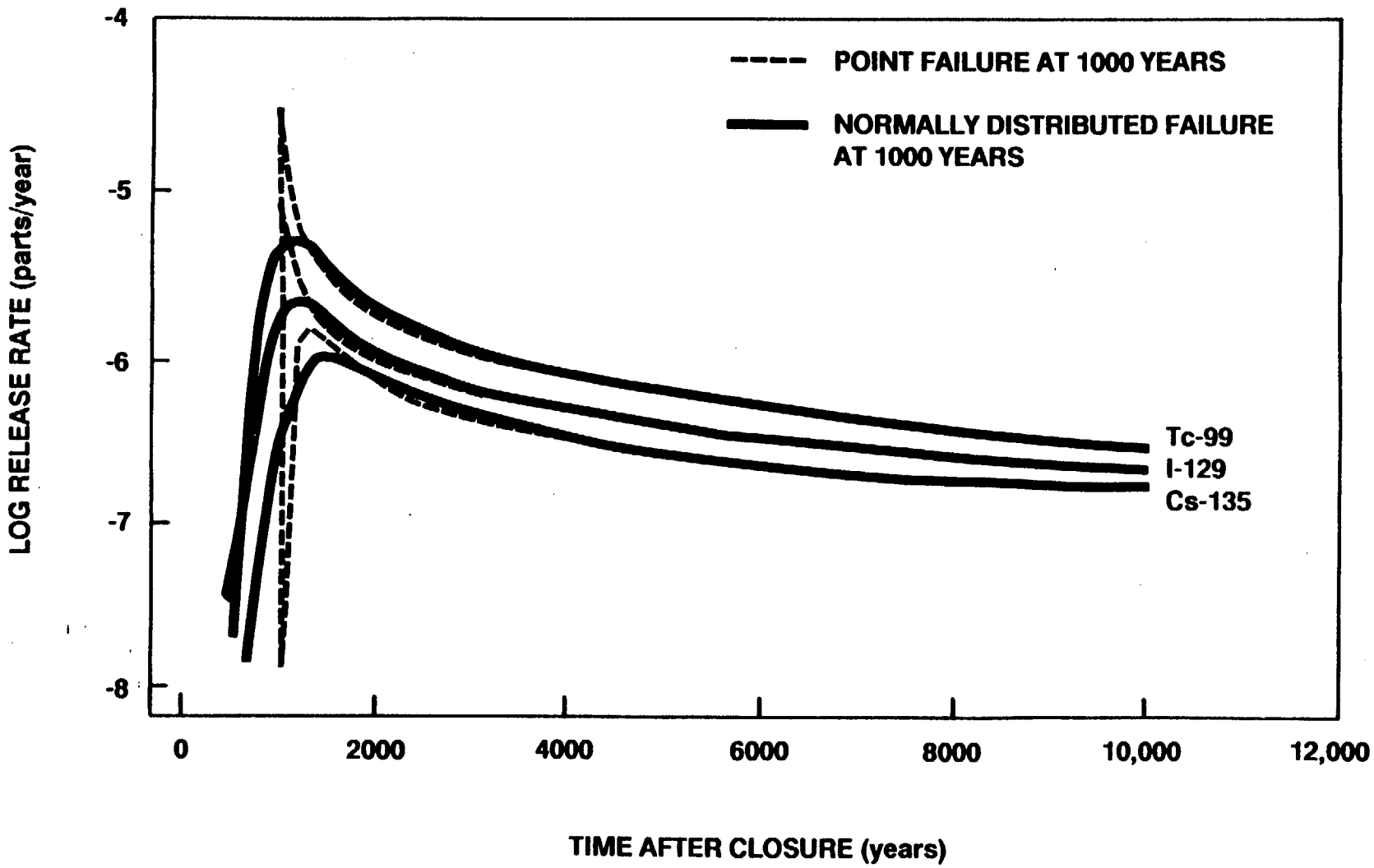
SCOPE OF PRESENTATION

- STRUCTURE OF AREST CODE
- TYPICAL RESULTS
- BENCHMARKING
