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Volume II: Implementation for Terminal Storage in Reference Repository and Other Applications

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DEVELOPMENT AND APPLICATION OF A RISK ASSESSMENT METHOD FOR RADIOACTIVE WASTE MANAGEMENT

Final Contract Report

Principal Investigator: Stanley E. Logan
Bureau of Engineering Research
The University of New Mexico
Albuquerque, New Mexico 87131

Volume II: Implementation for Terminal Storage in Reference Repository and Other Applications

S. E. Logan, M. C. Berbano

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Project Officer
Bruce J. Mann
Office of Radiation Programs-LVF
P. O. Box 15027
Las Vegas, Nevada 89114

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FOREWORD

The EPA Office of Radiation Programs carries out a national program to evaluate human exposures to radioactivity, and to promote the development of controls to protect the environment and public health from such radioactivity. An important part of this program consists of the development of environmental protection criteria and standards for radioactive waste management and disposal.

To sustain this effort, studies have been supported by EPA to develop methods to evaluate the environmental adequacy of proposed waste management alternatives, and this report describes one of the first attempts to develop a comprehensive assessment model. It has been funded at a very modest level. Much interest has been expressed in this work, and through publication, EPA is making it available to those involved with the development and use of models as decision-making tools.

In order for models to be useful as tools for decision-making concerning radioactive waste management alternatives, their capabilities and limitations must be fully understood. It should be noted that assessment models in themselves will not identify optimum waste management choices. However, they can be used to compare well defined alternatives. One of the necessary steps in any model development and validation process is the comparison of results with results obtained from the application of alternate models to test cases. It is hoped that as other comprehensive assessment models become available, comparison studies can be performed.

The methodology described herein has been applied, for model illustration purposes, to a reference repository in a bedded salt formation located in the southwestern United States. Any results published in this report should not be interpreted as implying conclusions concerning the suitability of the reference site or any site-specific method/repository combination for the preparation and disposal of radioactive waste.

Comments on this analysis as well as any new information would be welcomed; they may be sent to the Director, Technology Assessment Division (AW-459) Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C. 20460.

W. D. Rowe, Ph.D.
Deputy Assistant Administrator
for Radiation Programs (AW-459)

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ABSTRACT

A Radioactive Waste Management Systems Model, developed and implemented by The University of New Mexico under contract with the U. S. Environmental Protection Agency, is presented. The systems model and associated computer code called AMRAW (Assessment Method for Radioactive Waste), has two parts. The first part, AMRAW-A, consists of the Source Term (radioactive inventory versus time), the Release Model, and the Environmental Model. The Release Model considers various geologic and man-caused events which are potential mechanisms for release of radioactive material beyond the immediate environs of a repository or other location; the risk analysis mode uses events distributed probabilistically over time, and the consequence analysis mode uses discrete events occurring at specified times. The Environmental Model includes: 1) the transport to and accumulations at various receptors in the biosphere, 2) pathways from these environmental concentrations, and 3) resulting radiation dose to man.

The second part of the systems model, AMRAW-B, is the Economic Model which calculates health effects corresponding to the various organ dose rates from AMRAW-A, collects these health effects in terms of economic costs and attributes these costs to radionuclides, decay groups, and elements initially in the waste inventory. Implementation, with calculated results, of AMRAW for Terminal Storage in a Bedded Salt Reference Repository are presented. Preliminary demonstrations for the repository operations phase of waste management and terminal storage in a shale formation are described; possible applications to other radioactive and nonradioactive hazardous materials are discussed. AMRAW uniquely links all steps together in a continuous calculation sequence.

ACKNOWLEDGEMENTS

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Persons at the EPA, other federal agencies, national laboratories, federal contractors, and foreign correspondents have provided helpful suggestions during progress of the work or through review of draft reports. These contributions are greatly appreciated though space does not permit acknowledgement of each individual contribution.

Personnel at The University of New Mexico who participated and other persons making direct contributions are named in the Acknowledgements section of Volume I.

DEVELOPMENT AND APPLICATION OF A RISK ASSESSMENT METHOD FOR RADIOACTIVE WASTE MANAGEMENT

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VOLUME II	IMPLEMENTATION FOR TERMINAL STORAGE IN REFERENCE REPOSITORY AND OTHER APPLICATIONS
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VOLUME II

LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

CHAPTER 1

AMRAW	(Assessment Method for Radioactive Waste) Assessment Model and associated computer code
AMRAW-A	That portion of AMRAW which includes Source Terms, Release Model and Environmental Model
AMRAW-B	The economic part of AMRAW

CHAPTER 2, 3, AND 4

K_d	Distribution coefficient--a measure of retention of species on porous media

CHAPTER 5

I	Hydraulic gradient, in feet per feet
L	Width of aquifer
Q	Discharge, in cubic feet per day
T	Transmissivity in square feet per day

CHAPTER 6

Section A. None

Section B.

A_o	Initial total radioactivity of species subject to leaching
$\mathcal{D}_e$	Effective diffusivity for the species
DC1	Variable name in AMRAW for $\mathcal{D}_e$
F_s	Total exposed area of specimen
k	Dissolution rate constant
L_p	$\sum_m a_n$

P	Overall probability for release to ground water
R_k	Radius of diffusing particle in cm
RLEACH	Subprogram in FAULT which handles leaching into ground water
SPACT	Specific activity factor
t	Time
V_s	Specimen volume
$\eta(x, t)$	Transformation variable used is solution of diffusion equation

Section C.

a_L	Longitudinal dispersivity
a_T	Transverse dispersivity
A2	Time transfer coefficient, incorporating radioactive and environmental decay
ADJ1	Max fraction of inventory (or value of G_m) which can be transferred (program variable name)
ADJ2	Transfer rate constant used in calculating G_m (program variable name)
AIRDOS-II	Air dispersion code from ORNL
AREAG	Zone land surface area
AREAW	Zone surface water area
BIOFAC	Concentration or dilution to the consumed or exposed quantity
C	Concentration of the dissolved species, also transfer coefficient which transforms environmental concentration in a receptor to corresponding dose commitment rate to a specified organ
DECFAC	(In AMRAW) Effective decay factor between two times
DELTE	Time interval over which environmental decay constant is applied; also, time increment for which transfer is calculated ; same as Δt (program variable name)
DISPN	(In AMRAW) Dispersion parameter (land surface area or water volume)

DRC	Estimated dissolution rate constant (program variable name)
E_m	(ADJ1 in AMRAW) Max fraction of inventory (or value of G_m) which can be transferred
EDC	Environmental Decay Constant
F_m	(ADJ2 in AMRAW) Transfer rate constant
G_m	(ADJ in AMRAW) Fraction of inventory transferred from one receptor pool to another pool per unit time
GNDDIS	Ground dispersion, related to ground water velocity and aquifer dimensions (program variable name)
GNDEP	(In AMRAW) Non-accumulating matrix which retains integrated deposition for current time increment for use in calculating transfer to terrestrial food products
JF= 1, 2, 3 or 4	Program variable to denote environmental receptor: 1 - Air, 2 - Land Surface, 3 - Surface Water, 4 - Ground Water
K_d	Distribution coefficient--a measure of retention of species on porous medium
M'	Ratio of amount of particular radionuclide released by leaching during a release time interval to the thickness of aquifer in which released
r	Radial distance from the center of Zone 1
R_d	Retardation factor
R2TOT	(In AMRAW) Accumulated net total concentration in μCi per cm^2 or cm^3 by zone and Environmental Input Receptor
RKD	Program variable name for K_d, distribution coefficient
t	Time in the environment, d
Δt	(DELTE in AMRAW) Time interval over which environmental decay constant is applied; also, time increment for which transfer is calculated
v_p	Pore (or seepage) velocity
VOLINT	Amount of exposure or consumption per year
x	Distance along aquifer to point of usage or discharge, m

y	Transverse distance from plume centerline, m
y_w	Effective plume width, m
y_y	Transverse distance to average concentration, m
z_a	Aquifer thickness, m
ZONALO	Dispersion allocation factor for air concentration
ZONDEP	Dispersion allocation factor for ground deposition
ε	Porosity
ρ	Bulk density of porous medium

CHAPTER 7

Section A.

A	Proportionality constant used in calculation of $(K_d)_{border}$
DECFAC	Effective decay factor between two times (program variable name)
EDC	Environmental Decay Constant
K_d	Distribution coefficient--a measure of retention of species on porous medium
$(K_d)_{border}$	For selected assessment time period, distance to ground water discharge and ground water velocity, value of K_d beyond which marginal value of increased precision in value of K_d is small
R_d	Retardation factor
t_t	Approximate transport time
T	Limiting transport time
U	Pulse velocity
v, v_p	Seepage or pore velocity
x	Distance to point of discharge or usage
ε	Porosity of the aquifer
ρ	Density of solid medium

Section B.

EDC	Environmental decay constant
K_d	Distribution coefficient

CHAPTER 8

Section A.

EDC	Environmental decay constant
K_d	Distribution coefficient

Section B.

A1	Release fraction to a given input receptor
DECFAC	Effective decay factor between two times (program variable name)
K_d	Same as above
PROB	Probability of occurrence

Section C.

K_d	Same as above

APPENDIX A, B

None

APPENDIX C

a(r)	Area of intersection
P	Volcanism probability
r	Distance between C_1 and C_2
r_1	Repository radius with center at C_1
r_2	Volcano effect radius with center at C_2

APPENDIX D

a	A factor used in relating magnitude of shocks to number, function of area and time
b	A factor used in relating magnitude of shocks to number; for New Mexico $b \approx 1.0$

D	Maximum displacement
L	Length of faulting
M_L	Local magnitude of largest earthquake
N	Earthquake shock event

APPENDIX E

D	Diameter of crater
k	Empirical constant in Hartman's relationship
N	Number of craters with diameter greater than D
P	Probability of a direct strike by meteorite with enough energy to exhume material to given depth

APPENDIX F

dA	Differential area
r	Radial distance to center of Zone 1
r_o	Radius of Zone 1
Z_i	Fraction of total amount released which is deposited in Zone i
ZONALO	Zone allocation factor (program variable name)

APPENDIX J

ADJ1	Maximum fraction of inventory (or value of G_m) which can be transferred from one receptor pool to another per unit time (AMRAW variable name)
ADJ2	Transfer rate constant used in calculating G_m (AMRAW variable name)
AREAW	Zone Surface water area
BIOFAC	Concentration or dilution to the consumed or exposed quantity
DC1	AMRAW variable name used to store values of D_e, effective diffusivity

DISPN	(AMRAW variable name) Dispersion parameter (land surface area or water volume)
DOSFAC	Dose rate conversion per unit of exposure or consumption for the specified organ
DRC	Dissolution rate constant (AMRAW variable name for k)
EDC	Environmental decay constant
MAN1L	Average annual local dose to individual by nuclide (AMRAW variable name)
MAN1N	Average annual nonspecific dose by nuclide to population (AMRAW variable name)
MAN2L	Average annual local dose to individual, all nuclides, all receptors (AMRAW variable name)
MAN2N	Average annual nonspecific dose to individual, all nuclides, all receptors (AMRAW variable name)
MAN2NF	Average annual nonspecific dose to individual, all nuclides, for receptor JF = 1 to 4 (AMRAW variable name)
RELOUT	Release fraction by each cut set for each nuclide (AMRAW variable name)
R1J	Release increment to Preliminary Environment Input Receptor from all release events by nuclide (AMRAW variable name)
R2TOT	(In AMRAW) Accumulated net total concentration in μCi per cm^2 or cm^3 by zone and Environment Input Receptor
RKD	Distribution coefficient, same as K_d (AMRAW variable name)
VOLINT	Amount of exposure or consumption per year (AMRAW variable name)
ZONALO	Dispersion allocation factor for air concentration (AMRAW variable name)
ZONDEP	Dispersion allocation factor for ground deposition (AMRAW variable name)

APPENDIX K

JF= 1, 2, 3, 4	Preliminary Environmental Input Receptors (1 - Air, 2 - Ground Surface, 3 - Surface Water, 4 - Ground Water)

MAN1L MAN1N MAN2L MAN2LF MAN2N Man2NF RELOUT R1J R2TOT	Same as Appendix J

APPENDIX L, M, AND N

MAN1L MAN1N	Same as Appendix J

CHAPTER 9

A(t)	Transfer coefficient to a given preliminary environmental input receptor
A1	Fraction of effected inventory transferred if release occurs
B & C	Constants used in equation for P(t)
CFAI	Input to AMRAW as number of canisters exposed to leach incident (AMRAW variable name)
DECFAC	(In AMRAW) Effective decay factor between two times
DEPGND	Deposition on land surface of zone (AMRAW variable name)
DEPWTR	Deposition on water surface of zone (AMRAW variable name)
FAULT	AMRAW subroutine for Release Model calculations
IFLAG	AMRAW flag which designates probability function type
ITRE	AMRAW subscript to designate time at end of release
ITRS	AMRAW subscript to designate time at start of release
IW	Computer program flag to denote assessment branch
P(t)	Annual probability of release
$P_n(t)$	Component factor n, of release probability

CHAPTER 9 CONT'D

PROBB	AMRAW variable name for initial value of probability factor value
t_p	Time at which P(t) commences change or when discrete event occurs in using delta function
TP	AMRAW variable name for t_p
ZONALO	Zone allotment for direct dispersion to land surface

CHAPTER 10

None

CHAPTER 11

K_d	Same as previously defined, Chapter 4
r_1	Repository radius with center at C_1
r_2	Volcano effect radius with center at C_2

CHAPTER 12

AMRAW-A	That portion of AMRAW which includes Source Terms, Release Model, and Environmental Model
AMRAW-B	The Economic Model part of AMRAW
BIOFAC	Concentration or dilution to the consumed or exposed quantity
C	Transfer coefficient for human dose commitment
$\mathcal{D}_e$	Diffusivity coefficient
DOSFAC	Dose rate conversion per unit of exposure or consumption for the specified organ
k	Dissolution rate constant
K_d	Distribution coefficient
LC_{50}	That concentration of a toxic material which, over a given period of time, is likely to kill one-half the test animal species

CHAPTER 12 CONT'D

LD_{50}	That dose likely to kill one-half of a group of animals within a specified period of time
VOLINT	Amount of exposure or consumption per year

APPENDIX O

JF = 1 to 4	Environmental Input Receptor Identification
MAN2L	Average annual local dose to individual, all nuclides, all receptors (AMRAW variable name)
MAN2LF	Average annual local dose to individual, all nuclides, for receptor JF = 1 to 4 (AMRAW variable name)
MAN2N	Average annual nonspecific dose to individual, all nuclides, all receptors (AMRAW variable name)
MAN2NF	Average annual nonspecific dose to individual, all nuclides, for receptor JF = 1 to 4 (AMRAW variable name)

APPENDIX P

None

APPENDIX Q

D_e	As previously defined in Chapter 12
K	Stokes-Einstein constant
K_d	Distribution coefficient
R_k	Radius of diffusing particle
z	Ionic charge
μ	Solvent viscosity at absolute temperature T °K

CHAPTER 1

INTRODUCTION

The Radioactive Waste Management Systems Model and associated computer code, AMRAW, developed at The University of New Mexico (UNM), consists of two parts which are run separately: 1) AMRAW-A consists of the Source Term, Release Model, and Environmental Model, and 2) AMRAW-B is the Economic Model. Volume I gives the generic description of the AMRAW-A model. The model applies to any of the several phases in the radioactive waste management sequence (Fig. 4-1 in Vol. I), although most of the effort during this study, has been related to the terminal storage (disposal) phase.

