ANALYSIS OF HUMAN INTRUSION: DRILLING MODELS FOR NRC'S ITERATIVE PERFORMANCE ASSESSMENT CAPABILITY

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OVERVIEW

I. INTRODUCTION

II. PHASE 1 MODEL

III. PHASE 2 MODEL

IV. SUMMARY

WHY MODEL HUMAN INTRUSION BY DRILLING?

- REQUIRED TO GENERATE CCDF OF RELEASES PER EPA STANDARD
- SHOWS EFFECTS OF HUMAN INTRUSION
- SHOWS HOW WELL REPOSITORY RESISTS/ MITIGATES HUMAN INTRUSION
- EXPLORATORY DRILLING IS A POTENTIAL SCENARIO AT ANY SITE

MODELING OBJECTIVES

- PROBABILITY OF DRILLING (NOT THE FOCUS HERE)
  - (USED EPA GUIDANCE IN APPENDIX B OF 40 CFR PART 191)
- POTENTIALCONSEQUENCES OF DRILLING:
  - DIRECT RELEASES TO ENVIRONMENT

    (MODELED IN PHASE 1 AND PHASE 2)

MODELING OBJECTIVES *(CONTINUED)*

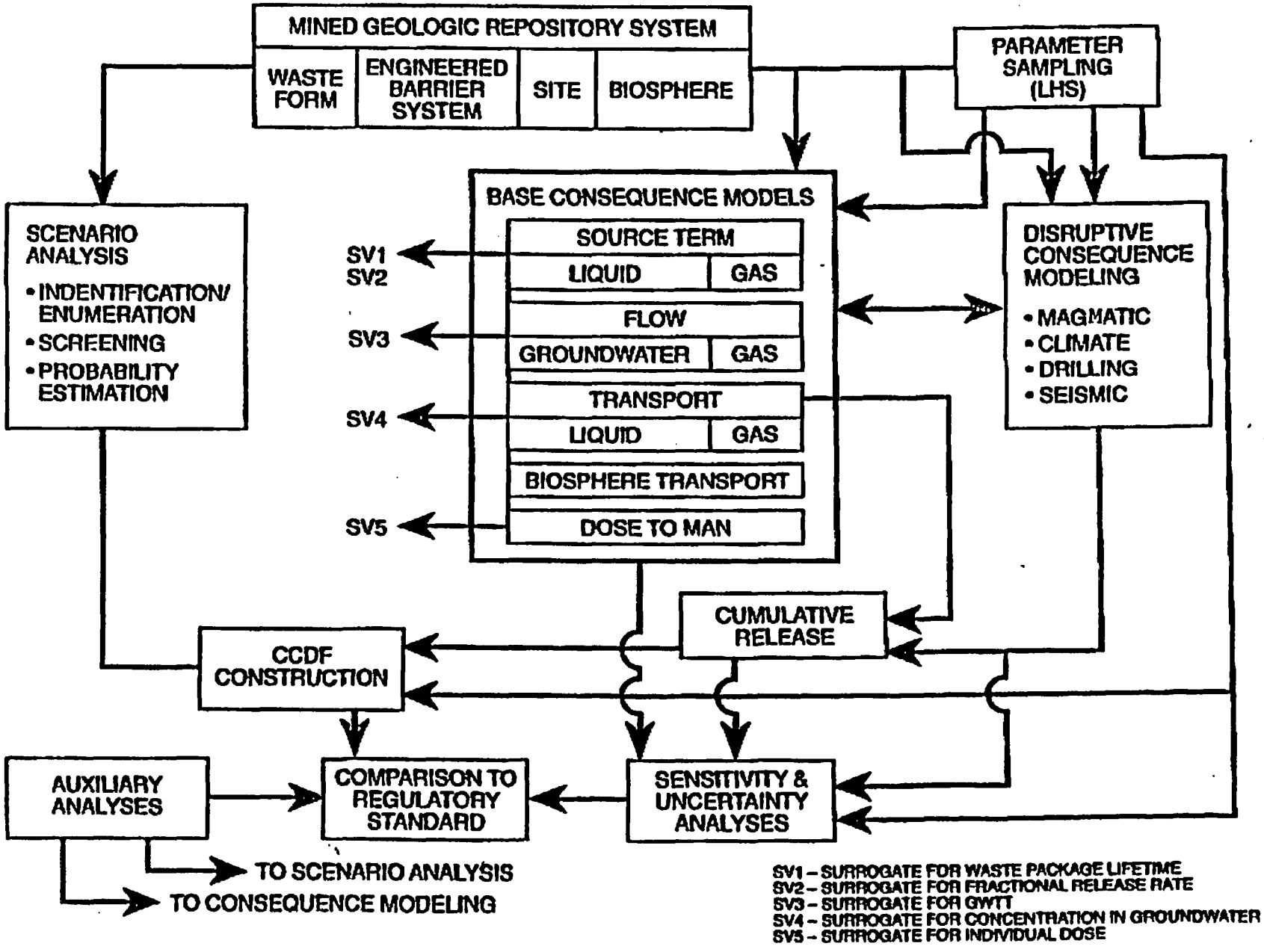
- DRILLING CAUSED FAILURE OF WASTE PACKAGE(S) AND/OR ENGINEERED BARRIER SYSTEM (EBS)

  (MODELED IN PHASE 2)

- EFFECTS OF DRILLING ON HYDROLOGIC FLOW AND RADIONUCLIDE TRANSPORT (LIQUID AND GAS PATHWAYS)

  (NOT YET MODELED)

PHASE 2 COMPONENTS OF TOTAL SYSTEM PERFORMANCE ASSESSMENT



SV1 – SURROGATE FOR WASTE PACKAGE LIFETIME
SV2 – SURROGATE FOR FRACTIONAL RELEASE RATE
SV3 – SURROGATE FOR GWTT
SV4 – SURROGATE FOR CONCENTRATION IN GROUNDWATER
SV5 – SURROGATE FOR INDIVIDUAL DOSE