- FUTURE ACTIVITIES

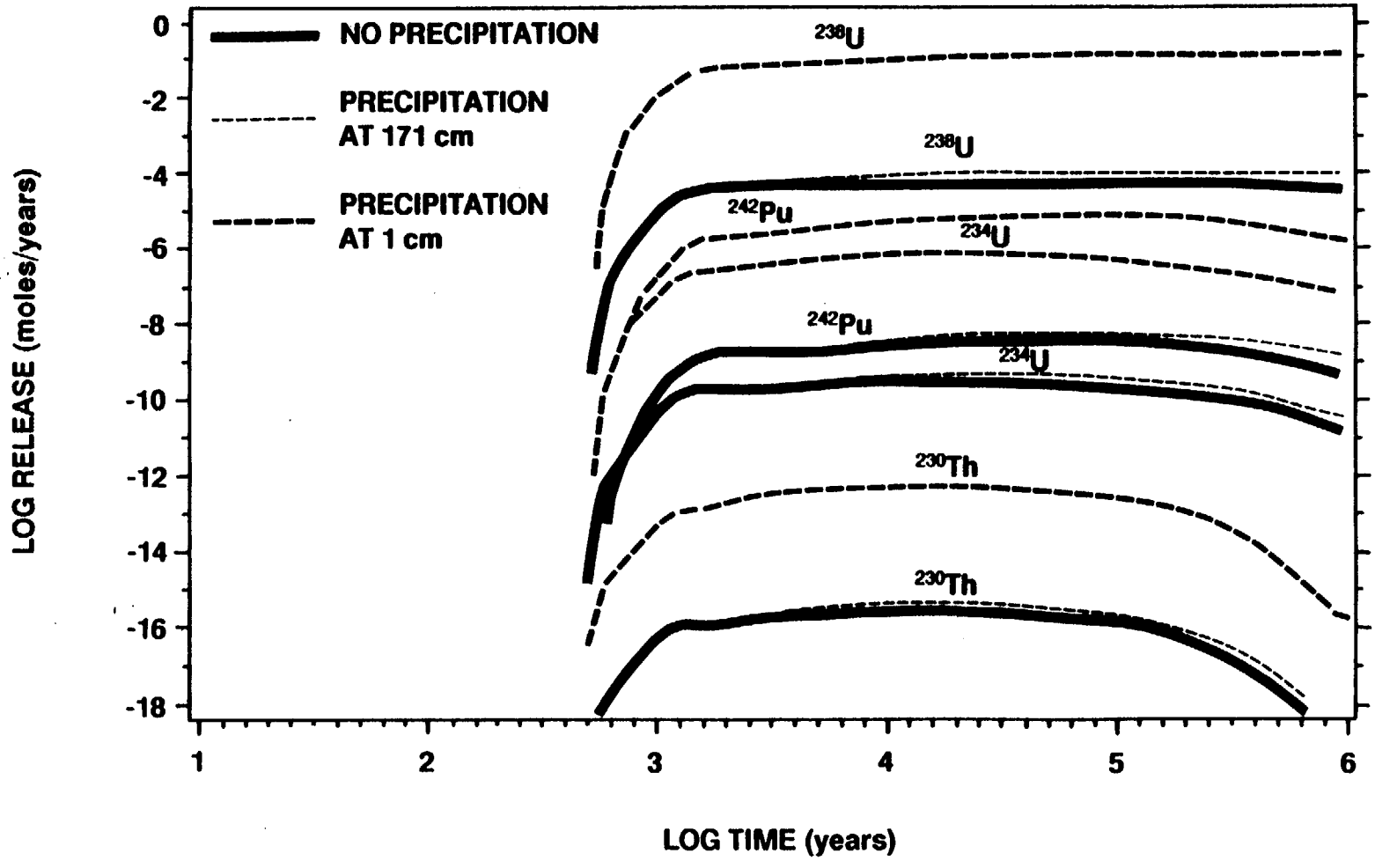
EFFECT OF STABILITY OF UO_2 MATRIX ON RELEASE (POINT FAILURE AT 300 YEARS)