As part of the generic model development work, an application to terminal storage in a bedded salt model repository has been completed. The development of an application in parallel with development of the model helped in: 1) identifying model provisions necessary to accommodate real situations, 2) providing a demonstration of the procedure for applying the model to any site, 3) provided some useful output for waste management planning, and 4) accumulated a data bank which includes site-specific and non site-specific components.

Calculated results from the demonstration application to a specific site are useful for several purposes including the following:

1) Determine behavior at each stage through the model: calculated releases from the repository, environmental concentrations, and dose equivalent rates to the population.

2) Determine relative importance of each environmental input receptor: air, land surface, surface water, and ground water.

3) Select the most significant radionuclides under various circumstances.

4) Determine effects of variations in parameters which have large uncertainties.

5) Study the consequences of various low-probability potential release scenarios.

Part 1 of this volume presents the application of AMRAW-A to terminal storage in a bedded salt model repository. The site chosen for this initial application is the Los Medaños area in southeastern New Mexico, an area under study for potential installation of a Waste Isolation Pilot Plant [Wr77]. The proposed pilot plant is for DOE trans-uranium waste and experimental retrievable emplacement of some high-level waste. There are no plans at the present time to expand this facility into a full scale high-level waste repository but the application of AMRAW reported here assumes it is a full scale repository for study purposes. A base case which simultaneously considers several release scenarios is first described in detail along with calculated results. This is followed by several series of other cases which examine component release scenarios and variations of selected parameters for sensitivity and consequence analysis purposes. The population dose calculations output from AMRAW-A become input data for the AMRAW-B Economic Model, detailed in Vol. III.

Part 2 of this volume presents additional applications of AMRAW-A. First, the model is applied to repository operations, the phase during which a repository is open and receiving waste shipments. Then, a discussion of application to ground surface storage is presented. A preliminary demonstration for another geologic setting (Denver Basin shales) is given to illustrate generic capabilities of the model. Finally, results of a feasibility study are presented which investigated the applicability of AMRAW to other than high-level radioactive wastes and to nonradioactive hazardous materials.

CHAPTER 2

SUMMARY

The generic description of AMRAW-A is presented in Vol. I. Implementation of the model and computer code for terminal storage in a bedded salt reference repository is presented in Part 1 of this volume. The model is not limited to the application described here; demonstration applications to other phases of the radioactive waste management sequence, and to another geologic setting are given in Part 2 of this volume.

A. PART 1: TERMINAL STORAGE IN BEDDED SALT

The site chosen for this initial application of AMRAW is the Los Medaños area in southeastern New Mexico. This area is in a stable region, has thick deposits of nearly horizontal bedded salt (Salado Formation), and is under study for potential installation of a Waste Isolation Pilot Plant [Wr77]. The proposed pilot plant is for DOE trans-uranium waste and experimental retrievable emplacement of some high-level waste. There are no plans at the present time to expand this facility into a full scale high-level waste repository. The application of AMRAW reported here assumes for study purposes that there is only one repository for commercial high-level waste and that it is located at Los Medaños. Concentration of the total waste inventory at one site represents a conservative case for demonstration of the assessment methodology; division of the total inventory into several different repositories reduces the risk associated with any one site.

The site and surrounding region is characterized for two categories of information: 1) geologic and hydrologic features of the area provides a base for evaluation of potential release events, and 2) demographic and agricultural data within a radius of approximately 150 km from the site provides for calculation of consequences of any release. The study region is divided into 8 zones along county boundaries with one or more counties in each zone. Exceptions are Zone 1 which is defined as a 5 km radius area enclosing the site, and Zone 8 which is defined as a corridor through Eddy County along the Pecos River having irrigated land. Zone 2 is the balance of Eddy County after Zones 1 and 8 are excluded.

The base case (see Chap. 6) is the primary vehicle used here for implementing the model. Other cases, summarized later for sensitivity consequence analyses draw from the base case input data with appropriate variations. The base case, run in the probabilistic mode, represents operation in a risk mode. Risk is defined as the product of probability of occurrence of an event and the consequence of the event if it occurs. Implementation for the base case involves defining and preparing input data used in the sequence of component models within AMRAW-A: Source Term (Inventory at Risk), Release Model, and Environmental Model (including the Transport to Environment and Environment-to-Man Pathways parts). Figure 2-1 illustrates one branch of the systems model, applied here to the terminal storage phase of waste management.

A first step in implementing the model is to select the number of time increments and the duration of each. Here, 50 increments are used over a total time range of 10^6 y; this permits each output table to be complete on one page of computer printout. The first six time increments (5 y each) from zero reference time through the increment ending at 30 y cover the repository operations phase. The next increment, of 10 y duration ending at 40 y reference time, starts the terminal storage phase. The size of the time increments is increased in steps at later times to reduce computer requirements. Also selected initially are the radionuclides to be evaluated (25 here), the geographic zones (8 here), and the human organs for which dose is to be calculated (8 here, including total body).

Source Term data is prepared externally to AMRAW. This is a matrix of grams of inventory of each selected radionuclide at each of the specified times. For this application, an underground repository area is assumed to be 10 km^2 which provides for accumulation of waste from reprocessing of 187,000 metric tons of spent fuel. This quantity applies to a 30 y accumulation for the moderately low growth case [Bk76, ERDA76] or slightly less than a 40 y accumulation for the low growth case [Ax77]. One hundred, eighty-seven thousand metric tons of fuel at a burnup of 33,000 megawatt-days (thermal) per metric ton and a thermal efficiency of 0.325 represent electrical energy generation of 5500 GW-y or 4.8×10^{13} kw-hr. This data reflects a projection of installed nuclear capacity and

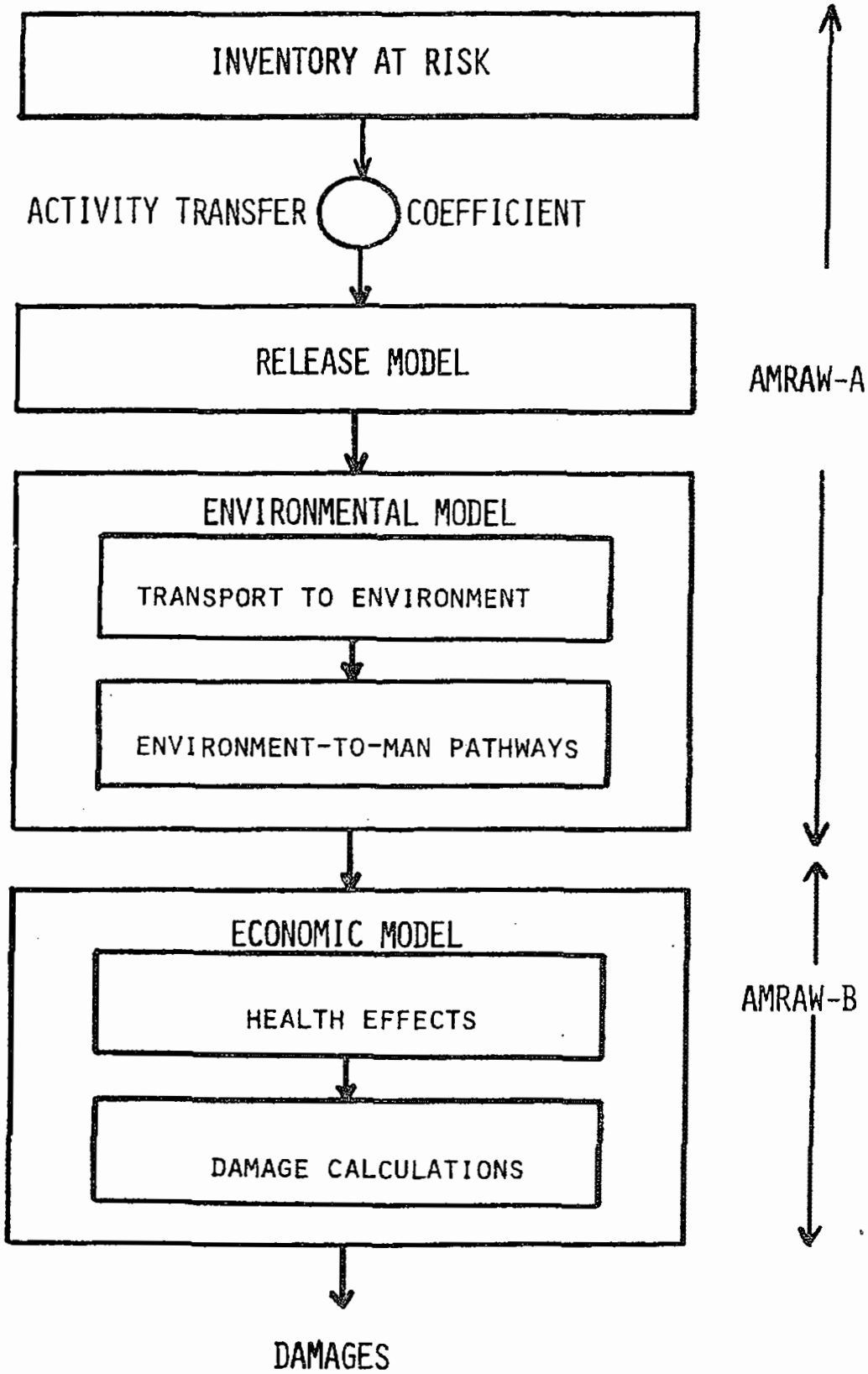

Figure 2-1. One branch of systems model.

reactor types, the step-by-step accumulation during the repository operations phase, simple decay, and chain decay, including ingrowth of daughters. The repository operations phase is illustrated by an application of AMRAW described in Part 2 of this volume.

The base case is run in the probabilistic mode in which several types of geologic disturbance events are considered: severe earthquake, volcanism, meteorite impact, and surface erosion. Data input for the Release Models is: estimated probabilities for each event occurrence, and the estimated fraction of Source Term inventory which is released by the occurrence of each event. For a leach incident associated with severe earthquake, data is furnished for calculation within AMRAW of quantities leached. An extended fault tree analysis ("extended" refers to a time-dependent probability capability) is used to represent the various geologic and man-caused events which may combine in various ways and result in release of radioactive material from a waste repository. Ten release scenarios are considered by the base case. While AMRAW provides for time-varying probabilities and/or release fractions, available geologic data at this time limit input to annual probabilities which are constant with time.

The most likely geologic event for disturbance of the repository assumed for this assessment demonstration appears to be offset faulting which could interconnect aquifers above and below the bedded salt formation. The annual probability of such faulting is estimated to be 1.4×10^{-7}. Subsequent slow leaching and retardation in ground water flow, calculated with presently available hydrologic data, minimize the consequences of this event over most of the total time range. This event contributes 9% of the total body dose in Zone 2 and 46% of nonspecific dose, integrated over 700,000 y. A volcanic explosion, assumed to transport 50% of the intercepted waste inventory into the air but estimated to have an extremely low probability for occurring within a repository zone (2.4×10^{-12} per year), and volcanogenic transport to the ground surface (8.1×10^{-12} per year) are the events which make the major contributions to the results calculated on a probabilistic basis until 700,000 y. At later times, breakthrough of Np moves ground water into a position of dominance and the faulting event then contributes 99% of the total body dose, and 53% of the nonspecific dose when integrated over the full

10^6 y, due to consequences after 700,000 y. These calculations conservatively assumed a ground water velocity six times the estimated seepage velocity; a somewhat less conservative adjustment would defer Np breakthrough and cancel out the major contributions from ground water after 700,000 y. While the method assigns some risk from volcanic explosion, it should be noted that the low probability means there is only one chance in 400,000 that such a volcanic event would expel material at any time during a one million year storage period. It should be noted that uncertainty in geologic event predictions does not justify the accuracy implied by two significant figures, but use of two figures helps to clarify the methods used in obtaining the values. In AMRAW, all input data, calculations, and output are standardized to three significant figures.

The first part of the Environmental Model handles Transport to Environment. Input factors expressing average air concentration and ground deposition in each zone per unit release to air were prepared with output from the AIRDOS-II air dispersion code [Mo75, Mo77a, Mo77b]. Average New Mexico meteorological data, but with directionally uniform wind, was used. Models for dispersion of material transported directly to land surface (and surface water), including ballistic trajectory distributions, are not well developed. A simple dispersion model (see Appendix F) was used for direct transport in the absence of a more detailed model. The retarded transport of radionuclides in ground water is handled by factors calculated within AMRAW using a simplified ground water transport routine. The method handles the effects of chain decay in an approximate but conservative manner. All of the ground water which flows slowly across and above the repository in the Rustler Formation discharges to the surface southwest of the repository by the time it reaches the vicinity of the Pecos River. A matrix of net environmental input receptor concentrations of each nuclide for each receptor (air, land surface, surface water, and ground water) in each zone, and at each time is calculated. This considers the dispersion discussed above, adjustment for transfers among the receptors, and environmental and physical decay (and buildup). Interreceptor adjustment for this application includes resuspension from land surface

to air, transfer of ground water by discharge to surface water, and transfer of surface water in Zone 8 as irrigation water to land surface. Resuspension is found to comprise most of the average air concentration, dominating over the average concentration component from passage of contaminated air plumes. A small token value of environmental decay constant, representing an "environmental half-life" of 30,000 y is used for surface land and water. This appears to be an unreasonably conservative assumption and leads to overstating the persistence of dispersed radionuclides and resulting dose rates. However, data for defining more correct values for the environmental decay constant are sparse. Radiodecay factors are generated within AMRAW as needed using the Source Term data. This provides a simple method for handling complex chain decay members.