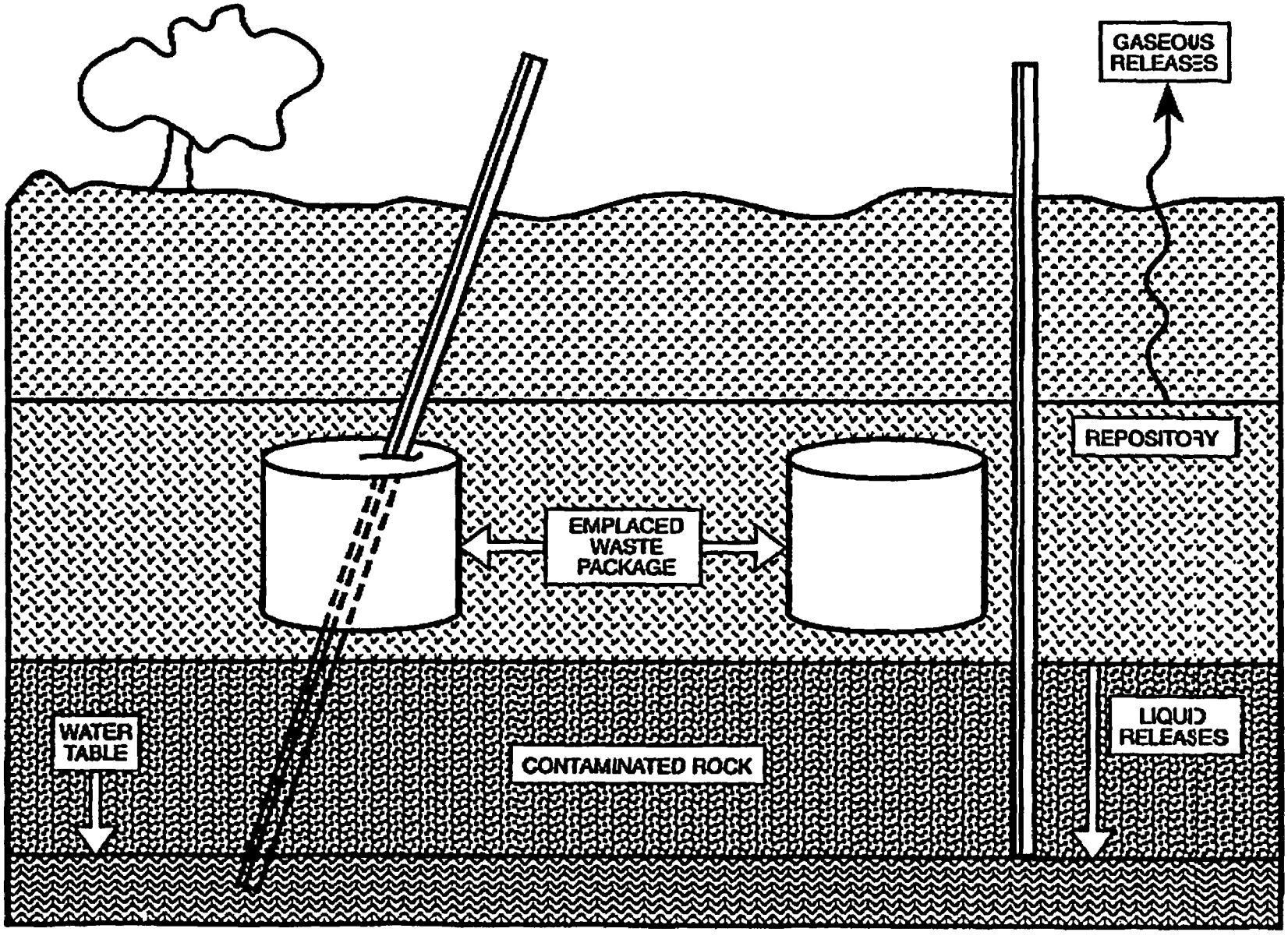
ASPECTS TO BE TREATED IN DRILLING CODE:

- RADIOACTIVE DECAY
- RADIONUCLIDE MIGRATION
- WASTE PACKAGE FAILURE FROM CAUSES OTHER THAN DRILLING
- DIRECT RELEASES

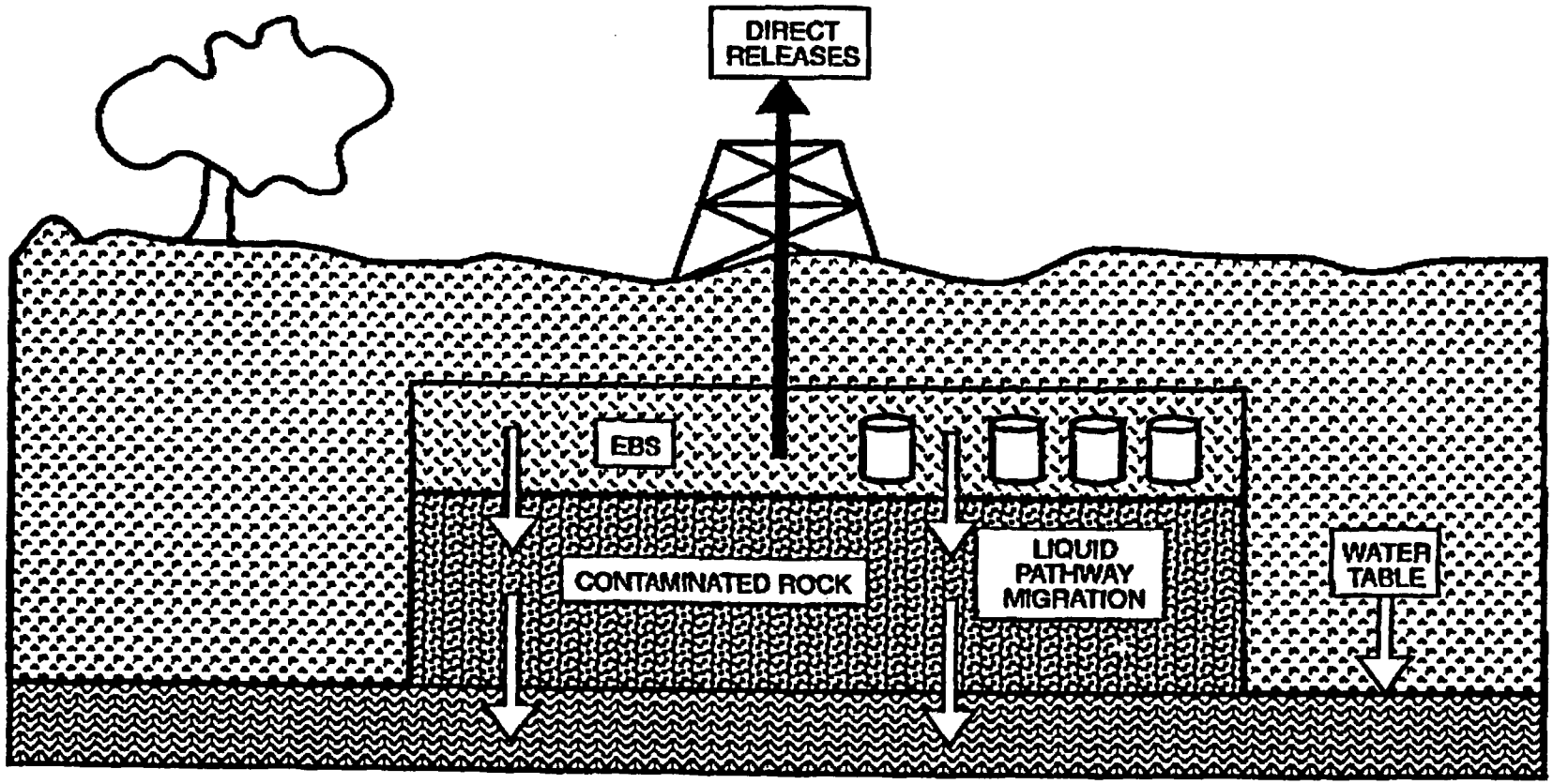
FACTORS NOT CONSIDERED IN EITHER MODEL

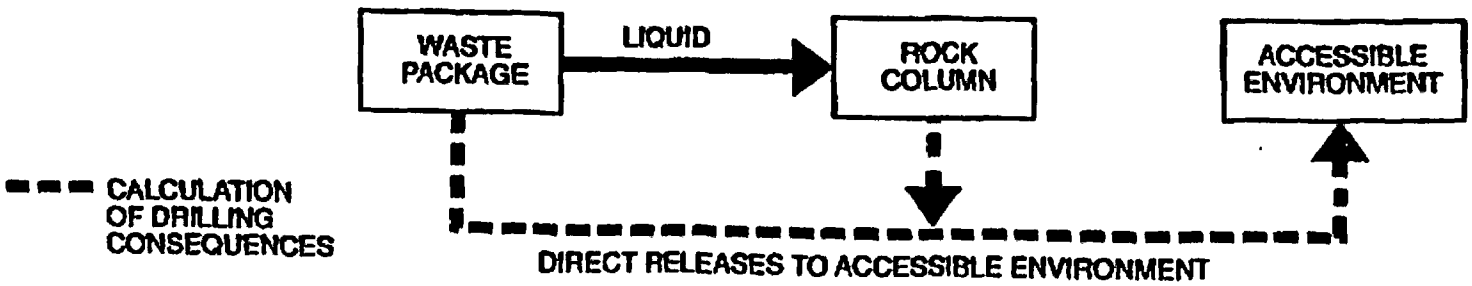
- SLANT DRILLING
- CHANGES IN LIQUID AND GAS FLOW DUE TO BOREHOLES
- WASTE DROPPED TO BASE OF BOREHOLE (SNL/DOE MODEL)
- EFFECT OF TOPOGRAPHY UPON DRILLING RATE
- ADDITION OF AND EFFECT OF DRILLING FLUID
- CONTAMINATED ROCK ABOVE REPOSITORY

DRILLING SCENARIO



2 COMPARTMENT ANALYSIS





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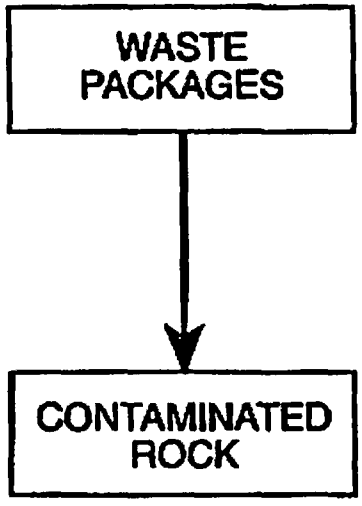
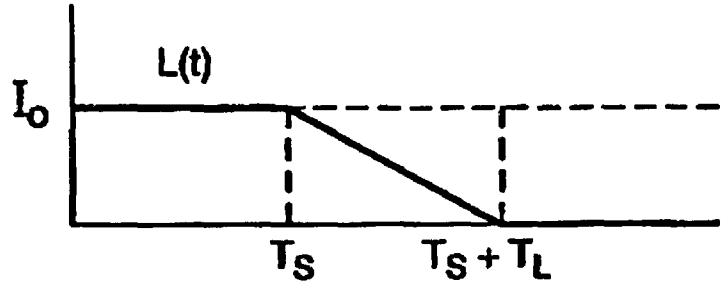
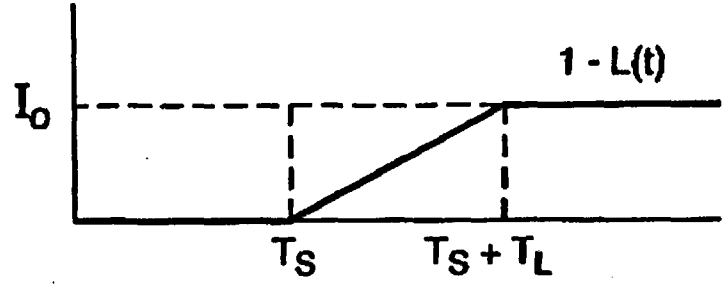




INVENTORY IN WASTE PACKAGES



INVENTORY IN CONTAMINATED ROCK

INVENTORY IN WASTE PACKAGE

$$I_i(t) = D_i(t)\, L(t)$$

INVENTORY IN CONTAMINATED ROCK

$$I_i^1(t) = D_i\,(1 - L(t))$$

ASSUMED: UNIFORM CONCENTRATION OF RADIONUCLIDES WITHIN HOST ROCK

$D_i\,(t) \equiv$ DECAY OF RADIONUCLIDE i

$I_o \equiv$ INITIAL REPOSITORY INVENTORY

$T_L \equiv$ TIME OF LEACHING = (Io/R)

$T_S \equiv$ TIME THAT LEACHING STARTS (WASTE PACKAGE LIFETIME)

CONSEQUENCE CALCULATIONS

- POISSON PROCESS
  - POISSON DISTRIBUTION GIVES PROBABILITY ON N BOREHOLES, GIVEN DRILLING RATE AND TIME PERIOD
  - EXPECTED VALUE CONSEQUENCES CALCULATED
- AVERAGE CONSEQUENCES CALCULATED FOR WASTE & CONTAMINATED ROCK EXHUMATION
  - CONDITIONAL PROBABILITIES:
    - ROCK COLUMN = 1.0
    - WASTE PACKAGE = $\frac{\text{INTERCEPT AREA}}{\text{REPOSITORY AREA}}$