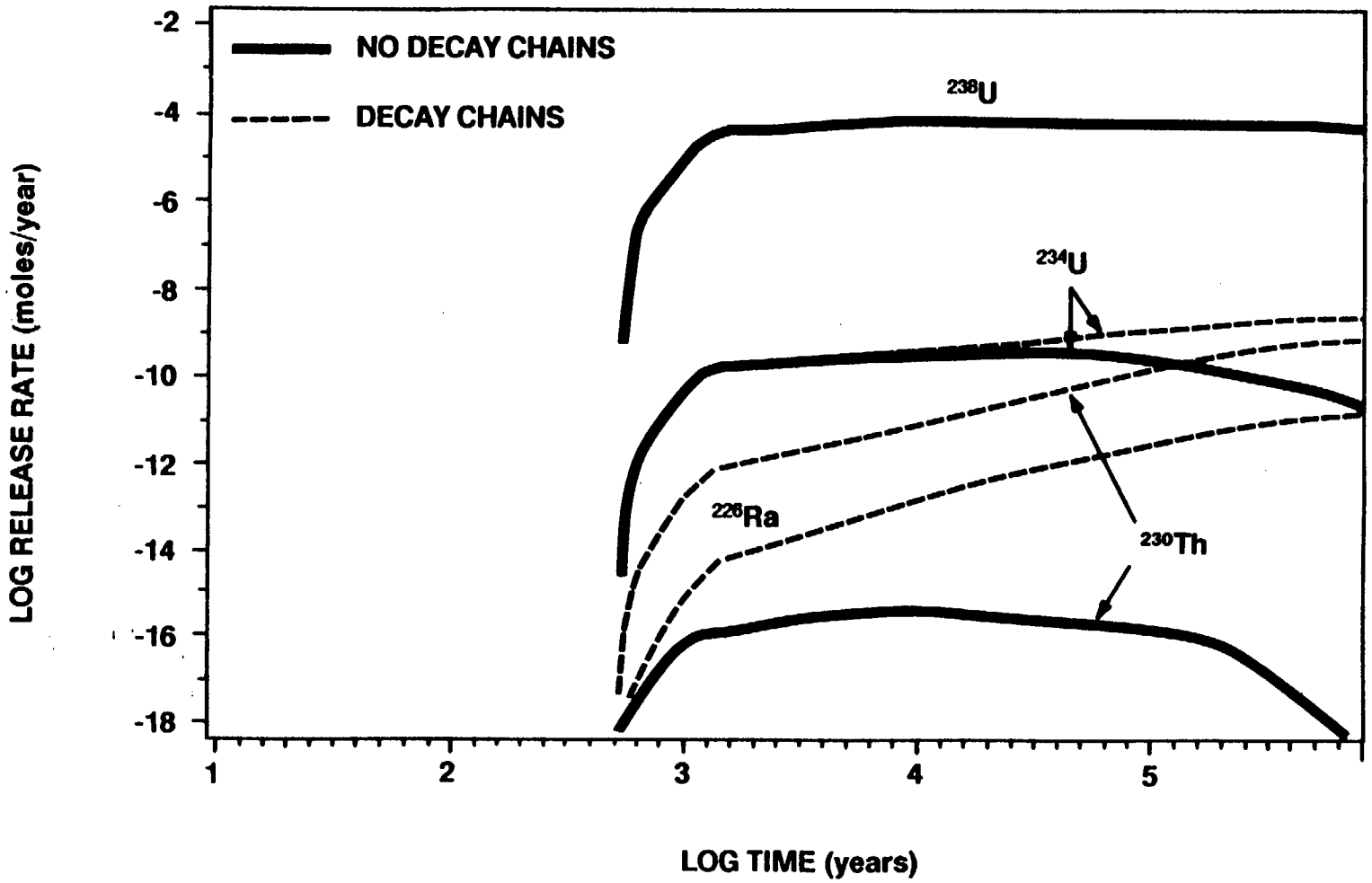
EFFECT OF DISTRIBUTED CONTAINMENT FAILURES ON EBS RELEASE