The last part of the Environmental Model is the Environment-to-Man Pathways Model which handles pathway analysis. The main pathways considered are: 1) air: immersion and inhalation, 2) land surface: direct exposure and ingestion of terrestrial foods, 3) surface water: submersion and ingestion, and 4) ground water: ingestion. Subpaths for ingestion from water consider aquatic foods, drinking water, and contamination components in meat and milk from animal ingestion of water. Subpaths for ingestion of terrestrial foods consider above surface crops, and contamination of meat and milk. Unique calculation techniques used in AMRAW, and reflected by the input data, consider potential contamination of meat during feeding within a contaminated region but excludes weight added at feed lots after export from the region. On the other hand, calculation of meat contamination beyond the region boundaries due to export of hay from the region is included. Also, meat and milk contamination through drinking water is usually neglected in environmental impact calculations but this pathway is included in the AMRAW calculations. Input data for the pathways and subpaths is defined for the three applicable factors used in this part of the Environmental Model: 1) the biofactor, which accounts for concentrations in foods, 2) consumption, exposure or food production rates, and 3) equivalent dose conversion factors. Integrated concentrations in terrestrial foods following a unit deposition on land surface (i.e. the biofactor) are

determined for this application by use of the TERMOD terrestrial code [Kℓ76].

The calculated dose rates are the final product of AMRAW-A. The term "dose" wherever used in this report refers to committed dose equivalent. Dose rates to 8 organs are calculated: total body, G.I. tract, gonads, liver, lungs, bone marrow, bone, and thyroid. Local dose rates in each geographic zone are dose rates to an individual in the zone from local exposure through immersion in air, inhalation, direct exposure to land surface, submersion in water and ingestion of drinking water. As the bulk of agricultural products are exported from the region, dose rates from associated pathways are designated as nonspecific dose rates and represent dose to an undefined population. The results from the base case do not represent predictions of environmental concentrations and population doses, as the geologic events have very low probabilities for occurrence and are therefore unlikely to occur during the one million year time period studied. Allowing the events to partially "occur" via the probabilistic method provides a basis for risk comparisons between alternate repository sites, types of geologic formations, fuel cycles and waste forms. The present status of available geologic data results in large uncertainties in estimates of probabilities which affects the calculated risk, but doesn't preclude relative evaluation of various management options. The calculated dose rates, used as a representation of risk, are very low. For example, the highest calculated dose rates are obtained for Zone 1 (local dose) which is the immediate area around the site. The average total body dose rate for this zone is 0.006 mrem/y. The corresponding average nonspecific dose rate (from agricultural products from all zones in the region) is 0.7 man-rem/y. The latter means a maximum individual dose rate from the nonspecific category of approximately 7×10^{-4} mrem/y as the exported agricultural products represent the food for close to one million persons. Average calculated dose rates to individuals become much less when dilution by food from noncontaminated sources is considered.

Following the base case, results from a series of cases comprising a sensitivity analysis are presented. Each of these cases considers one or a combination of the release scenarios from the base case.

at 10^3, 10^4, and 10^5 y reference times are examined. With the conservative assumptions that one-half of the repository inventory intersected by the volcano becomes expelled and is not reburied, it is found that if this event occurred, the local dose rate in Zone 2, close to the repository site, becomes far greater than regulatory limits but is not at a lethal level. In Zone 1, containing the repository site, the indicated dose rate is too high for continuous residence, if in fact anyone would care to live there during or shortly after a volcanic eruption. These calculations assume there is no cleanup nor disruption of normal agricultural or residency patterns. Another series of cases examines a leach incident associated with offset faulting from a severe earthquake, commencing at times of 10^2, 10^3, and 10^4 y. For the sorption properties used, only C-14, Tc-99, I-129, and Np-237 appear at a distance of 10 km (Zone 2) within 10^6 y. The corresponding dose rates are low. After 10^4 y, local total body dose rates in Zone 2 reach only 7×10^{-2} mrem/y, primarily from Tc-99, and drop off after 10^5 y. Breakthrough of Np, commencing at 700,000 y, produces an increase reaching 660 mrem/y at 10^6 y. The corresponding nonspecific dose rates reach 218 man-rem/y in the 10^4 - 10^5 y time frame, drop off and then reach 788 man-rem/y by 10^6 y due to Np. Again, as the agricultural products associated with the nonspecific dose represent the food for close to one million persons, the maximum individual dose rate from the nonspecific category is limited to only 0.8 mrem/y. It should be remembered that these results are based upon the severe earthquake occurring, the resulting fracture remaining open to permit continuous release by leaching, and a ground water velocity greater than the estimated value.

A more severe faulting and leach incident case with occurrence at 100 y assumes all values of K_d are decreased by a factor of 20 from the nominal values, in addition to the increased ground water velocity, to demonstrate sensitivity to K_d values. Decreasing K_d induces Cs-135, Ra-225 and Ra-226 (K_d now 3.5) to appear with the maximum concentration of Ra-226 reached at about 700,000 y. With this large reduction in assumed sorption effectiveness, the total body dose rate, totaled for all nuclides, reaches a maximum of 4.7×10^4 mrem/y in Zone 2 after 700,000 y and the nonspecific dose rate reaches 1.5×10^7 man-rem/y after 10^6 y. These results indicate the importance of obtaining site-specific K_d data

During the first 700,000 y, the total from all volcanism events contributes 90% of the integrated total body dose in Zone 2 and 54% of the integrated nonspecific dose; faulting and leaching to ground water contribute 9% and 46% respectively; meteorite impact contributes the remaining less than 1%. After 700,000 y, as mentioned earlier, breakthrough of Np at an average distance of 10 km in Zone 2 greatly increases the ground water contribution such that it accounts for 99% of the local dose in Zone 2 and 53% of the nonspecific dose when integrated over the full 10^6 y. In other zones net downflow from the repository, a ground water component is not involved. Surface erosion does not contribute to releases within the 10^6 y period. Over most of the time range, the most significant environmental receptor (to which initial releases occur) is surface water when it is a source of drinking water, followed in turn by land surface and air. At later times, ground water becomes the most significan receptor but this is primarily due to transfers to surface water. Dose from direct exposure to land surface is a minor component of the total and the dose from immersion in water is negligible due to the short exposure times. Increase of the environmental decay constant by two orders of magnitude resulted in reduction of dose rates by less than one order of magnitude.

Additional sensitivity analysis was performed for ground water transport using auxiliary computer programs instead of the full AMRAW code. It is shown that there are border values of the important sorption parameter, K_d (distribution coefficient), for a given combination of ground water velocity, distance to a point of usage, and time period assessed. The border value represents sorption behavior which retards the radionuclide migration sufficiently that it does not appear within the time period considered. Above the border value, precise values need not be determined. For a ground water velocity of 4×10^{-3} m/d, and a distance of 10 km, a K_d value of only 10 retards the peak concentration travel time to $> 10^6$ y. Also, for K_d slightly greater than zero, the widths of concentration versus time peaks from a pulse release broaden considerably.

A series of cases for discrete events occurring at various times comprises a consequence analysis. Volcanic explosion releases to air

but should not be considered to be expected dose rates.

B. PART 2: OTHER APPLICATIONS

The implementation for the terminal storage phase in bedded salt considers a reference repository in the Los Medaños area of southeastern New Mexico, containing an inventory of high-level radioactive waste from reprocessing of 187,000 MT of spent fuel. Repository operations covers the approximately 30 y period during which the waste inventory is accumulated. Surface operations include receival, brief interim storage and associated handling. Underground operations include lowering canister via a mine hoist, transport through mine drifts and emplacement of canisters in drilled holes in the formation. Because of the relatively short time period for this waste management phase, slow geologic processes and very low probability events need not be included in the Release Model.

For this simplified demonstration, a number of basic disruptive events are lumped together in the Release Model as "major events" and "minor events" for both surface and underground operations, and preliminary estimates of occurrence probabilities are made. The net inventory quantity of each radionuclide at each time of interest during the operations period accumulation is handled by the same input matrix used for the subsequent terminal storage phase. During repository operations however, the total accumulation at any time is generally not exposed to each release scenario. That is, the quantity at risk for each potential handling accident is some fraction of the total accumulated inventory. This is handled in AMRAW by using one of the time-dependent factors which comprise the release probability to express the time-dependent fraction of inventory subject to the given release scenario.

Results obtained for repository operations indicate maximum calculated dose rates occur near the end of the operations period and subsequently drop off as residuals decay away. A detailed repository design, with operating procedures is needed for extending this demonstration into a more complete assessment.

Application of AMRAW to ground surface storage is discussed but

not implemented at this time. The methods demonstrated for repository operations are directly applicable.

As a supplement to the application of AMRAW to a repository in bedded salt, a preliminary demonstration for another geologic setting is made to illustrate the generic nature of the model. The other setting chosen is the Denver Basin, which has a thick deposit of Pierre shale. This formation is assumed to be at the Los Medaños model site in lieu of the existing bedded salt formation, to illustrate different geologic parameters with the same demographic and agricultural setting. Due to the lower thermal conductivity of shale, compared to bedded salt, the required repository area is assumed to double. The corresponding disruptive event probabilities are adjusted to reflect this change in area. Data from the Oklo natural reactor is used to estimate sorption properties of Denver Basin shale. Seismic and hydrology data is not presently available for the Denver Basin and Los Medaños area data was therefore assumed to apply.

Results calculated for the application to shale indicate dose rates to be consistently lower for shale, but not dramatically lower. The better sorption properties estimated for shale prevent discharge of C-14, Tc-99, and Np-237, each of which breaks through for the bedded salt application. The only nuclide with breakthrough in ground water in shale is I-129. Because of the preliminary nature of this demonstration, input data uncertainty is such that detailed analysis of the output is not justified. Conclusions comparing bedded salt with shale should not be drawn prior to running the AMRAW model with more complete input data.

The feasibility of applying AMRAW to other radioactive and non-radioactive hazardous materials is investigated. In general, the model is directly applicable to low- and intermediate-level radioactive materials as well as high-level, with appropriate adjustment of release scenarios and other effected input data. There can be difficulty in establishing the radionuclide inventory and effective leaching parameters due to a possibly wide range of waste components and waste forms.

Nonradioactive hazardous materials is a broad category addressed by the Resource Conservation and Recovery Act of 1976 [P&76]. The AMRAW model is traced step by step to determine the applicability of the major sequential parameters used in calculations. Input of inventory

masses in grams and setting "specific activity" = 1.0 obtains releases, environmental concentrations, and intake in terms of grams instead of in Curies as with radioactive materials. The dose conversion factor, DOSFAC, does not have a nonradioactive equivalent at the present time, though simply setting it equal to 1.0 obtains intake rates in lieu of "dose rates."

The concept of incidence rates of health effects corresponding to intake rates (used by the Economic Model, AMRAW-B) is not well developed for nonradioactive materials. Subject to limitations because of the lack of information correlating toxic materials with health effects, AMRAW can be applied to these materials for some assessment objectives.

CHAPTER 3

CONCLUSIONS

There are two groups of conclusions presented in this volume. The first group refers to the development of the AMRAW-A model and computer code; the second group refers to implementation of the model. Part 1 of this volume covers terminal storage in a bedded salt model repository; Part 2 covers other applications. Conclusions from development and implementation of the Economic Model (AMRAW-B) are presented in Volume III.

The AMRAW model, including the AMRAW-A part, is interdisciplinary and successfully brings together results from several fields of study for technology assessment of each phase of radioactive waste management. AMRAW does not replace established models which are in use for various segments of the problem, such as air dispersion, geosphere and biosphere transport, environmental pathway analysis, and dosimetry Instead, most of the calculations within AMRAW make use of input arrays and matrixes of factors or coefficients obtained from the established models, augmented by the judgements of experts in each discipline. Simplified versions of leaching and ground water transport models are used internally, but these as well as the major model sections (Fig. 2-1) are each contained in subprograms, providing for replacement should this become desired. Output from AMRAW is provided at several stages through the model giving calculated release quantities, environmental concentrations, and doses to population.

AMRAW-A interfaces the component models providing continuous calculations from the Source Term (Inventory at Risk), through the Release Model and the two parts of the Environmental Model (Transport to Environment and Environment-to-Man Pathways), obtaining output doses to population. This output is the major input to AMRAW-B which then calculates health effects and the corresponding damages in economic units. The two parts of AMRAW can be linked together for a continuous run, but it has been convenient to maintain them separately for development purposes and parametric studies.

The model is unique in that it simultaneously can consider a wide range of potential geologic disturbances, including events leading to expulsion into the air or to surface land or water as well as release to and transport by ground water. The provisions for input of geologic modeling data are flexible, permitting representation by time dependent functions. When progress is made in dynamic simulation of repositories, which seeks to calculate degradation of repository containment from slow tectonic and thermal processes, the present programming in AMRAW will accommodate the resulting time dependent release data. At the present time, data for prediction of future geologic events is subject to large uncertainties. However, AMRAW can be run for ranges of input to determine importance of improved prediction and can also be run for discrete event occurrences to explore consequences independently from probability predictions.

A. PART 1: TERMINAL STORAGE IN BEDDED SALT

Implementation of the model to terminal storage in a bedded salt model repository leads to numerous findings. First, consider the base case, run in the probabilistic mode. This case considers several types of geologic disturbance events: severe earthquake (leading to possible leach incident), volcanism, meteorite impact, and surface erosion distributed probabilistically over 10^6 y. Each conclusion reached may be altered as new data becomes available and each might or might not apply to a different site.

1) Contributions to dose from releases to ground water are minimized due to low ground water velocity and sorption effects. Only C-14, Tc-99, I-129, and Np-237 among 25 radionuclides studied with present data, emerge at 10 km distance within 10^6 y.

2) At times up to 700,000 y, local dose rates are dominated by low probability/high consequence volcanic events releasing to air, land surface, and surface water, over dose rates from releases to ground water via offset faulting and leaching. After 700,000 y in a zone where ground water is a factor (e.g., Zone 2), breakthrough of neptunium is indicated (if ground water velocity is conservatively increased by a factor of 6), resulting in

dominance by ground water releases in the 700,000 - 10^6 y time interval. However, in Zone 2, the average local dose rate to 700,000 y is only 0.0008 mrem/y and to 10^6 y, including the late ground water dominance, is only 0.09 mrem/y. In Zone 1, which contains the repository and is not influenced by ground water, the average dose rate over 10^6 y is obtained as 0.006 mrem/y.