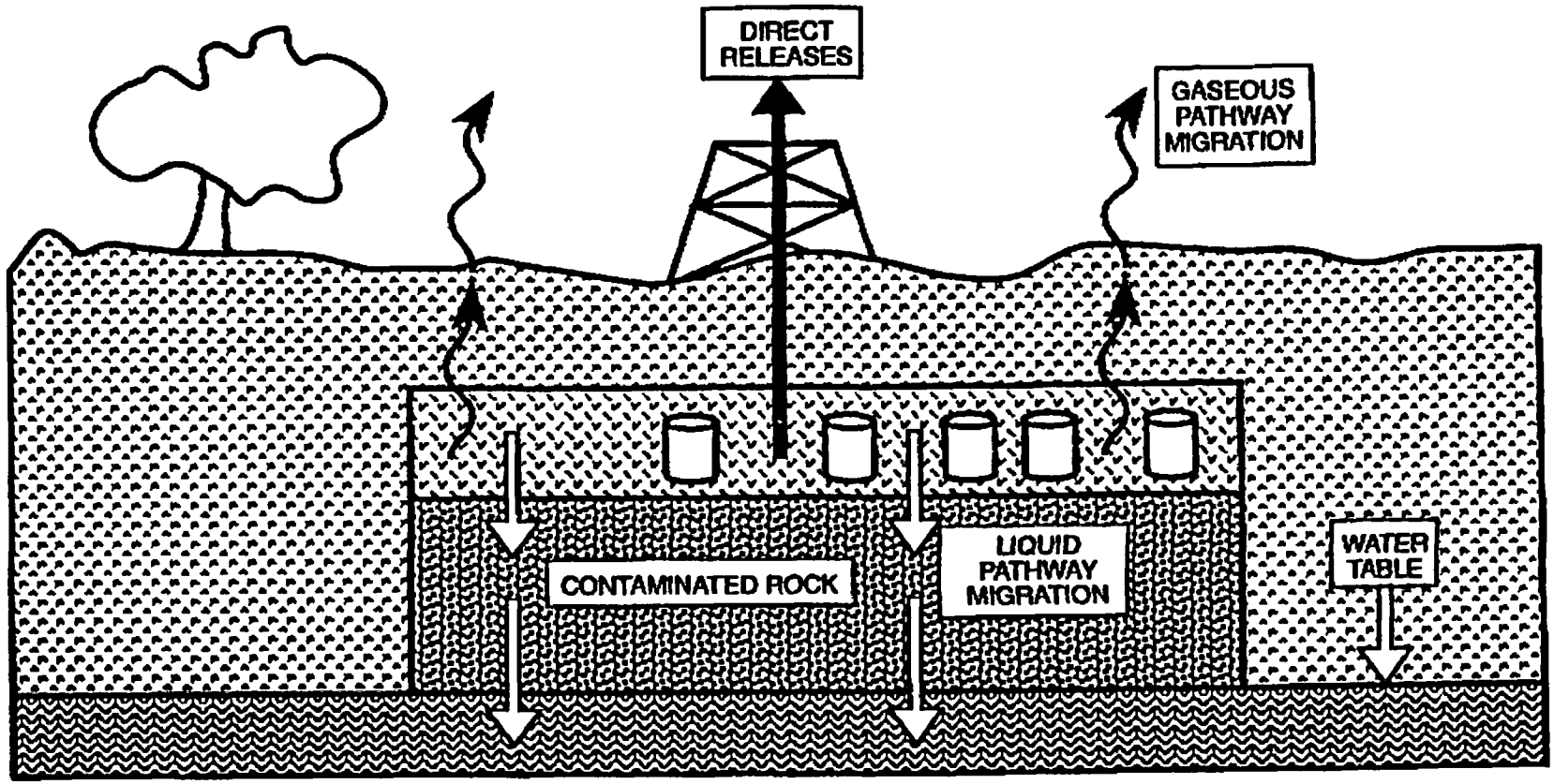
CONSEQUENCE CALCULATIONS *(CONTINUED)*

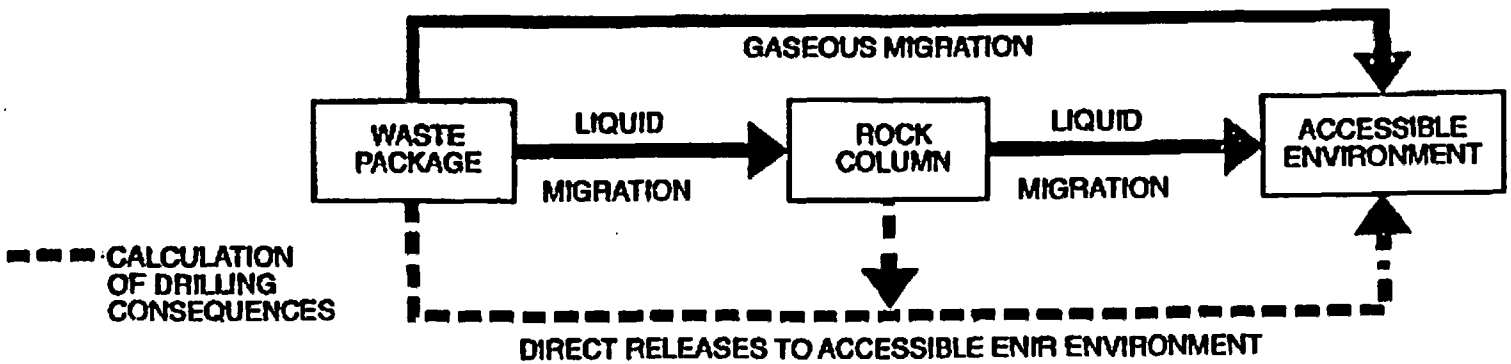
$$\text{EXPECTED VALUE} = P_{WP}\, C_{WP} + P_{RC}\, C_{RC}$$

$$C_{WP} = I_{WP} \left[\frac{V_e}{V_{WP}} \right] \qquad C_{RC} = I_{RC} \left[\frac{A_e}{A_{RC}} \right]$$

A = CROSS-SECTIONAL AREA
C = AVERAGE COSEQUENCES OF REMOVING RADIONUCLIDES FROM THE COMPARTMENT
I = INVENTORY OF RADIONUCLIDES IN THE COMPARTMENT
V = VOLUME
P = CONDITIONAL PROBABILITY OFDRILLING INTO THE COMPARTMENT
e = BOREHOLD (EXCAVATED)
RC = ROCK COUMN (SAME AREALEXTENT AS REPOSITORY)
WP = WASTE PACKAGE