EFFECT OF PRECIPITATION



EFFECT OF DECAY-CHAIN IN-GROWTH



SCOPE OF PRESENTATION

- STRUCTURE OF AREST CODE
- TYPICAL RESULTS
- BENCHMARKING
- FUTURE ACTIVITIES

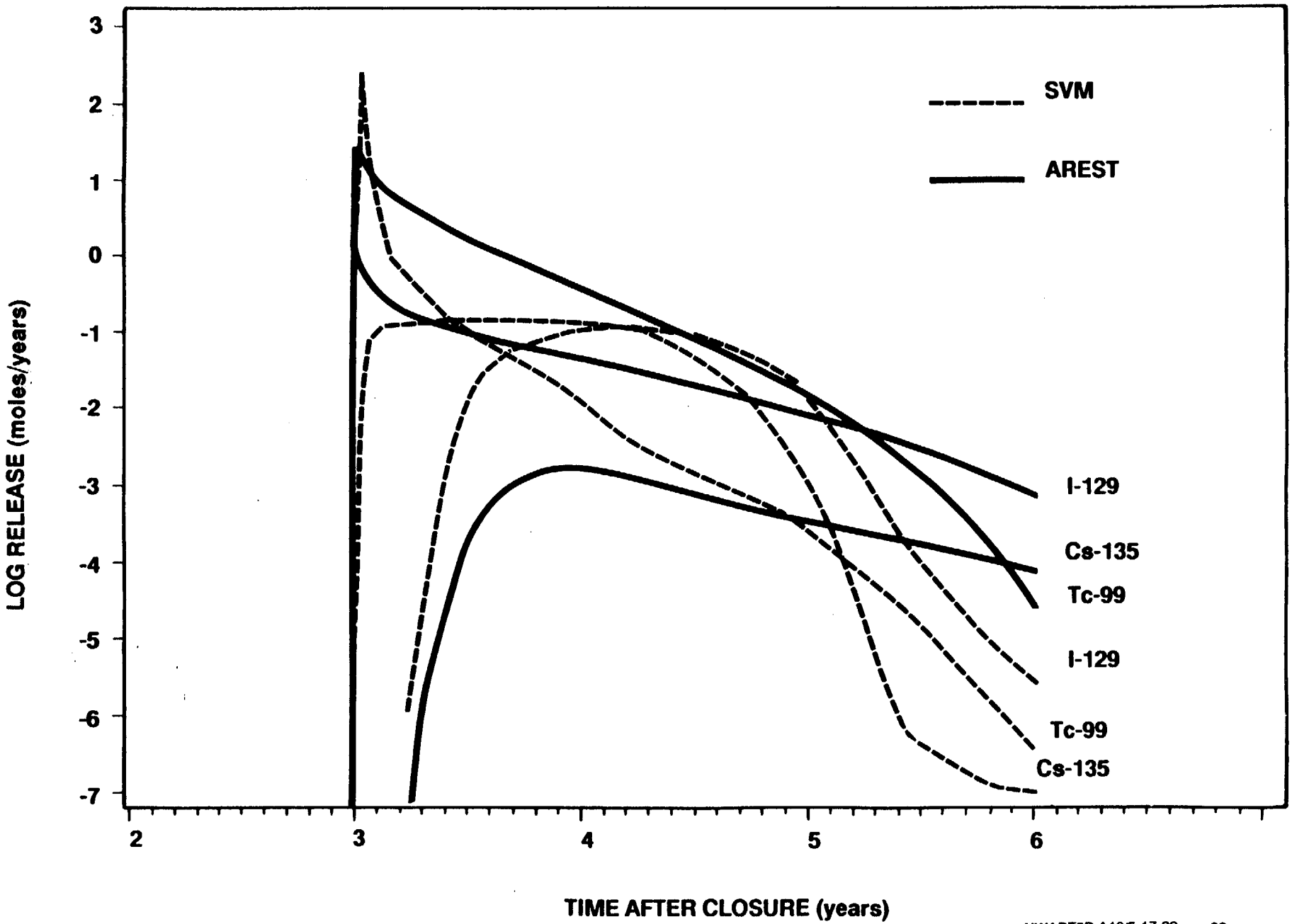
BENCHMARK OF AREST AND SYVAC-VAULT CODES

- ESTABLISH CREDIBILITY OF CODES FOR PREDICTIVE PERFORMANCE ASSESSMENT OF WASTE PACKAGES
- IDENTIFY DEFICIENCIES
- IDENTIFY FUTURE IMPROVEMENTS
- FORM A BETTER UNDERSTANDING OF BOTH APPROACHES