3) Nonspecific dose, calculated for largely exported agricultural products, corresponds to a low individual dose rate. The agricultural products for the study region represent the total food for close to one million persons, though in fact such persons would have this food greatly diluted by uncontaminated sources. For the base case, the 10^6 y integrated nonspecific dose is obtained as 6.9×10^5 man-rem, representing an average rate of 0.7 man-rem/y or a maximum individual rate (10^6 persons, averaged over 10^6 y) of $0.7/10^6 = 7 \times 10^{-5}$ rem/y = 0.07 mrem/y.

4) In geographic zones where surface water is a major source of drinking water (> 25%), surface water generally becomes the most significant environmental receptor for contributions to local dose rates, followed closely by air; otherwise, air is the most significant receptor. Note, however, that initial release to air is the major pathway for surface water contamination and that deposition on land leads to resuspension in air. When significant breakthrough occurs in ground water (such as Np in Zone 2 after 700,000 y), it is the discharge of ground water to surface water which is the major factor in affecting dose rates.

5) The average concentration in air (or integrated concentration during an interval of time) is primarily from resuspension from land surface accumulations. Note, however, that the surface accumulation is largely via deposition from air originally.

6) The most significant radionuclides shift as one progresses through the model: masses in inventory, radioactivity in inventory, environmental receptor concentrations, and dose rates. Also at each stage in the model, the nuclides included among the most significant change with time. Twenty of the 25 nuclides

studied are among the 5 most significant in one or more instances of: environmental activity or dose to population. Actinides and daughters and Tc-99 completely dominate dose after 100 y.

7) The 5 most significant nuclides at each of several times during the 10^6 y range comprise close to 100% of the total dose rates at each time.

8) Only 7 nuclides comprise almost all of the total nonspecific dose rates: Cs-137 and Sr-90 are virtually the total up to 400 y; Am-241 and Am-243 are the major contributors from 400 - 5000 y; Ra-226 and Tc-99 are virtually the total for all times > 5000 y, but Np-237 dominates after breakthrough near 10^6 y.

Extension of the base case through the sensitivity analysis series leads to additional conclusions related to the probabilistic mode of operation:

1) The total of all volcanism scenarios contributes approximately 90% of the base case total for environmental concentrations and local dose to population (e.g., Zone 2); faulting and leaching to ground water contributes 9%; meteorite impact contributes the remaining less than 1%. However, breakthrough of Np after 700,000 y leads to dominance by ground water releases after that time. Further consideration of plate tectonic concepts may lead to reduction of the volcanism probabilities.

2) Over most of the time range, volcanism release to surface water (considering Zone 2) is the most significant of the volcanism components for local dose, followed in turn by volcanism releases to land surface and to air in the time interval from 200 y through 100,000 y (the latter two reverse at earlier and later times).

3) Dose from direct exposure to land surface is a minor component of the total and dose from water immersion (relatively short exposure time) is negligible.

4) For a given ground water velocity, distance to discharge location, and travel time, only nuclides with values of the distribution coefficient, K_d, less than a boundary value will emerge.

In this application, $K_d > 10\ cm^3/g$ retards the peak concentration to after 10^6 y for a water velocity of 4×10^{-3} m/d and distance of 10 km.

5) Increasing the estimated value of the environmental decay constant decreases rates of dose to population. However, a two order of magnitude increase in environmental decay constant results in less than a one order reduction of dose rates.

6) The large uncertainties in available K_d data preclude benefits from further ground water model refinements at this time. Meanwhile, the provisions in AMRAW handle chain decay in an indirect manner without requiring complex calculations.

The series of consequence analysis cases consider discrete events, volcanic explosion release to air and leach event following severe earthquake, occurring at specific times. Volcanic events are postulated at times of 1000 y, 10,000 y and 100,000 y; leach incidents are postulated commencing at 100 y, 1000 y and 10,000 y.

1) With the conservative assumptions that one-half of the repository inventory intersected by a volcano becomes expelled and is not reburied, it is found that if this event occurred at 1000 y or later, the local dose rates in Zone 2, close to the repository site, become far greater than regulatory limits but are not at a lethal level. In Zone 1, containing the repository site, the indicated dose rates are too high for continuous residence. Here it should be noted that the volcano would induce prolonged evacuation of the population independent of a radiological increment to the consequences. Site selection can preclude early disruption by volcanic action.

2) For the sorption properties used, only C-14, Tc-99, I-129, and Np-237 appear at a distance of 10 km within 10^6 y following start of a leach incident at 100 y. The corresponding dose rates are low.

3) Decreasing all K_d values by a factor of 20 induces Cs-135, Ra-225, and Ra-226 (K_d for Ra = 3.5) to appear at 10 km with the maximum concentration of Ra-226 reached at about 700,000 y.

For this case, the dose rates are negligible through 30,000 y (< 0.1 mrem/y total body in Zone 2 and < 200 man-rem/y nonspecific, also for total body), but substantial dose rates accrue as 10^6 y is approached, because of greatly reduced retardation. While this case does not represent an expected condition, it emphasizes the importance of obtaining good data for K_d.

4) An increase of the environmental decay constant by a factor of 100 reduces the total local dose impact following a volcanic explosion release to air (total body dose rate integrated over 10^6 y) by a factor of 18 and nonspecific dose impact by a factor of 55.

In addition to the above conclusions, general conclusions based upon all of the cases can be drawn. The results for the probabilistic calculations show dominance by the low probability/high consequence events over most of the time range but faulting and leaching release to ground water dominates at times close to 10^6 y. The discrete event cases show that events such as volcanic release to air do have relatively high consequences. There is bound to be a disagreement on interpretation of these findings. Some persons believe the extremely low probabilities for an occurrence justify neglecting these events, while others find no comfort in probabilities. It has been beyond the scope of this study to compare these results with the consequences of the same type of events in major metropolitan centers or through naturally radioactive ore bodies. It is apparent, however, that if further development of reason concerning assessment of low probability/high consequence events dictates that this source of risk must be minimized, one comes to the conclusion that multiple repository sites are needed. This approach reduces the inventory in any one location; the consequences may be reduced to tolerable levels. The probability of more than one such site being affected by severe events is infinitesimal. Next, if meteorite protection is to be provided, multiple sites plus burial depth become important. Increased depth reduces the probability of a sufficiently energetic impact for exhumation.

The site selection should maintain favorable ground water conditions.

A site should have low ground water velocities and have a hydrologic setting which provides low susceptibility for augmented flow by pluvial conditions from climatic changes. The geologic medium either in the repository horizon or bordering it should have good sorption properties (K_d) to retard nuclide migration.

The waste inventory and waste form has a direct bearing on risk. Risk is reduced if the actinide content in emplaced waste is lowered. A corollary of this is that with multiple repositories, partitioning of the waste and emplacement of actinides in the most secure of the sites reduces risk. Good leach resistance of the waste form is necessary to preserve all factors of the multiple barrier isolation concept. This suggests that all high-level waste should be incorporated in a leach resistant matrix.

B. PART 2: OTHER APPLICATIONS

The preliminary demonstration of AMRAW to the repository operations phase illustrates that AMRAW has the flexibility to be applied to each of the phases in the waste management sequence. Flexibility in the model provides for representing waste quantities being handled and subject to release at any time, both at the surface and underground, as functions of time related to the total inventory accumulation. Dose rates resulting from repository operations are a maximum near the end of the operations period and subsequently decline.

Application of AMRAW to ground surface storage may be made using methods for data preparation similar to those used for the repository operations demonstration.

AMRAW is generic in nature and is applicable to a variety of geologic settings. Subject to limitations related to the availability of data, the model can be used to compare various repository sites and waste inventories.

It is feasible to apply AMRAW to other radioactive (low-level and intermediate-level wastes) and nonradioactive hazardous materials. This may be done directly for radioactive materials. In the case of nonradioactive materials, the various parameters used in AMRAW for radioactivity

and radiation dose can be adapted to other appropriate quantities and toxicity indices. Revision of output table headings may be made to reflect quantities calculated in units other than Curies and rem. The major difficulty in applying AMRAW to nonradioactive hazardous materials is the lack of a systematic toxic index system for paralleling and accumulating contributions from a variety of components in an inventory.

CHAPTER 4

RECOMMENDATIONS

The systems model and computer code, AMRAW, are operational. There will always be improvements in the model which can be made, and there will never be as much data or data as accurate as the user of the assessment method would like to have. Also, there will continue to be uncertainty with prediction of geologic events. Certain areas of data need attention as shown by this study. Additional applications of the model and further study of calculated results will be helpful in understanding the most important contributors to risk from waste disposal, and defining the ways to minimize the risk. However, caution should be exercised to avoid non-ending studies prior to completing assessments and making decisions to resolve radioactive waste management questions. Recommendations given here relate to AMRAW-A in general; recommendations relating directly to AMRAW-B are given in Vol. III.

Areas of data which have significant effects on results obtained by AMRAW and which need attention are: distribution coefficient (K_d), environmental decay, resuspension and improved water usage information. While results here indicate that contributions to dose from release to ground water are smaller than from releases by lower probability/higher consequence events to other receptors over most of the 10^6 y range of time, it is found that reducing all K_d values by a factor of 20 increased 10^6 y integrated local and nonspecific dose by factors of about 360 and 6×10^4, respectively; this dominates the strong dependence upon sorption properties. Comprehensive K_d data is needed for several types of geologic media, and ranges of water analysis. Corresponding sorption data is needed for fractured media [Ws77]. Environmental decay relates to removal and retention mechanisms which reduce the environmental concentration of a nuclide with time, independent of radiodecay. This includes leaching down from the soil surface past the root zone, sedimentation in water, removal via harvest of agricultural products, and chemical retention. In this study, a token recognition of these processes uses an environmental half-time of 30,000 y and investigates sensitivity to

reduction of this half-time by a factor of 100. Comprehensive correlation of data in the literature plus new studies should be done to obtain more realistic estimates for environmental persistence following dispersal. Resuspension from ground surface to air is partly related to environmental decay. As a radionuclide migrates down from the surface, it becomes unavailable for resuspension. Also, weathering processes can produce agglomeration, reducing resuspension. As resuspension is found to dominate the average air concentration, improved understanding of this mechanism is needed. The surface water receptor is found to be the most significant environmental receptor for contributions to local dose rates. Surface water receives contamination from several sources including deposition from the air and discharge by ground water. In this study, assumptions were made regarding areas and volumes of surface water present and the usage of this water for drinking. In further work, a detailed survey should be performed to determine specific water usage details. Non-use of water sources having excess salinity would tend to lower the impact calculated here.

Additional modeling, external to AMRAW, can provide improved understanding of volcanic interactions with a waste repository and of slow processes. Volcanic processes are found to dominate the environmental impact when AMRAW is run in the probabilistic mode, under the assumptions used. It is assumed that one-half of the repository inventory intersected by a volcanic process is transported and not reburied. This is to say that not all will be pushed aside and not all with be carried to an exposed position. Remaining to be determined from additional modeling by geologists is the degree to which repository inventory becomes entrained by flowing magma or volatiles, and the degree to which transported material becomes mixed and diluted in surface deposits or becomes reburied. Also the chemical form after transport may not render radionuclides immediately available for biological intake, as assumed in this study, but may involve a delay period for weathering and leaching. If further study shows that mitigating processes may be assumed, the relative importance of the volcanic release scenarios will be reduced. Also, further consideration should be given to modern tectonic plate concepts to determine whether lower volcanic probabilities or whether lower or zero probabilities until some specified time are

more appropriate. Modeling of slow tectonic, thermal, and other processes which can potentially degrade repository containment through fracturing of surrounding structure and altering of the hydrologic system is another imcomplete area of geologic study. Similarly, mechanisms for breaching repository mine shaft seals and transport via that route to the surface, and response to drilled holes penetrating a repository, have not been defined sufficiently to provide input data for an assessment model.

Application to repository operations and ground surface storage beyond the preliminary demonstration and discussion presented in Part 2 of this volume requires design details and operating procedures for the facilities. This includes details of protective features of interim storage facilities (including earthquake and missile resistance), the number of waste canisters involved in various storage and handling operations and data on the possibility of and consequences of canister rupture. Further application of AMRAW to these waste management phases depends upon a restudy of release scenarios based upon complete facility design details to upgrade the AMRAW input data.

If an application of AMRAW to nonradioactive hazardous materials is to be made, a version of AMRAW for this purpose should be prepared. This involves changing terminology in output table headings to other than radioactivity and radiation dose units. The altered version can consist of merely changing the wording in format statements to provide changed table headings. If more flexibility is desired to accommodate various units for quantities and toxicity indices for different categories of hazardous materials, provision can be made in AMRAW for reading in appropriate alphanumeric variables for use in titles of output tables.

The major need in application of AMRAW to nonradioactive hazardous materials is not in model adaptations but is in obtaining a better understanding of biological effects of these materials and in systematizing environmental and intake quantities with respect to health effects. Much less is known about effects of nonradioactive materials than is known about radioactive materials. Additional work is needed to characterize each material by a consistent set of toxicity parameters to permit similar generic treatment of several components in an assessment model.

There are several types of AMRAW applications recommended for

further work. The model should be applied to various proposed repository sites in different geologic media: shale, basalt, granite, and dome salt. Different emplacement methods such as a drilled hole matrix and conventional mining may affect the results and should be investigated. An application which can help to place results obtained to date into perspective is the calculation of risk associated with an undisturbed uranium ore body. This is a naturally radioactive "repository" of low concentration but having a large area. Responses to assumed releases without fully characterizing the release mechanism can be helpful in comparing different demographic or agricultural settings, various environmental pathways, or movement via ground water. Extension of sensitivity analysis is recommended to further bracket the important ranges of significant parameters.

Unreprocessed spent fuel disposed of as high-level waste would increase the environmental risk from the terminal storage phase due to: 1) increased volume of waste which increases total repository area required, 2) large increase of plutonium in the waste inventory, and 3) increased thermal energy release and continuation of thermal effects over long time periods which accentuates this perturbation. Also, unless some processing is done to incorporate the material in a leach resistant matrix, the waste form is more susceptible to releases by leaching. The long term environmental risk of spent fuel as waste should be assessed.