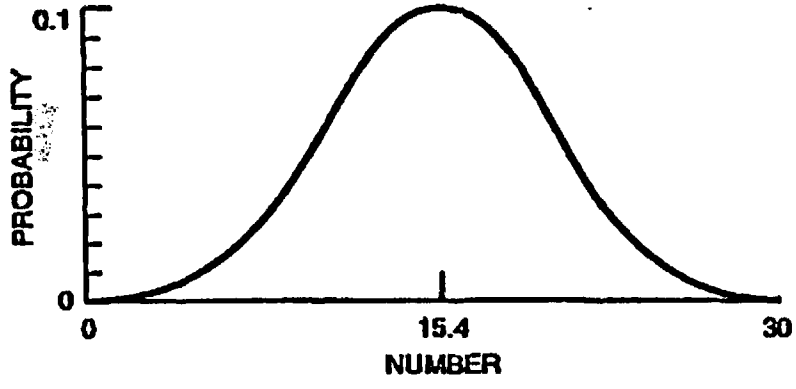
3 COMPARTMENT ANALYSIS



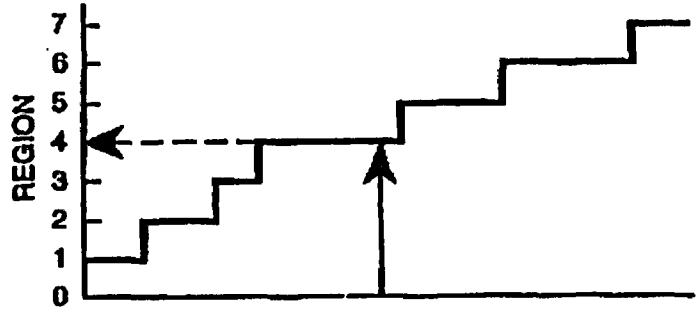


SAMPLED DRILLING EVENTS

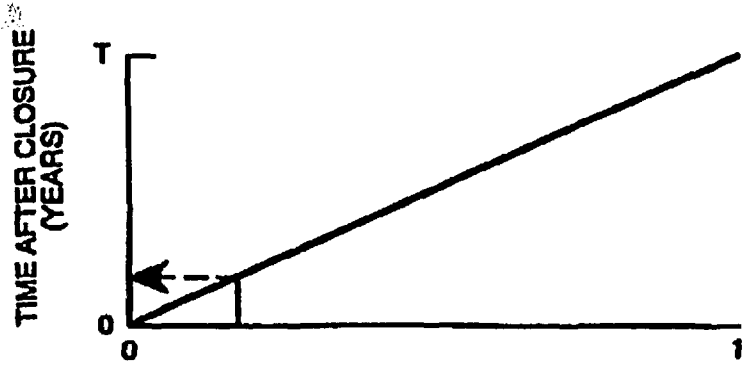
NUMBER OF DRILLING EVENTS



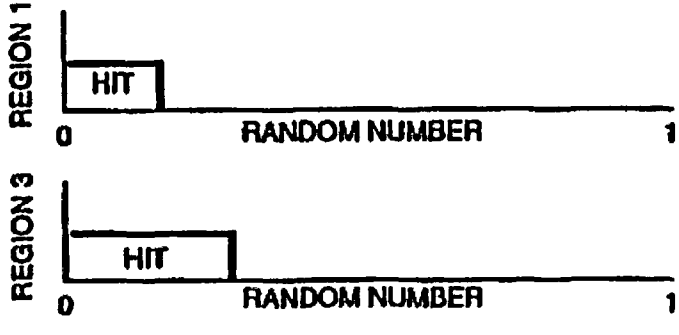
REGION OF THE REPOSITORY



TIME OF EVENT



HIT DETERMINATION



PHASE 2 DRILLING CONSEQUENCE ANALYSIS

$$\frac{dI_i}{dt} = -\lambda_i I_i + \lambda_{i-1} I_{i-1} + M_i(t)$$

I_i = INVENTORY OF NUCLIDE i IN THE GIVEN COMPARTMENT
λ_i = DECAY CONSTANT FOR NUCLIDE i
$M_i(t)$ = RATE OF MASS INSECTION OR REMOVAL OF NUCLIDE i IN THE COMPARTMENT

FOR BATEMAN SOLUTION:

$$M_i(t) = 0 \qquad I_i(t=0) = I_{0i}$$

TO USE BATEMAN SOLUTION, ASSUME:

$$M_i(t) = \sum_{j=0}^{J} \delta(t-t_j)\,\Delta t_j F_{ij}$$

$\delta(t-t_j)$ = DIRAC DELTA FUNCTION
Δt_j = LENGTH OF TIME INTERVAL

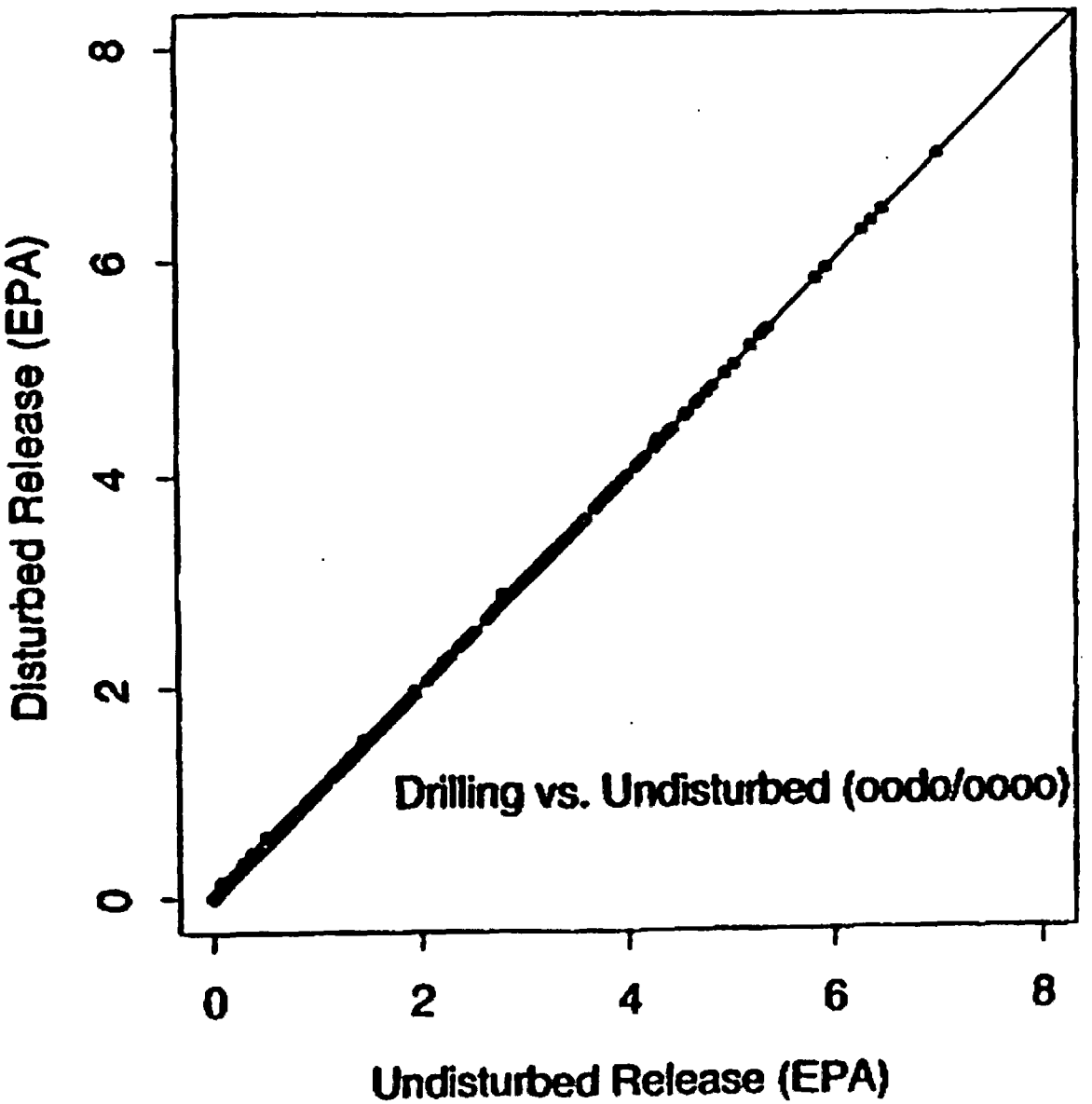
PHASE 2 DRILLING CONSEQUENCE ANALYSIS *(CONTINUED)*