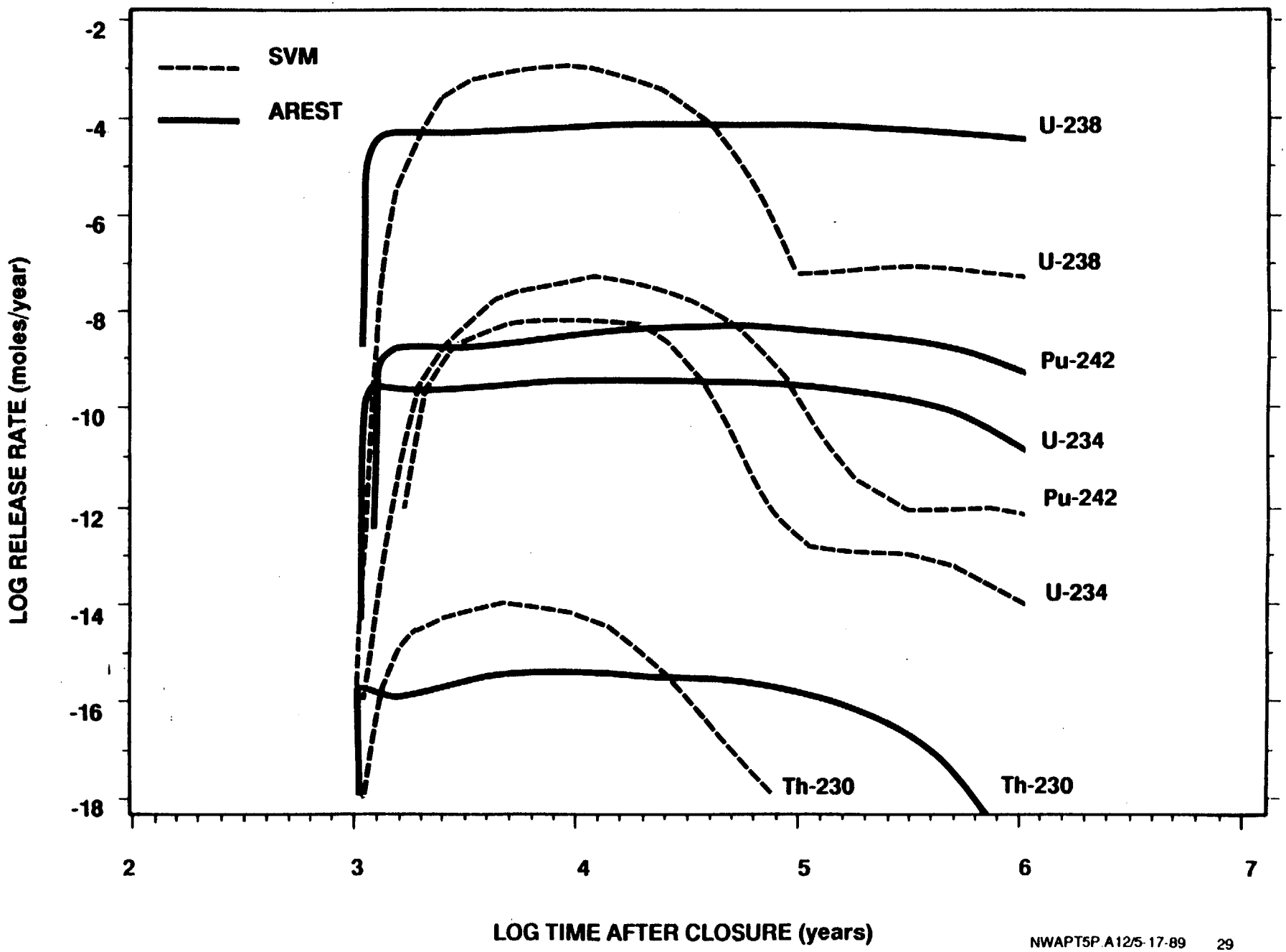
COMPARISON OF RELEASE MODELS AND ASSUMPTIONS

AREST	SYVAC-VAULT (SVM)
• SPHERICAL WP GEOMETRY	PLANAR WP GEOMETRY
• EXACT ANALYTICAL SOLUTION OF DIFFUSIONAL MASS-TRANSFER	APPROXIMATE TRANSIENT SOLUTION (EXACT FOR STEADY-STATE)
• EBS MODELED AS SUMMATION OF INDIVIDUAL WASTE PACKAGES	EBS MODELED AS A SINGLE, CONTINUOUS "SLAB" SOURCE
• SEMI-INFINITE HOST-ROCK THICKNESS	FINITE (500 METERS) HOST-ROCK THICKNESS
• INITIAL CONCENTRATION OF NUCLIDES IN HOST ROCK EQUALS ZERO	SAME
• SOLUBILITY LIMITS ATTAINED AT TIME OF CONTAINMENT FAILURE	SAME
• NO DECAY-CHAIN GROW-IN	SAME
• NO PRECIPITATION	SAME