Further refinement of the AMRAW code is not recommended at this time, although specific applications may suggest providing additional or alternate subprograms or output forms. There is a tendency for persons to suggest that each component model in an assessment model be expanded to the most sophisticated level available. This leads to the false belief that greater accuracy is necessarily achieved where in fact the greatest limitation is generally due to data uncertainty. As complex a code as desired may be used external to AMRAW for preparation of input data, but AMRAW itself should be kept as simple as possible. Two of the five subprograms in AMRAW-A utilize analytic modeling equations to calculate quantities using basic nuclide-dependent parameters: RLEACH calculates leach rates, and CRATIO calculates concentration ratios in ground water at a point of interest compared to the vicinity of release. This internal treatment is in lieu of working only with input parameters determined by

external models. Where either of these internal modeling provisions limits applicability of AMRAW or where there is user preference for other approaches, alternate subprograms for leaching or ground water transport can be adapted as part of follow-up work. This can be done by either of two approaches: 1) provide a simplified version of an alternate calculation sequence, appropriate to repetitive calling in a computer code, or 2) run an alternate code externally and fit results to simple functions which may be used in an AMRAW subprogram.

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PART 1

IMPLEMENTATION FOR TERMINAL STORAGE IN BEDDED SALT REFERENCE REPOSITORY

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CHAPTER 5

DESCRIPTION OF REFERENCE REPOSITORY SITE

Application of the assessment methodology to a specific site has been accomplished for purposes of: 1) aiding a more complete development of the model and AMRAW computer code, and 2) providing useful output for waste management planning. The site chosen for this initial application is the Los Medaños area in southeastern New Mexico. This area is in a stable region, has thick deposits of nearly horizontal bedded salt (Salado Formation) and is under study for potential installation of a Waste Isolation Pilot Plant [Wr77]. The proposed pilot plant is for DOE trans-uranium waste and experimental retrievable emplacement of some high-level waste. There are no plans at the present time to expand this facility into a full scale high-level waste repository. Further, it is expected that there will ultimately be as many as six repositories in the United States for commercial high level waste [Mc76]. The application of AMRAW reported here assumes for study purposes that there is only one repository, located at Los Medaños. The reader should note that concentration of the total waste inventory at one site represents a conservative case for demonstration of the assessment methodology and does not represent present waste management planning.

A. LOS MEDAÑOS AREA

The Los Medaños area is in southeastern New Mexico approximately 40 km (25 miles) east of the city of Carlsbad. The present waste repository study area is centered between Sections 20 and 29, Township 22 South, Range 31 East (103° 43' West Longitude, 32° 22' North Latitude). This location is shown on the map in Fig. 5-1 [Jn73].

Figure 5 - 2 shows a stratigraphic column for the area [Jn75], and Table 5 - 1 describes the rock units. A cross-section of the region from east of the study area, west to the Guadalupe Mountains is in Fig 5 - 3. The proposed horizon for location of a high-level radioactive waste repository is in rock salt at a depth of about 800 m in the lower Salado Formation. The repository disposal area is assumed to be 10 km^2 (see Section 6.A.). This is indicated, approximately to scale, on Fig. 5 - 1. The deep deposits below the Salado Formation are shown in Fig. 5 - 4. Additional geologic information may be found in references Jn73, Jn75, Cℓ74, BLM75, and Ke71b.

For assessment purposes, a region consisting of 13 New Mexico and Texas counties within a radius of 200 km of the repository site is considered. This region is divided into eight zones, described in Section 5.C. A more detailed geologic and hydrologic discussion follows.

Ref: USGS-4339-7

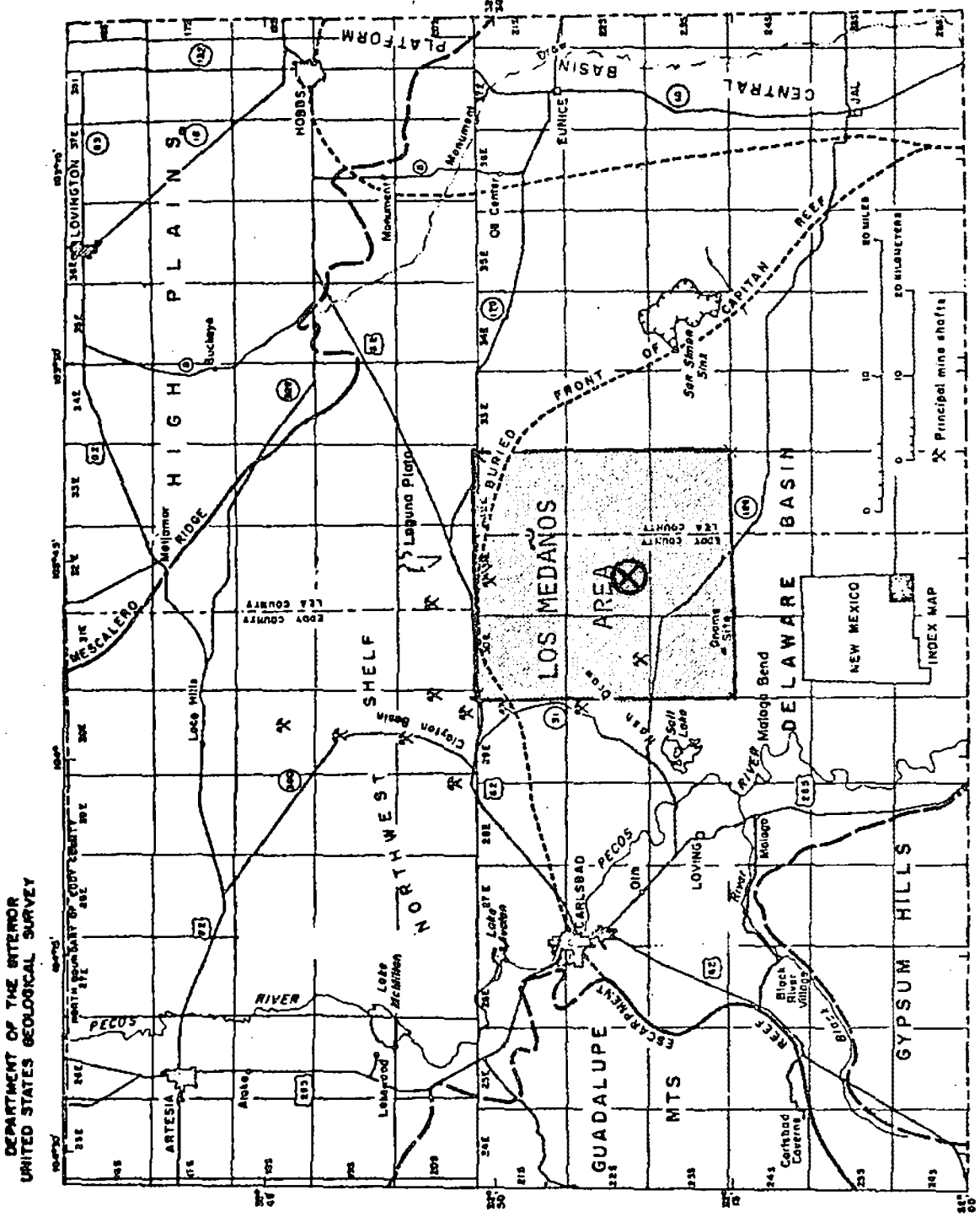
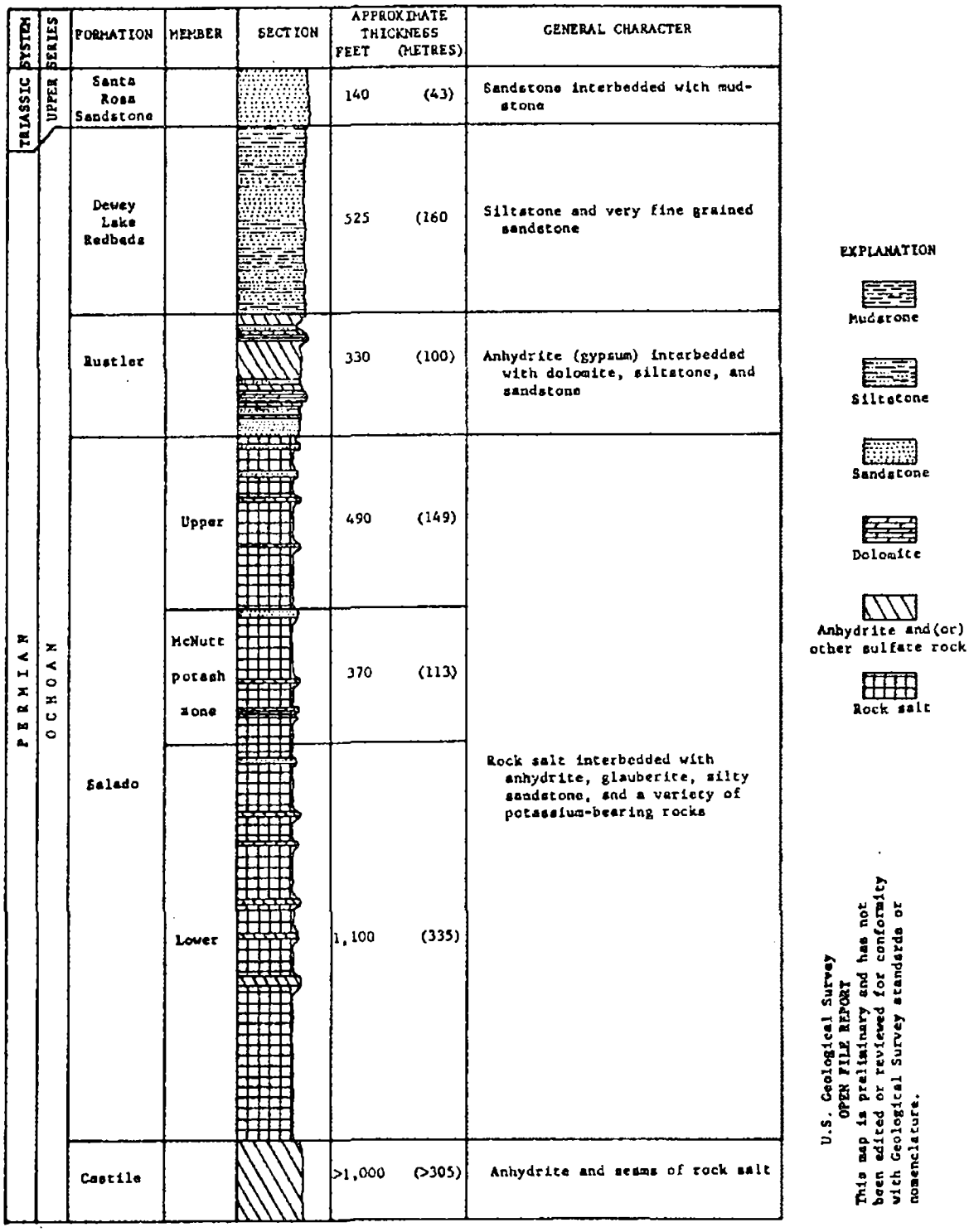


Figure 5-1. Location of Los Medaños area, Southeastern New Mexico.



Ref: USGS-75-407

Figure 5-2. Stratigraphic column of consolidated rocks penetrated by site evaluation borings sunk in Los Medaños area.

Table 5-1. Summary of Rock Units of Latest Permian (Ochoan) and Younger Age, Los Medaños Area, Eddy and Lea Counties, New Mexico (Ref: USGS-4339-7)

Age		Rock Unit	Thickness (feet)	Description
Quaternary	Holocene	Mescalero Sand	0-15	Dune sand, uniformly fine-grained, light-brown to reddish-brown
				UNCONFORMITY
		Caliche	0-5	Limestone, chalky, includes fragments of underlying rock
				UNCONFORMITY
	Pleis-to-cene(?)	Gatuna Formation	0-375	Sandstone and siltstone, poorly indurated, dominantly reddish-orange
				UNCONFORMITY
Tertiary	Plio-cene	Ogallala Formation	20-60	Sandstone, fine- to medium-grained, tan, pink, and gray, locally conglomeratic, and typically has resistant cap of well-indurated caliche
				UNCONFORMITY
Triassic	Late Triassic	Chinle Formation	300-800	Mudstone shaly, reddish-brown and greenish-gray, interbedded lenses of conglomerate, and gray and reddish-brown sandstone
		Santa Rosa Sandstone	212-245	Sandstone, medium- to coarse-grained, commonly cross-stratified, gray and yellowish-brown, contains conglomerate and reddish-brown mudstone
				UNCONFORMITY
Permian	Ochoan	Dewey Lake Redbeds	505-560	Siltstone and sandstone, very fine to fine-grained, reddish-orange to reddish-brown, contains interbedded reddish-brown claystone, small-scale lamination and cross-stratification common
				UNCONFORMITY
		Rustler Formation	280-490	Anhydrite and rock salt with subordinate dolomite, sandstone, claystone, and polyhalite
		Salado Formation	1200-2310	Rock salt with subordinate anhydrite, polyhalite, potassium ores, sandstone, and magnesite
		Castile Formation	30-1830	Anhydrite and rock salt with subordinate limestone