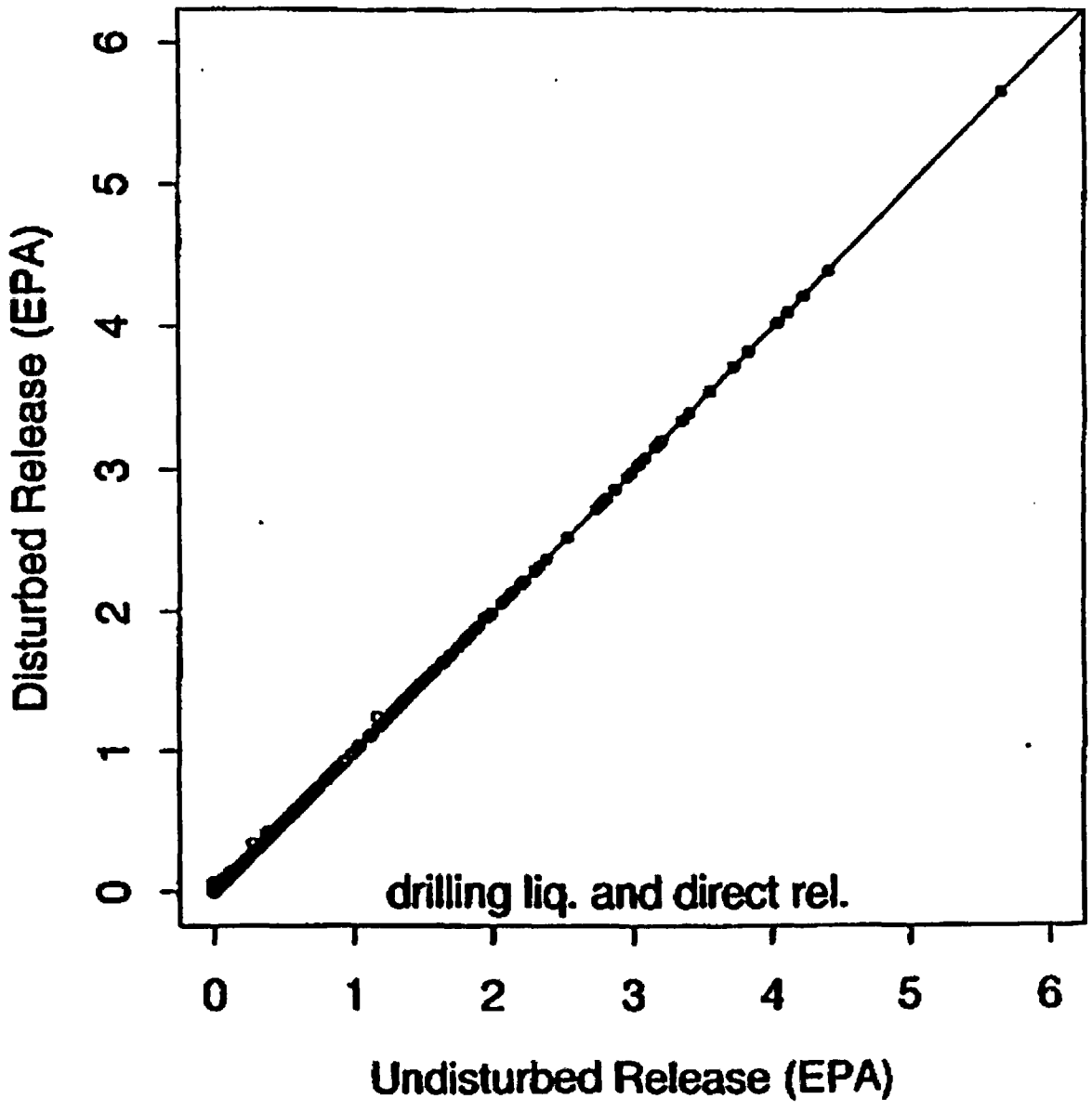
F_{ij}^{WP} = - POINT ESTIMATE OF THE RELEASE OF RADIONUCLIDE i AT TIME j TO THE GEOSPHERE

F_{ij}^{RC} = + POINT ESTIMATE OF THE RELEASE OF RADIONUCLIDE i AT TIME j FROM THE WASTE PACKAGE - POINT ESTIMATE OF THE RELEASE OF RADIONUCLIDE i AT TIME j TO THE ACCESSIBLE ENVIRONMENT

$$C_{HIT} = I_{WP}\left[\frac{A_e}{A_{WP}}\right] + I_{RC}\left[\frac{A_e}{A_{WP}}\right]$$

$$C_{MISS} = I_{RC}\left[\frac{A_e}{A_{RC}}\right]$$


Drilling vs. Undisturbed (oodo/oooo)
Disturbed Release (EPA)
Undisturbed Release (EPA)
0
2
4
6
8
0
2
4
6
8


Disturbed Release (EPA)
0
1
2
3
4
5
6
drilling liq. and direct rel.
0
1
2
3
4
5
6
Undisturbed Release (EPA)

Without C-14

TAB K
Replacement Page

HUMAN INTRUSION SCENARIOS: DOSES TO MEMBER OF THE PUBLIC

ASSUME:

---HUMAN INTRUSION RESULTS IN A HIT ON A CANNISTER AND RELEASE OF RADIONUCLIDES DIRECTLY TO THE SURFACE ABOVE THE REPOSITORY

---4% OF MATERIAL BROUGHT TO SURFACE BECOMES AIRBORNE & RESPIRABLE

---MEMBER OF PUBLIC DOWNWIND AT 5 KILOMETERS FOR 5550 HOURS PER YEAR

---THE PLUME DEPOSITS RADIONUCLIDES ON CROPS SUBSEQUENTLY INGESTED BY FARM ANIMALS AND HUMANS (CONTAMINATED MILK, BEEF, VEGTABLES)

HIGHEST LIFETIME EFFECTIVE DOSE FOLLOWING HIT:

HIT AT:	DOSE AT:	REMS/70YRS:	R=SUM Q/L
100 YRS	140 YRS	4.2E-01	2.97E-02
500	560	4.7E-01	2.25E-02
1,000	1,050	2.5E-01	2.18E-02
10,080	>10,080	<3E-06	1.89E-02

NOTE: AM-241, PU-239, PU-240, NP-237 ARE MAJOR CONTRIBUTORS TO DOSE. CONTRIBUTION FROM C-14 IS NEGLIGIBLE AT ALL TIMES SHOWN.