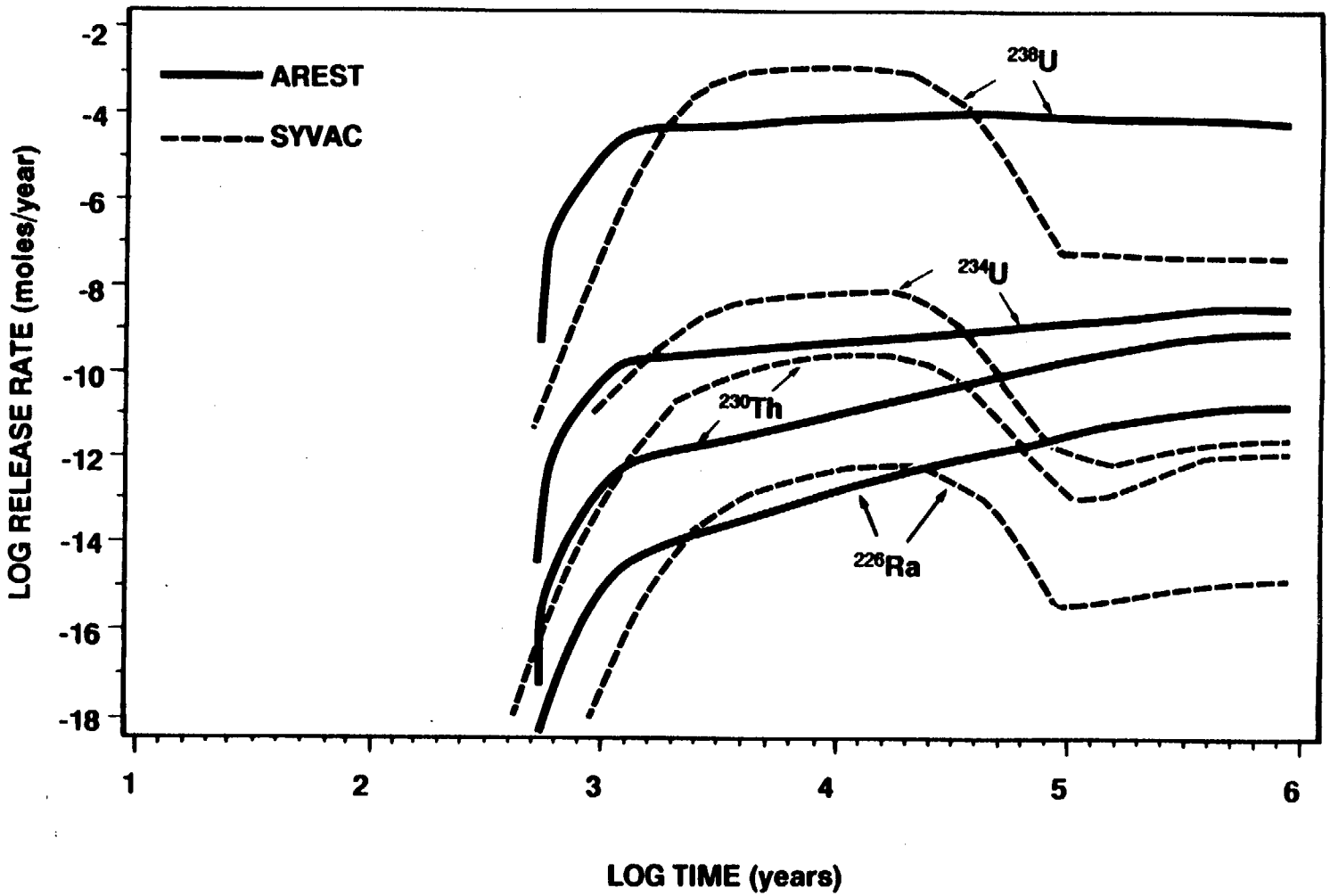
COMPARISON OF GAP RELEASE



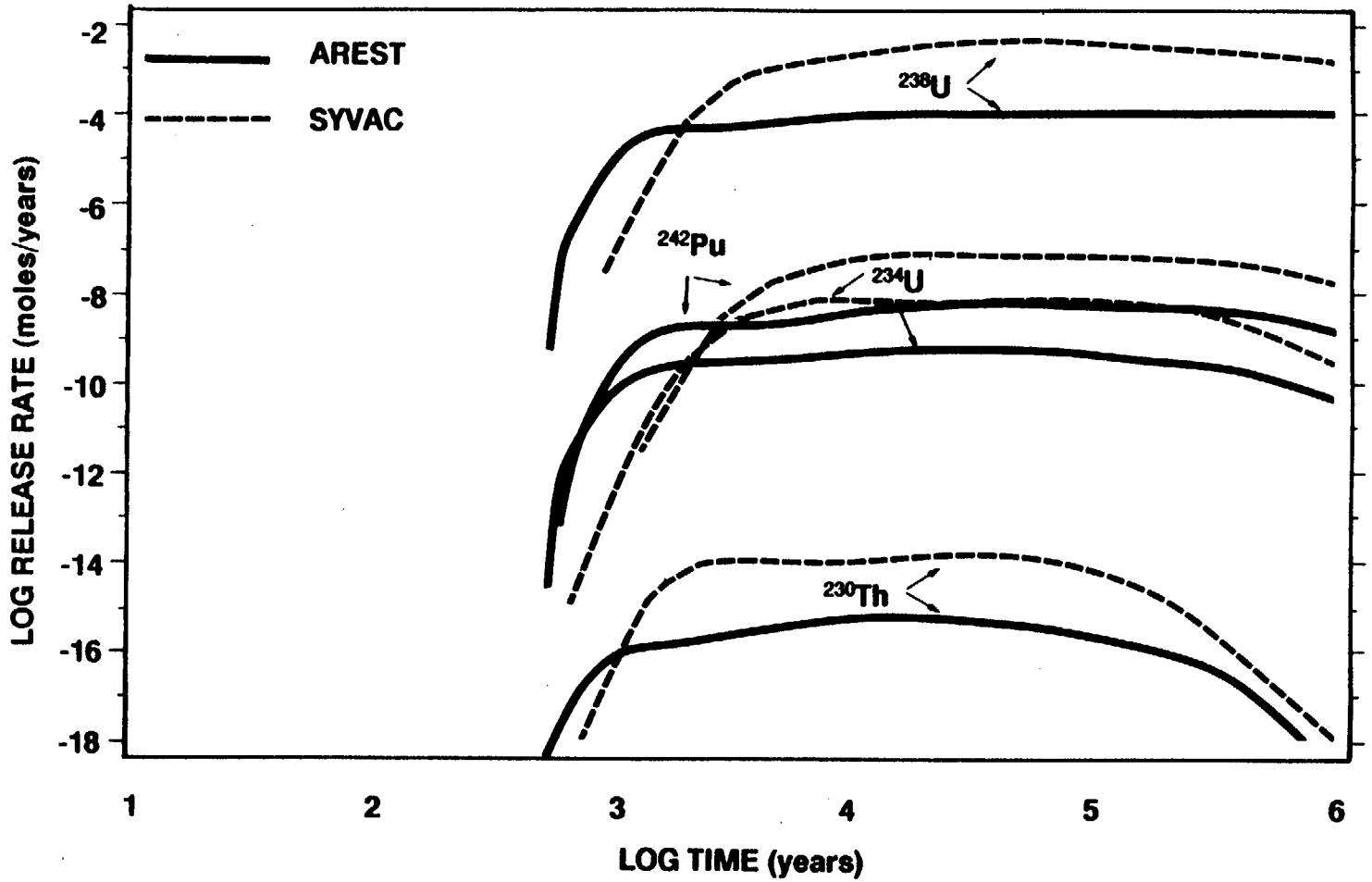
COMPARISON OF MATRIX RELEASE: BASE CASE



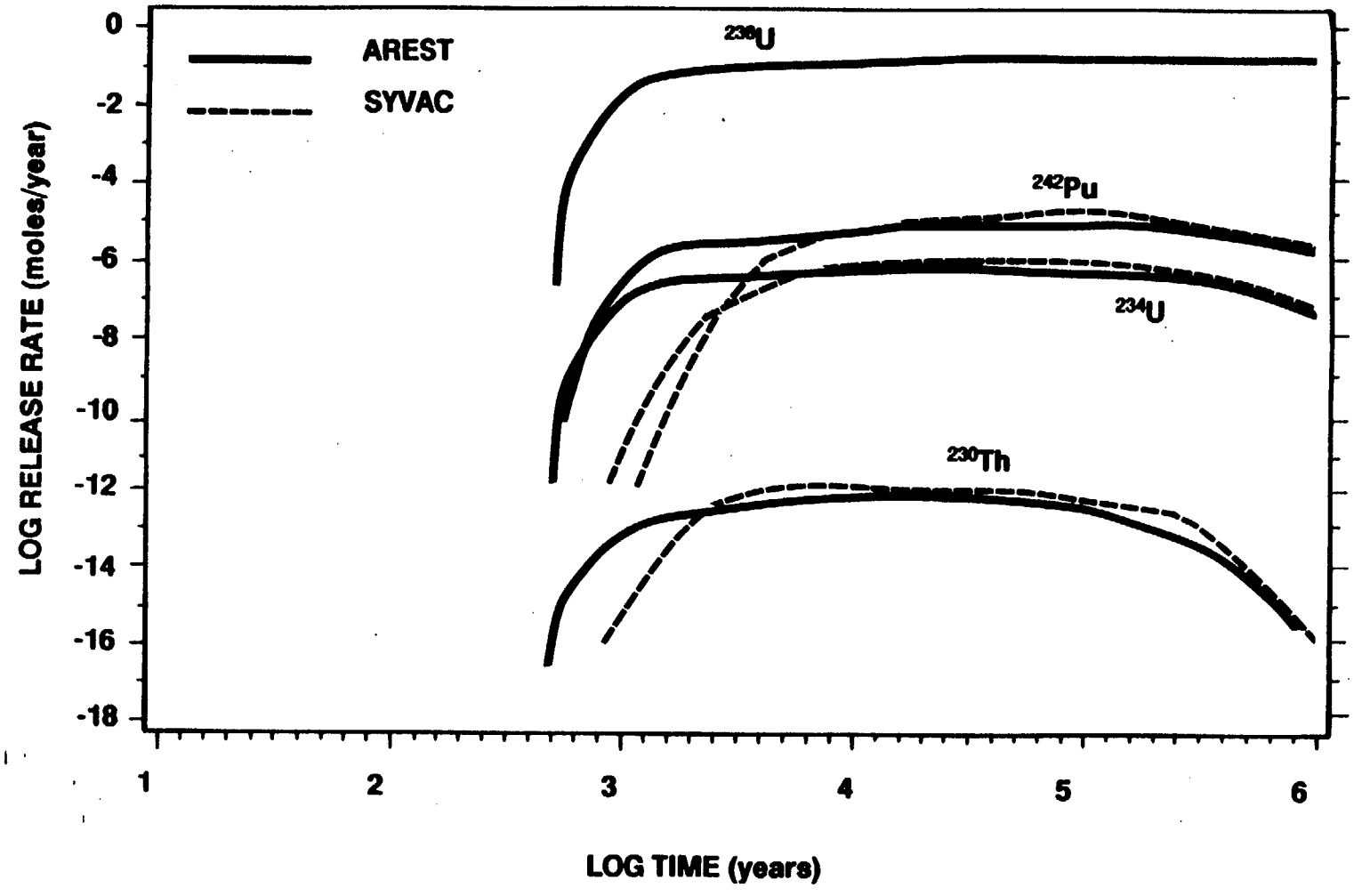
COMPARISON OF MATRIX RELEASE: DECAY-CHAIN IN-GROWTH



COMPARISON OF MATRIX RELEASE: PRECIPITATION AT HOST ROCK



COMPARISON OF MATRIX RELEASE: PRECIPITATION NEAR WASTE FORM



CONCLUSIONS FROM BENCHMARK TESTS