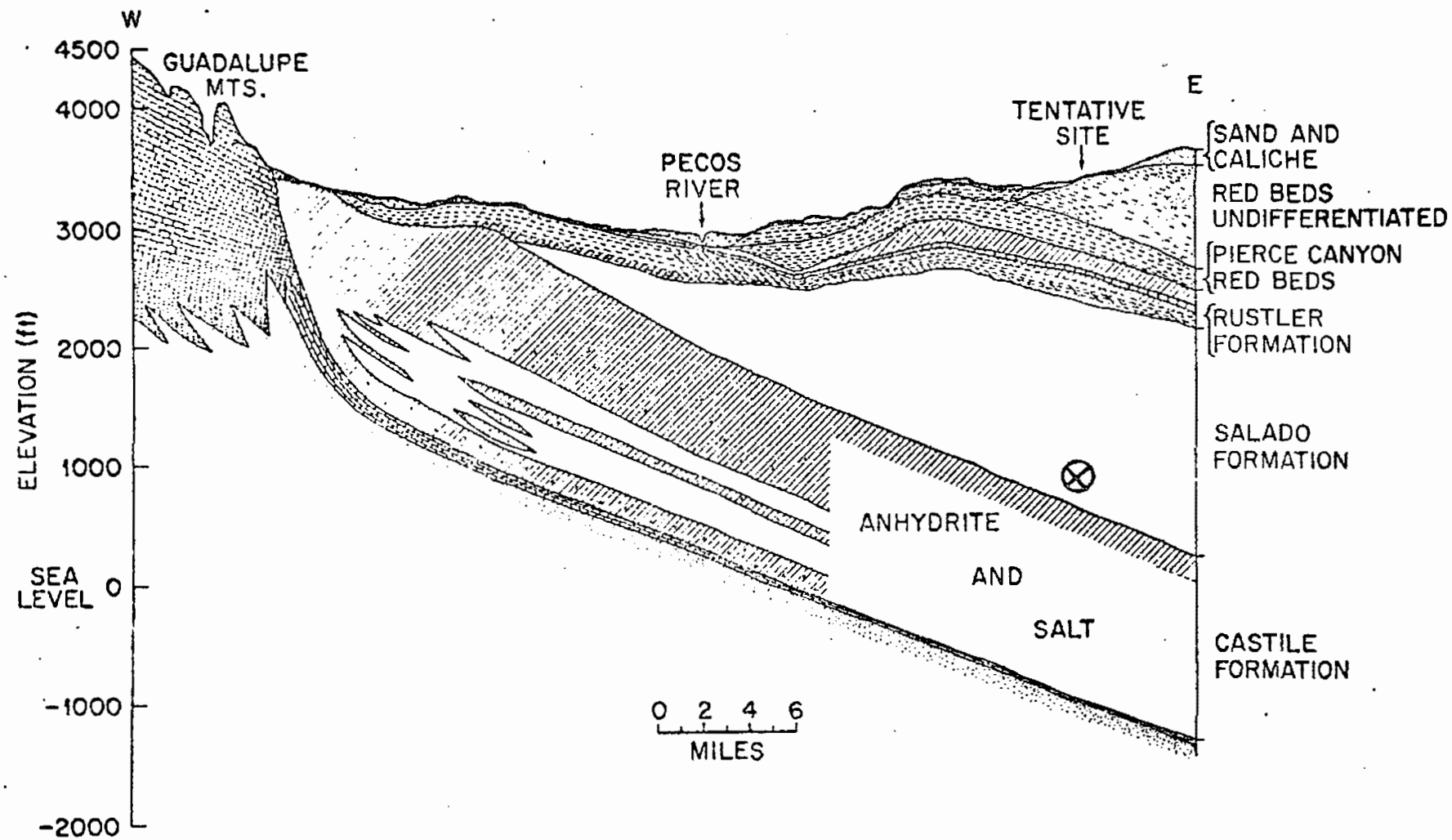
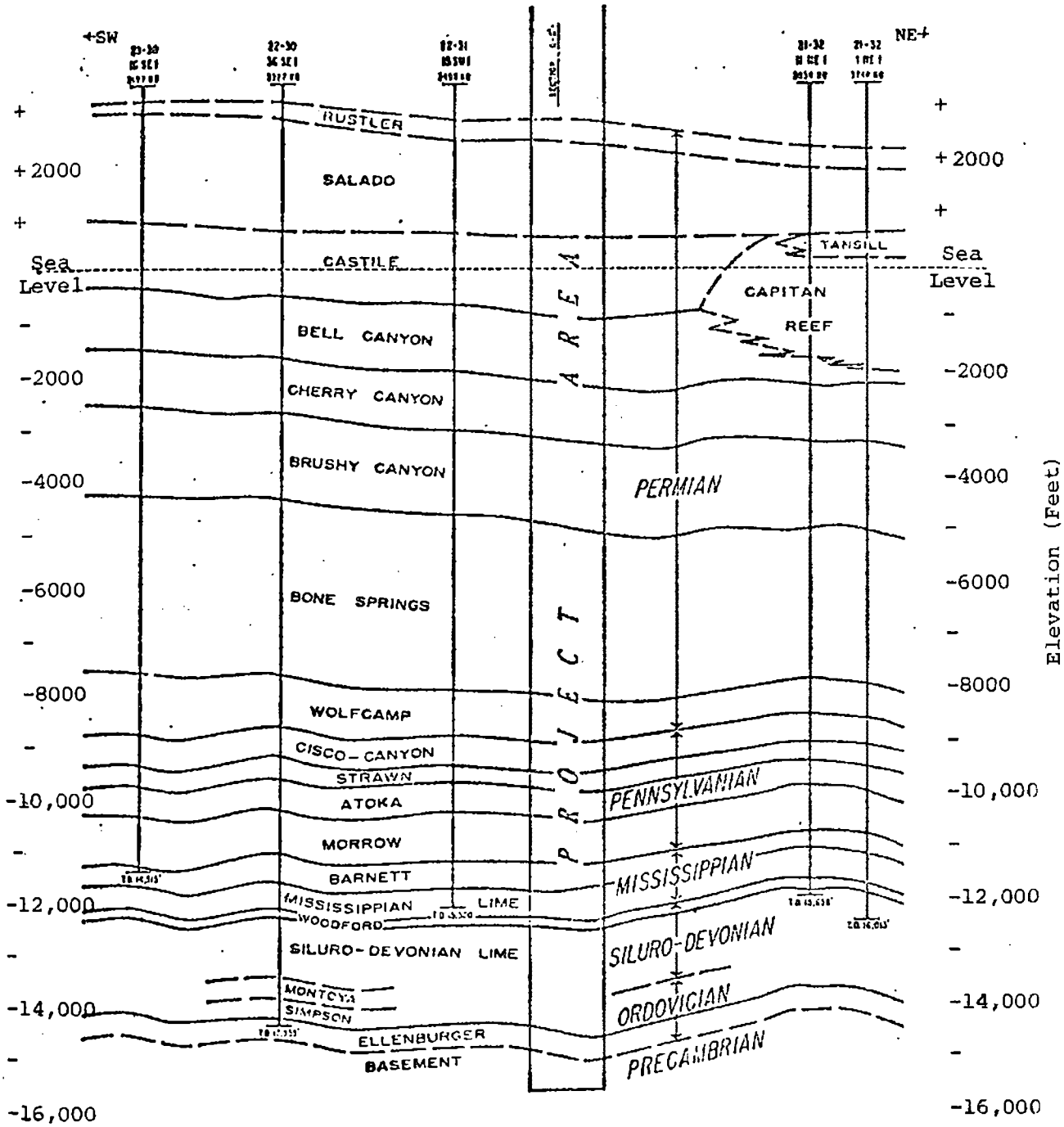


Figure 5-3. Cross section of region.



Ref: "Evaluation of Hydrocarbon Potential AEC Study Area, Southwest New Mexico," Rpt. on ORNL Project 78X 382 844, May 1974.

Figure 5-4. Deep deposits below Salado Formation.

B. GEOLOGIC/HYDROLOGIC DESCRIPTION

A discussion of geologic and hydrologic features of the Los Medaños area provides a base for evaluation of potential release events considered in the AMRAW model application. No attempt is made to model the many complex geologic processes within AMRAW. Instead, each generic process is subjected to study by geologists to determine the potential for occurrence at the specific site, to estimate the extent and repository implications of any such occurrence, and to develop the interrelationships between synergistic events. Input to the AMRAW computer code consists of the Release Model data, discussed later, which reflects geologic data and judgements by geologists. The following discussion describes processes which either may or may not affect the site. Table 5 - 2 lists geologic time divisions. The figures and table in the previous section also help in interpreting the references to various formations.

Table 5 - 2 . Geologic Time Divisions

Era	Period	Beginning, million years ago
Cenezoic	Quaternary	0.60
	Tertiary	65
Mesozoic	Cretaceous	135
	Jurassic	180
	Triassic	230
Paleozoic	Permian*	280
	Pennsylvanian	310
	Mississippian	345
	Devonian	405
	Cambrian	600

*The Permian includes Dewey Lake Redbeds, Rustler, Salado, Castile, and other lower formations at Los Medaños Site.

1. Structure and Tectonic Processes. The Los Medaños site is located on the margin of the North American craton [KiP69], a region that has been relatively stable since Precambrian time, at least 570 million years ago. Tectonic processes currently operative in the craton mainly involve broad, epeirogenic warping, principally minor vertical movements.

These vertical movements may result in broad folds with low dips or high-angle faults, mostly with small stratigraphic displacements. Jointing may occur with either folding or faulting; at least one set of joints and probably two sets will be about perpendicular to bedding. Thus, folding and/or faulting could create fractures through which ground water might move.

It is not known whether the joints would provide a fairly continuous vertical access for waters, as the joints might not be propagated through strata that tend to deform plastically, such as shales or evaporite.

Faults may be marked by breccia, which is extremely permeable, or by gouge, which is impermeable. Carbonate rocks under low confining pressures tend to brecciate. It is likely that faults in this region would be very steeply dipping and therefore, would cut through the stratigraphic column about normal to bedding.

It also seems likely that recent faults would tend to occur along older faults at depth (in late Pennsylvanian deposits) and be propagated upward through those strata that are younger than the prior fault.

The Los Medaños area is not part of the Basin-Range tectonic province that is currently undergoing crustal extension. However, the eastern margin of this province is the Sacramento uplift about 120 miles to the west [Ke71a] and it is possible that the zone of crustal extension in the western United States may gradually extend eastward to include the Los Medaños area. This seems highly unlikely at this time.

The structural processes that have been operative locally at the Los Medaños site are discussed below. Inferences about these processes are based on a description of the local structure by Jones [Jn73].

The main structures in this area, the Delaware basin and northwest shelf, are of Permian age and thus appear to have been stable for a long

part of geologic time (about 225 million years). Los Medaños is located near the northern edge of the Delaware basin which has a homoclinal dip of about 2 degrees to the southeast here. This basin is bounded on the north by a monocline in this area. These regional structures appear to be stable.

Local structures include intraformational folds apparently caused by downdip gravitational flow of salt and folds caused by subsidence as underlying salt units changed thickness.

Structure contour maps by Jones [Jn73] of the base of the Castile and the base of the Salado show that within this area there are folds that plunge moderately to the southeast. However, the folds are disharmonic (form or magnitude of fold varies with depth), due to differences in thicknesses of stratigraphic units across the area.

The monoclinal that is in evidence at the base of the Castile Formation disappears upsection and is not present above the top of the formation. A gentle homoclinal (group of inclined beds of same dip) dip toward the southeast is maintained throughout the section with little or no change in direction or amount of dip from one level to the next.

At intermediate and other levels in the section, the structure is generally more uneven than at the base of the Castile Formation, and minor folds are more prominent. Salt and anhydrite in the middle member of the Castile are crumpled in sharp intraformational folds that appear to die out northwestward updip and become more pronounced southeastward downdip. Spatially, the intraformational folding of evaporite appears to be confined to a single long northwestwardly trending belt, about 2 km wide, that more or less coincides in trend and extent with the prominent southeast-plunging trough at the base of the Castile. The folding has resulted in buckling in the Salado Formation.

Uplift of the Salado and rocks as young as the Chinle Formation has resulted in a fairly broad arch that trends northwestward across the area. The exact age of the deformation is unknown, but is post-Late Triassic to pre-Pliocene (late Tertiary). Deformation may have occurred during or shortly after regional tilting that followed the deposition of Cretaceous rocks. The deformation probably occurred before any great thickness of Cretaceous rocks was removed by erosion.

Structure at the level of the pre-Tertiary terrane (above Salado salt bed), by Jones [Jn73], is complex. It includes most features apparent at lower levels plus additional features of subsidence folds that combine the total effect of all the warping and settling of rocks to conform with the topography of the upper surface of salt in areas where salt movement took place. Subsidence folds contribute considerably to the general unevenness of the structure at all levels above the upper surface of salt in central and western Los Medaños area, and they rather noticeably disrupt and otherwise modify the southeast homoclinal dip and continuity of the northwest-trending arch related to post-Cretaceous salt deformation. The folds are clearly post-Cretaceous, but may have formed during mid-Tertiary or earlier time. The folds extend into areas where the Ogallala Formation of Pliocene (late Tertiary) age has escaped deformation related to subsidence, but where other rocks above the Rustler-Dewey Lake contact have subsided.

The Salado Formation appears to be little deformed internally, as most of the salt movement probably took place in the Rustler and stratigraphically higher units.

2. Hydrology. The Los Medaños area of east-central Eddy County and west-central Lea County is characterized by a flat, gently undulating topography which, on a regional scale, slopes toward the Pecos River. Superimposed on this surface are numerous arroyos and closed depressions; consequently there is little integrated surface-water drainage toward the Pecos. The maximum topographic relief on this surface is about 210 m (700 ft). Average rainfall in the Los Medaños area is about 35 cm (14 in.) per year.

This site takes advantage of the thick halite sequence present in the Salado Formation; conversely, very few test holes have been drilled in the area and it is assumed that the hydrologic conditions that exist are essentially undisturbed. The Salado Formation consists primarily of halite, small amounts of anhydrite, polyhalite, and potassium salts which are mined in the area. No wells are known to produce from the Salado. In the potash mines near Los Medaños, no pore spaces capable of transmitting water have been found, and there is no water in any of these mines. Locally oil tests have encountered small pockets of

super-saturated brine within the Salado, but this cannot be considered as an aquifer.

In the immediate vicinity of the Los Medaños area there are five stratigraphic formations that are potential sources of ground water that could be induced into the Salado Formation: Silurian-Devonian carbonates; the Delaware Mountain Group; the Capitan Reef complex; the Rustler Formation; the Santa Rosa Sandstone. Each of these are discussed below, beginning with the deepest formation:

(a) Silurian-Devonian Carbonates. This sequence of limestone containing dolomitic zones underlies all of the Los Medaños area. Although these carbonates are a major oil producing horizon along the Vacuum trend east of the project area, the rocks are relatively untested at Los Medaños. A map constructed by Haigler and Cunningham [Hg72] shows that the top of the carbonate sequence is located at a depth of about 3,734 m (12,250 ft) below sea level at Los Medaños.

From the various formation and drill-stem tests that have been made in the Silurian-Devonian sequence, hydrostatic pressures generally exceed 316 kg/cm^2 (4,500 psi) or 3,168 m (10,395 ft.) of head. However, most of these tests were made at a considerable distance from the Los Medaños area itself. Also there is insufficient data available near the site to construct a potentiometric map of the formation which would be meaningful.

The base of the Salado Formation is presently at a depth of about 183 m (600 ft.) above sea level at Los Medaños. The repository itself would be located near the base of the Salado. Assuming that a pathway were opened from the repository to the underlying Silurian-Devonian sequence, water from the carbonates would rise to a level of about 610 m (2,000 ft.) below sea level, or approximately 792 m (2,600 ft.) <u>below</u> the repository.