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HIGHEST LIFETIME EFFECTIVE DOSE (REMS) FOR YEARS FOLLOWING HIT:

HIT AT:	DOSE AT:	REMS/70YRS:	CONTRIBUTING NUCLIDES
100 YEARS	310 YEARS	4.2E-01	AM-241, PU-239, PU-240, NP-237
500	1,130	4.7E-01	AM-241, PU-239, PU-240, NP-237
1,000	2,120	2.5E-01	AM-241, PU-239, PU-240, NP-237
10,080	14,630	<E-07	---

NOTES: DOSE TO INDIVIDUAL FROM C-14 IS NEGLIGIBLE AT TIMES SHOWN

COPIES OF INVENTORIES AT TIMES SHOWN ARE ATTACHED

OVERVIEW OF MODEL DIFFERENCES BETWEEN PHASE 1 AND PHASE 2:

	PHASE 1	PHASE 2
COMPARTMENTS	2	3
MIGRATION PATHWAY(S)	LIQUID ONLY	LIQUID AND GASEOUS
DECREASE IN ROCK COLUMN INVENTORY	DECAY ONLY	DECAY AND MIGRATION TO ACCESSIBLE ENVIRONMENT
METHOD OF CONSEQUENCE DETERMINATION	AVERAGE	SAMPLED
MODEL SOPHISTICATION	RUDIMENTARY	SIMPLE
NUMBER OF AREAL REGIONS USED	1	7
INVENTORY MODELING	DECAY ONLY	DECAY & DAUGHTER PRODUCTION
DRILLING FAILURE OF CANISTERS	NO	YES
CONSEQUENCES (CUMULATIVE RELEASE)	SMALL	SMALLER

PROBLEM AREAS:

- DISCRETIZATION IN TIME AND SPACE
- APPROPRIATE LEVEL OF DETAIL
- PROBABILITIES MAY BE INFLUENCED BY SAMPLED VARIABLES
- INTEGRATION WITH OTHER SCENARIOS
- MANAGING CONCURRENT EVENTS
- VARIABILITY IN CHARACTERISTICS AND SCOPE OF HUMAN INTRUSIVE EVENTS (e.g., TYPE OF DRILLING, MINING, INJECTION)

LESSONS LEARNED

- SIGNIFICANT UNCERTAINTY IN PREDICTING HUMAN ACTIVITY:
  - FULL RANGE OF POTENTIAL ACTIVITIES CAN NOT BE MODELED
  - MODELS MAY FOCUS ONLY UPON ASPECTS EASILY MODELED

LESSONS LEARNED *(CONTINUED)*

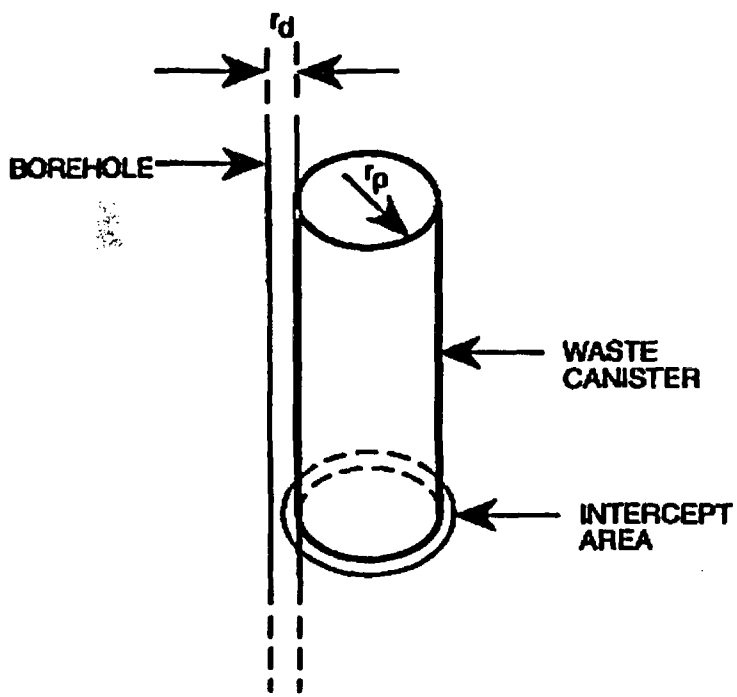
- REPOSITORY SYSTEM PERFORMANCE IS DIFFICULT TO ESTIMATE
  - THE SYSTEM IS COMPLEX WITH SUBTLE COUPLING OF SUBSYSTEMS
  - DETAILED MODELING IS REQUIRED TO OBTAIN ESTIMATES OF SYSTEM OR SUBSYSTEM PERFORMANCE.

LESSONS LEARNED *(CONTINUED)*

- COUPLING OF BASE PERFORMANCE AND DISRUPTED PERFORMANCE:
  - A REPOSITORY BETTER AT RETAINING RNs FOR UNDISTURBED CONDITIONS WILL BE VULNERABLE TO DISRUPTIVE EVENTS.
  - A REPOSITORY LESS ABLE TO RETAIN RNs FOR UNDISTURBED CONDITIONS WILL BE MORE IMMUNE TO DISRUPTIVE EVENTS.