- RESULTS IN REASONABLE AGREEMENT

- DIFFERENCES WERE ANTICIPATED AND ARE ATTRIBUTABLE TO:

  - ANALYTICAL FORMATION
    * EXACT VS. APPROXIMATE TRANSIENT SOLUTION

  - GEOMETRY
    * PLANAR VS. SPHERICAL

  - BOUNDARY CONDITIONS
    * SEMI-INFINITE VS. FINITE ROCK THICKNESS
    * USE OF CONCENTRATION-DEPENDENT (TIME-DEPENDENT) MASS-TRANSFER COEFFICIENTS

SCOPE OF PRESENTATION

- STRUCTURE OF AREST CODE
- TYPICAL RESULTS
- BENCHMARKING
- FUTURE ACTIVITIES

FUTURE ACTIVITIES

- MODIFICATIONS TO CONTAINMENT MODELS
  - ALTERNATE CONTAINER MATERIALS
  - CLADDING FAILURE
- ENHANCEMENTS TO RELEASE MODELS
- FURTHER EVALUATION OF COUPLED PROCESSES
  - THERMAL-HYDROLOGICAL
  - THERMAL-MECHANICAL
  - GEOCHEMICAL-RADIATION
- SCALE EFFECTS ON NEAR-FIELD ANALYSIS
- BENCHMARK COMPARISON ON TEST PROBLEMS
- SENSITIVITY ANALYSES