(b) Delaware Mountain Group. This sequence of sandstone, shale and limestone directly underlies the Castile Formation and the Salado. A great deal of hydrologic data are available for this Group owing to the extensive oil and gas production from these rocks. Contours on the potentiometric surface of the Group indicate that the formation water would rise to elevations of about 1,036 m (3,400 ft.) above sea level

at the Los Medaños area (Hiss, unpublished data). Therefore an open pathway from the repository to the underlying Delaware Mountain Group would result in migration of formation fluid from the Group, through the Castile and Salado formations, and the repository.

Although significant formation pressures have been found in the Delaware Mountain Group [Hi75], the transmissivity of the deposits is extremely low. Therefore, the actual volume of water transferred probably would be relatively small.

(c) Capitan Reef Complex. In general the arcuate reef complex borders the Los Medaños area in the west, north, and east at a minimum distance of about 16 km. Hiss reported that ground water moves northeastward along the axis of the reef from the Guadalupe Mountains and discharges into the Pecos River. Water flows the opposite direction to the river from the Eddy-Lea County line. East and south of this county boundary, ground water seemingly migrates out of the reef complex through the so-called Hobbs channel and into the permeable formations that underlie the High Plains of Texas.

The unique hydrologic characteristics of the Capitan Limestone have led to a great deal of study in recent years. The most recent study has been made by Hiss [Hi75]. There are two facies of the limestone; the reef facies of this limestone forms an arcuate belt extending from the Guadalupe Mountains northeastward to Carlsbad, then east and south into Texas. This unit, which is locally as much as 610 m (2,000 ft.) thick, is highly permeable and contains good to excellent quality water. Due to the high permeability of the reef facies and its proximity to numerous oil fields, many oil companies have developed wells in this aquifer and produced water for secondary recovery of oil fields.

The transmissivities of the Capitan reef complex are higher than those of any of the other formations in the area; conversely, the hydrostatic head is less than the more deeply buried Delaware Mountain Group. An open pathway between the two geologic units would result in movement of water from the Delaware Mountain into the reef complex.

(d) Rustler Formation. East of the Pecos River the Rustler Formation unconformably overlies the Salado Formation. In general the Rustler outcrops in the bluffs along the east bank of the Pecos River and

it dips east and southeast into Texas. This formation is characterized by numerous facies changes; primary lithologies include interbedded red and green sandy shale, interbedded shale and dolomite, as well as local deposits of anhydrite and gypsum. Near Los Medaños the Rustler is approximately 152 m (500 ft.) thick and can be divided into two units: a lower clastic unit of variegated shale and some evaporites, and the upper unit of anhydrite and dolomite.

Due to the erratic distribution of the various lithologies that comprise this formation, the hydrologic characteristics are extremely complex. Most workers agree that the ground water in this formation is locally perched, may often be present under water-table conditions, and/or is locally under artesian conditions. Most of the contours shown in Fig. 5 - 5, described later, are based on the hydrologic conditions in the Rustler. These closely resemble the contours of Cooper and Glanzman [Cp71]. Water movement is generally toward the south and west with the major discharge points in Nash Draw and the Pecos River near Malaga Bend.

Several of the potash companies have wells yielding several hundred gallons per minute from aquifers in the Rustler; greatest yields probably are obtained from the Culebra Dolomite Member of the Rustler.

According to Hiss [Hi75], the average porosity of the Rustler Formation is about 15 percent. This value may be slightly higher in the dolomite facies of the deposits; however, the effective porosity in the shale units would be considerably less. Consequently 15 percent is probably a valid approximation of the porosity of the formation as a whole.

Aquifers in the Rustler Formation are locally recharged directly by precipitation; however, the total amount of recharge from rainfall probably is inconsequential. Most recharge probably enters the Rustler from runoff that has been impounded in the numerous sinkholes and playa lakes that have developed on the surface.

According to a study made in the vicinity of the potash mines, some playa lakes in the Rustler hold storm runoff for a much longer period of time than others, thus suggesting that there may be more leakage from some of the playas than from others. It was estimated that in this

EXPLANATION

0.76

Direction of ground water flow. Number is rate of flow in feet per year. Calculation is based on length and direction of vector, average transissivity of 12 square feet per day, and average aquifer thickness of 300 feet.

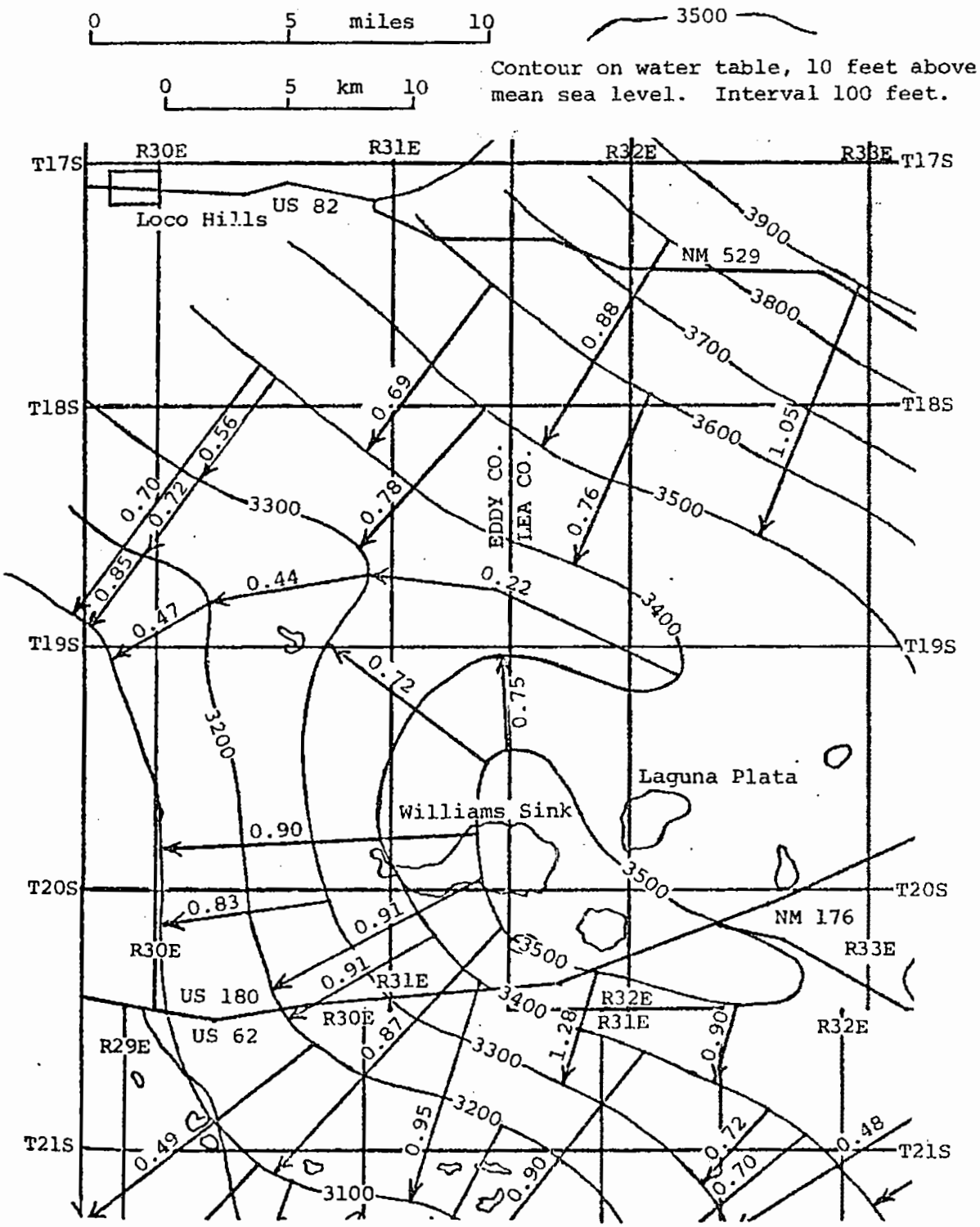


Figure 5-5. Water table map.

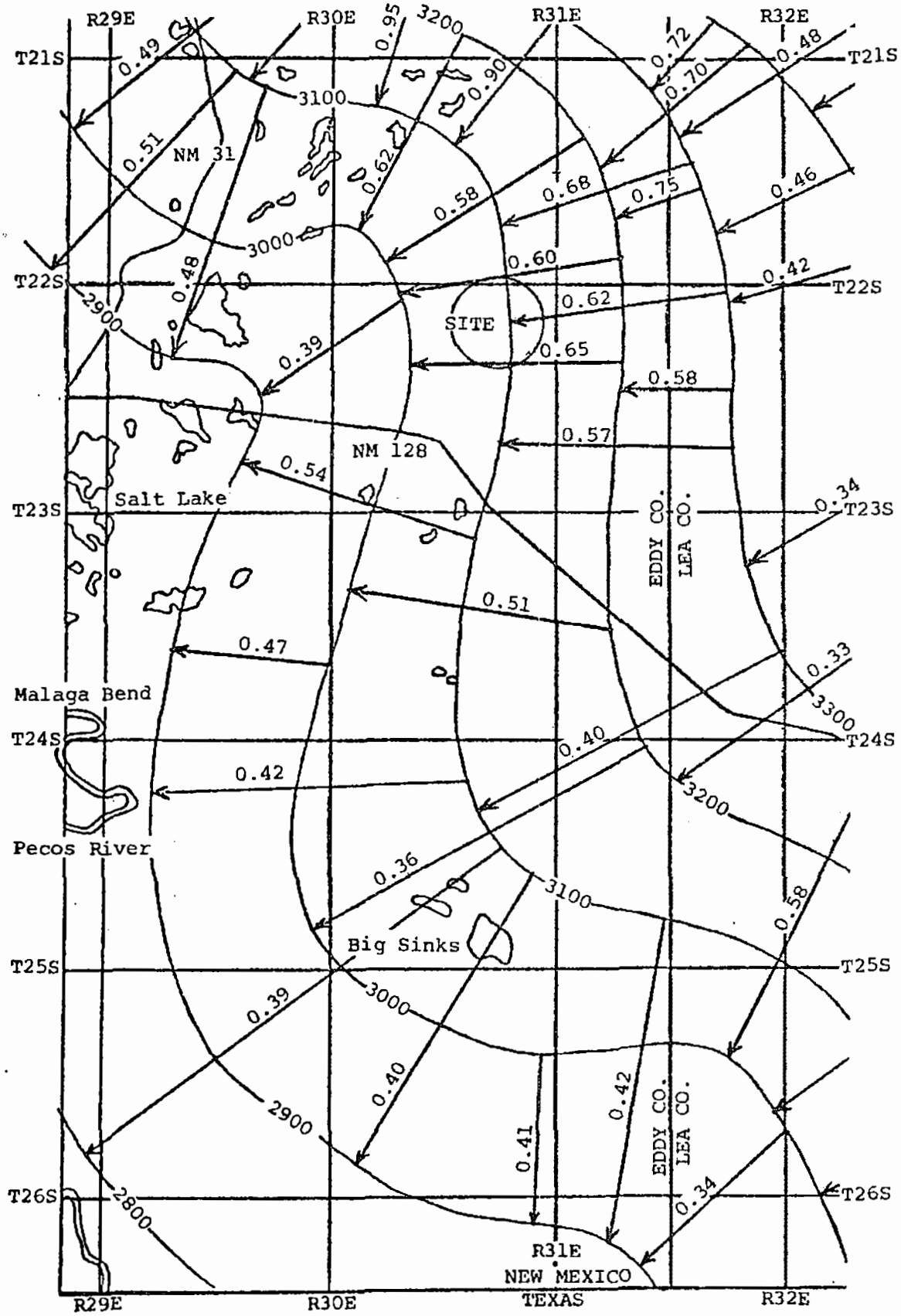


Figure 5-5. Water table map, continued.

vicinity the total area of ephemeral and permanent lakes contributing recharge to the Rustler is approximately 20 km^2 (5,000 acres).

One of the major topographic features near the Los Medaños area is Nash Draw, a tributary to the Pecos River. Robinson and Lang [Rb38, p. 88] estimated that there may be as many as 7.71×10^8 m^3 (625,000 acre feet) of ground water--predominantly brine--within this draw. This water moves southwestward where much of it is discharged as brine into the Pecos River at Malaga Bend. Hale et al. [Hl54, p. 2] and others estimated that the natural discharge of brine from the Rustler Formation into the Pecos River at Malaga Bend was about 3.70×10^5 m^3 (300 acre feet) per year or 0.012 m^3/sec (185 gpm).

Not all of the playa lakes represent recharge areas; some serve as discharge points for ground water. A detailed study was made by Robinson and Lang [Rb38] at Salt Lake which is located near Malaga Bend in Nash Draw. Test holes indicate that the lake is actually a ground-water discharge point and that there is no leakage from the Salt Lake into the Rustler. Theis [Ts42, p. 71] reached a similar conclusion. Both studies indicated that the water in Salt Lake was derived from precipitation, storm runoff, effluent from industrial developments, and from ground-water discharge.

(e) Santa Rosa Sandstone. This formation generally overlies the Rustler at Los Medaños; however, it extends only a short distance west of the site according to Cooper and Glanzman [Cp71]. The deposit consists of a series of red shale, siltstone, and sandstone beds; the latter yields small quantities of water to wells.

The potentiometric surface within this formation was mapped by Cooper and Glanzman; however, in many areas it is known that both artesian and water-table conditions exist. (These data are included in Fig. 5 - 5). In general, water within the Santa Rosa migrates south and southeast into San Simon Swale in Lea County; the ultimate discharge point is the Pecos River in Texas.

(f) Other Formations. A description of the Ogallala Formation (above the Santa Rosa Sandstone), and alluvium deposits is presented in Appendix A.

(g) Ground Water Flow. In order to determine the rate and direction of the ground-water flow in the region surrounding the proposed disposal site, hydrologic data were obtained from a variety of sources. Water-level data were obtained from Hendrickson and Jones [He52] and from Nicholson and Clebsch [Ni61]; unpublished data from the U. S. Geological Survey was also used. The water table map prepared during this study, Fig. 5 - 5 , was made with current hydrologic practice, using English units. In the following discussion, metric units are also stated.

It is recognized that these data points may include water levels from perched aquifers, the regional water table, and the potentiometric surface within the Rustler Formation. However, when contoured on a regional basis and using a 100 ft. (30.5 m) contour interval, the general shape and configuration is believed to be reasonably accurate. Furthermore, the erratic distribution of most of the aquifers on the Ogallala Formation and the alluvium, as well as variations in permeability of the Rustler, preclude construction of water-table or potentiometric maps of individual aquifers in the Los Medaños area.