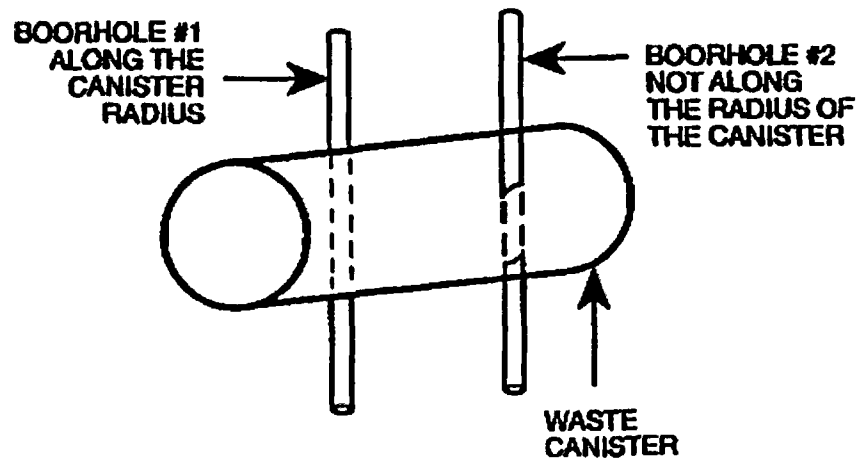
VERTICAL EMPLACEMENT

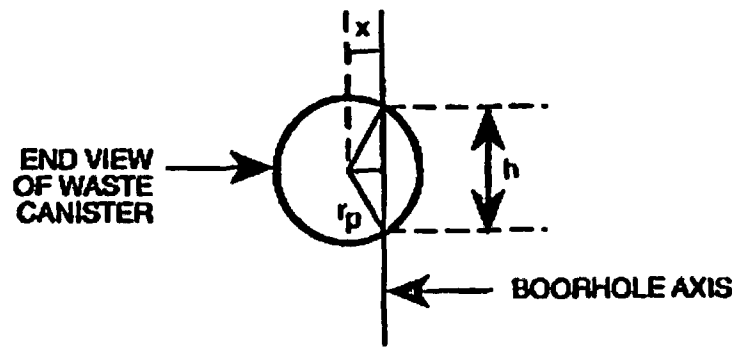
$$V_e^v = \pi r_d^2 L$$



HORIZONTAL EMPLACEMENT

$$V_e^h = \frac{r_p(\pi r_d^2)}{2}$$





V_e^h = VOLUME OF WASTE EXCAVATED FROM A HORIZONTALLY EMPLACED WASTE PACKAGE

V_e^v = VOLUME OF WASTE EXCAVATED FROM A VERTICALLY EMPLACED WASTE PACKAGE

r_p = RADIUS OF THE BOORHOLE

r_d = RADIUS OF THE WASTE PACKAGE

L = LENGTH OF THE WASTE PACKAGE

RADIONUCLIDE MIGRATION

WASTE PACKAGE

▼

EBS

▼

GEOSPHERE

▼

BIOSPHERE

REPOSITORY

ACCESSIBLE ENVIRONMENT

HUMAN INTRUSION SCENARIOS: EXTERNAL DOSES DUE TO CANNISTER HIT

ASSUME:

---CORE SAMPLE - 1.5 METERS LONG AND DIAMETER 0.1 METER

---DAMP CORE SAMPLE - NO AIRBORNE DUST - NO INHALATION

---NO INGESTION OF CORE SAMPLE MATERIAL (UNREALISTIC?)

---CORE SAMPLE IS UNSHIELDED (BOTH BETA AND GAMMA DOSE CALCULATED)

---CONSIDER ONLY EXTERNAL EXPOSURE TO GEOLOGIST THAT HANDLES SAMPLE

---ALL OPERATIONS CONDUCTED AT ARM'S LENGTH (2 FEET)

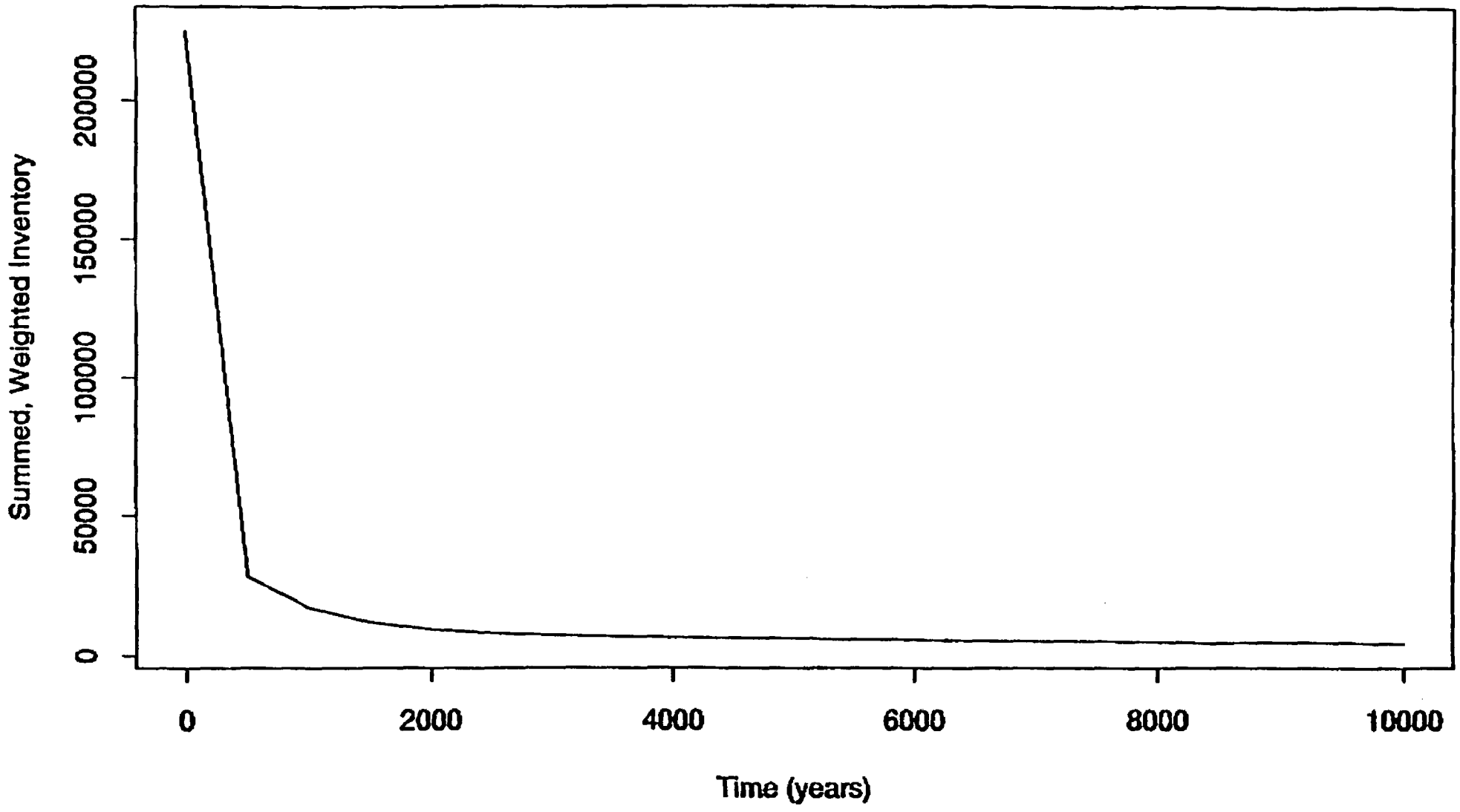
---EXPOSURE FOR ONE HOUR (TO DECOUPLE SAMPLE, LOG IN, STUDY, STORE)

---EXTREMITY DOSES NOT CONSIDERED, ONLY WHOLE BODY DOSE

---DOSE BASED ON INVENTORY OF PARENT AND DAUGHTERS AT TIMES SHOWN

DOSE AT:	REMS/HOUR:	CONTRIBUTING NUCLIDES:
100 YRS	60.7	99.7% CS-137
10,000 YRS	0.3	94.5% NP-237; 5.5% NB-94

NOTE: COPIES OF INVENTORIES AT TIMES SHOWN ARE ATTACHED



Repository inventory as a function of time, assuming no release, only decay and production. Measured in units of R = sum(Qi(t)/Li).