In general the map indicates that the ground water is moving from northeast to southwest. The 3,500 ft. contour (1,067 m) is closed near the center of the map indicating a recharge area. This closed contour coincides with the location of several large sinks in Township 20 South, Range 31 and 32 East. Regional maps of the water table indicate that the ground water drains into the Pecos River which is located along the west side of the study area.

The vectors indicate the general direction and rate of movement of the ground water as calculated for each particular vector. Rates were calculated and plotted in feet per year. Ground-water velocities range from about 0.39 ft. (0.12 m) per year near the southern part of the area to 1.05 ft. (0.32 m) per year in the north. At Los Medaños the average rate of flow is about 0.70 ft. (0.21 m) per year toward the west-southwest.

Rates of ground-water movement are based on the equation:

$$Q = TIL$$

where: Q = discharge, in cubic feet per day

T = transmissivity, in square feet per day

I = hydraulic gradient, in feet per feet

L = width of aquifer.

Transmissivity is estimated to vary between zero and 520 ft^2/day as determined from unpublished data by Hiss [Hi75] for the Rustler Formation in the vicinity of Los Medaños. For these calculations, an effective average value of 12 ft^2/day is used. The hydraulic gradient was determined from the contours on the map; one foot was used for width of the cross section. The ground-water flow velocity in feet per day is obtained by dividing the discharge rate by the estimated thickness of the aquifer (300 ft.) and the porosity (0.15).

C. STUDY REGION AND DIVISION INTO ZONES

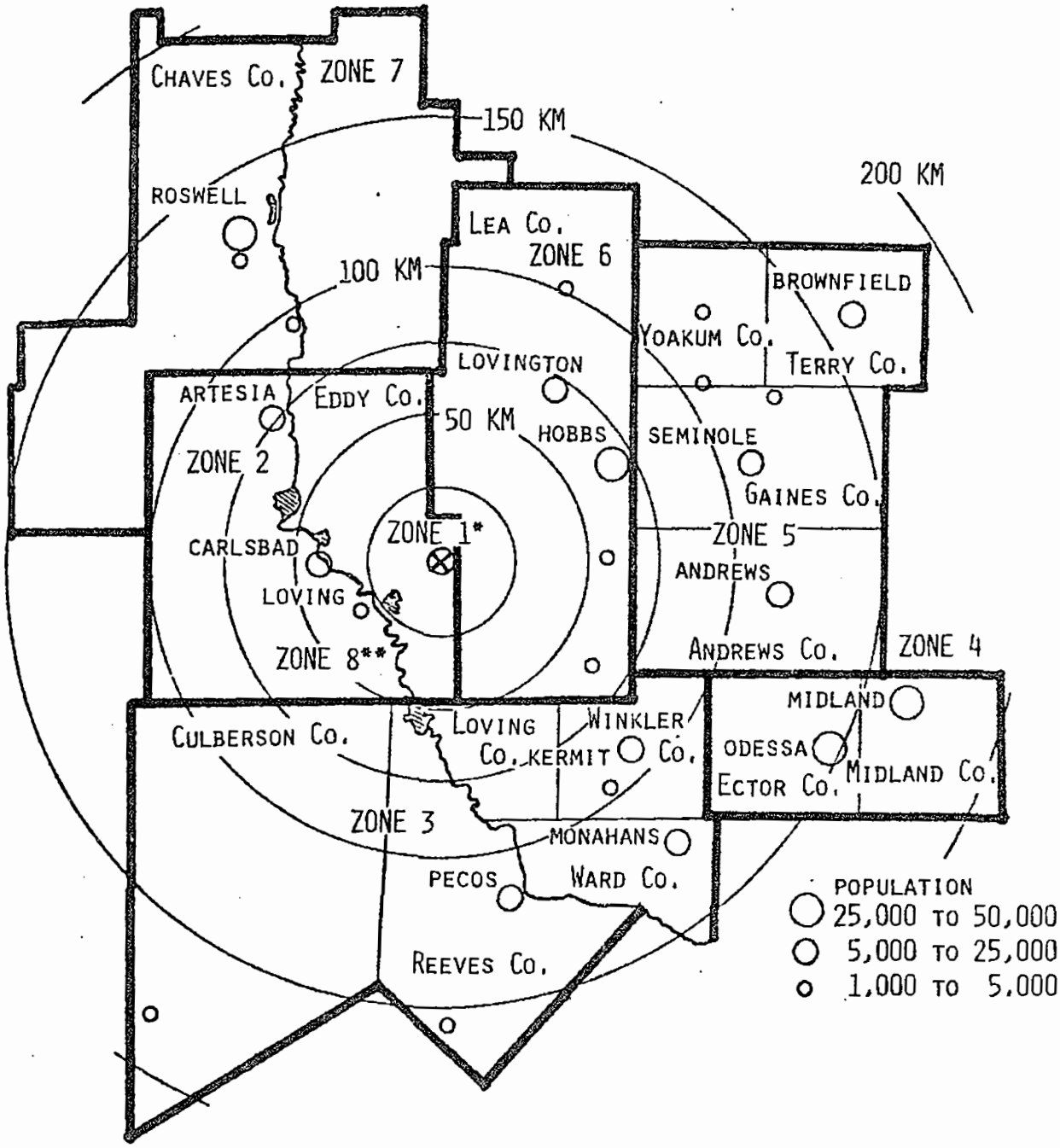
A region within a radius of approximately 150 km from the proposed repository site is chosen for study. It is expected that most of any release of material would be dispersed within this region. To provide for non-uniform dispersal, population, and other factors, it is appropriate to divide the region into several zones. For this study, a division into 8 zones, as shown in Fig. 5 - 6, is used.

Population projections to the year 2020 are used in the economic model for damage calculations. For New Mexico, the UNM Bureau of Business Research supplied two projections (to be used as high and low), as seen in Table 5 - 3. A Texas projection was obtained from the Population Research Center of the University of Texas at Austin. This projection for Texas was calculated using the high New Mexico rate and assuming constant annual growth rate for 10 year intervals. Agricultural data is listed in Table 5 - 4.

A circular zone with a radius of 5 km from the center of 10 km^2 assumed disposal site is designated as Zone 1. This zone, in Eddy County, New Mexico, has an area of 78.5 km^2; it represents a possible controlled area during the first several decades after start of the terminal storage phase. For computational purposes in the economic model the zone is considered to have a constant population of 101 individuals.

Zone 2 includes all of the arid land in Eddy County outside of Zone 1. Irrigated land in Eddy County comprises Zone 8, described later. Carlsbad Caverns National Park is in the southwest quadrant of Zone 2.

Five Texas counties comprise Zone 3. The counties are Culberson, Reeves, Loving, Ward and Winkler. This zone, due to the Pecos River running through it, could potentially receive a share of any radiation release through the air and water medium. Zone 3 only had 1.6% of its farm land in irrigation (Table 5 - 4) whereas 85% of the land is farmed. Thus the primary impact of a release would be in terms of airborne dispersion of waste to crop land. The principal towns in the zone are Pecos and Kermit with an overall population density of .019 people per hectare (1 hectare = 10^4 m^2 = 0.01 km^2).



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*Zone 1 is a 5 km radius area centered on the Los Medanõs site.

**Zone 8 is a 4 km corrider centered on the Pecos River in Eddy County

Figure 5-6. Study region and zones.

Table 5-3. High and Low Population Projections
1970 - 2020

High

ZONE

YEAR	1+2+8 *	3	4	5	6	7
1970	41,119	42,778	157,237	43,452	49,552	43,335
1980	66,500	77,813	286,014	79,039	84,600	92,400
1990	85,350	101,935	374,678	103,541	112,450	121,900
2000	104,200	126,135	436,629	128,122	140,300	151,400
2010	138,050	169,650	587,266	172,324	192,850	202,250
2020	171,900	213,168	783,533	216,526	245,400	253,100

Low

1970	41,119	42,778	157,237	43,452	49,554	43,335
1980	44,000	38,236	163,406	43,462	53,600	47,800
1990	48,000	36,778	173,634	42,231	58,400	52,400
2000	52,000	39,099	188,319	45,547	63,200	57,000
2010	56,500	44,678	204,314	50,599	68,600	62,400
2020	61,000	53,578	224,047	57,869	74,000	67,800

*Values for zones 1+2+8 are totals for Eddy County.

Estimated breakdown used for year 2020:

Zone	High	Low
1	101	101
2	17,200	6,100
8	155,000	54,900

Table 5-4. Land Use Patterns for 1969 by Zone[a]

	1+2+8[b]	3	4	5	6	7
Approximate land area (1000 hectares)[c]	1079	2284	478	1223	1138	1576
Land in farms (1000 hectares)	435	1944	495	899	939	1089
% of Land in Farms	40	85	109	73	83	69
Irrigated land (1000 hectares)	22	32	6	153	22	35
% of Farm Land Irrigated	5.0	1.6	1.2	17.0	2.3	3.2
All Cattle (1000's)	55	100	39	53	71	140
Milk Cows	721	679	360	384	1680	2490
All Hogs (1000's)	4.5	1.8	1.6	14.8	6.4	5.2
All Sheep (1000's)	43.8	1.3	12.9	15.6	21.3	165.7
Chickens (1000's)	200	16.5	59.6	282.9	28.2	21.7
Field Corn for Grain (1000 kilograms)	191	0	3	145	228	413
Sorghum for Grain or Seed (1000 kilograms)	2598	7208	3830	239050	18872	4941
Wheat for Grain (1000 kilograms)	47	3849	120	11824	118	470
Soybeans for Beans (1000 kilograms)	0	0	0	824	433	0
Hay (1000 Metric tons)	115	4.8	6.3	52	30	193
Cotton (1000 kilograms)	5282	14063	2539	51131	3355	7315

[a] As listed in the Census of Agriculture 1969 [USCB69].

[b] Values listed for zones 1+2+8 are totals for Eddy County.

[c] 1 hectare = 10^4 m^2 = 0.01 km^2.

The fourth zone includes the Texas counties of Midland and Ector. The principal towns are Midland and Odessa. The percent of farm land irrigated is only 1.2%. This irrigated water is most likely from ground water sources. Zone 4 has the highest population of 157,237 in 1970. Additionally the population density is the greatest, with .32 people per hectare.

Zone 5 includes the Texas counties of Andrews, Gaines, Terry and Yoakum. The principal towns are Andrews, Seminole, and Brownfield. The population density is .036 people per hectare. This zone has only 73% of its land area in farms but a high of 17% for all the zones is irrigated farm land. The principal crop of the zone is sorghum which is used primarily for grain and seed.

The sixth zone includes exclusively Lea County of New Mexico. The principal towns are Hobbs and Lovington. The population density is only .04 people per hectare. Additionally Zone 6 has 83% of its land area in farms.

Zone 7 is Chaves County of New Mexico. Roswell is the principal town in the zone. The population density is .027 people per hectare.

Zone 8 is a corridor along the Pecos River within Eddy County, consisting of the river bed, irrigated land and directly associated land. This is taken as 60,000 hectares, somewhat less than three times the area of irrigated land listed in Table 5 - 4. Zone 8 includes the cities of Artesia and Carlsbad, and most of the population in Eddy County. This zone is set up because of the concentrated belt of irrigated land, much of which is in the general direction of ground-water flow from the repository area.

From this discussion it is seen that in the zones surrounding the repository, agriculture is the predominant activity, with few large urban areas. The population projections imply that the population mix between the zones will remain relatively constant over time. Thus development of large metropolitan centers in the zones is not expected; most likely a predominant role will continue to be played by agriculture.

CHAPTER 6

IMPLEMENTATION OF MODEL: BASE CASE

The base case is the primary vehicle used here for implementing the AMRAW model and computer code to the terminal storage phase at a reference high level waste repository. The reference site, described in Chapter 5, is in the Los Medaños area in southeastern New Mexico, with thick deposits of bedded salt. It should be emphasized again that this site was chosen for study purposes to aid in development and demonstration of AMRAW, and does not represent present planning for the area. It is expected that there will ultimately be as many as six repositories in the United States for commercial high level waste; whether commercial waste will or will not be included in a repository at the Los Medaños site is not known. The study region surrounding the reference site is divided into the eight geographic zones shown earlier in Fig. 5 - 6.

The base case is run in the probabilistic distribution mode in which several geologic disturbance events are considered: severe earthquake, volcanism, meteorite impact, and surface erosion. Potential releases to four environmental receptors (air, land surface, surface water, and ground water) are calculated for the 25 most significant selected radionuclides. Calculations use 50 times over a range of one million years. Dose rates to 8 human organs (including total body) are calculated.

In Chapter 7, other cases are described in which discrete events are assumed at various times and the consequences are evaluated. In Part 2 of this volume, applications of AMRAW to repository operations and ground surface storage phases of waste management are presented and an initial demonstration is given for application of AMRAW to another geologic setting (in shale).

The following sections in this chapter describe the input data preparation for the Source Term, Release Model, and Environmental Model components of AMRAW-A.

A. SOURCE TERM (INVENTORY AT RISK)

Assessment of potential releases from a radioactive waste repository and the consequences of releases requires a definition of the quantity of waste present, the concentrations of significant radionuclides, and the variation of these concentrations with time due to radiodecay. While present plans by ERDA at the Los Medaños site involve only pilot plant studies with TRU waste and experimental emplacement of high level waste, the purpose of this EPA study is to assess a full-scale repository. It is therefore assumed for study purposes that the Los Medaños site becomes a repository for high level waste. It is further assumed as a conservative case that all high level waste generated from fuel reprocessing goes to the one repository. It is expected that several repositories will eventually come into use, dividing the waste load, and reducing the risk from any one site.

The accumulated inventory in the assumed repository depends upon two time-dependent major factors: 1) expansion of nuclear power, and 2) the types of reactors and fuel cycles in the mix. Projections for both of these factors are changing, with the result that the projected quantities and compositions of waste are also changing.

1. Repository Size. The underground repository area is assumed to be 10 km^2, equivalent to a square 3.2 km on a side or a circular area with a 1.8 km radius. As shown shortly, this area is adequate for a range of nuclear power projections. The moderately low growth case prepared in 1975 and used for the ERDA Technical Alternatives Document [ERDA76] assumed growth to 800 GWe nuclear operating capacity by the year 2000, projecting further to 920 GWe in the year 2002, as listed in Table 6 - 1. The reference time used in this and other tables has zero arbitrarily corresponding to year 1972 for operating power capacity, and accumulated fuel reprocessing or spent fuel (1982 for 10 y old waste from reprocessing). The corresponding accumulated fuel reprocessing after 30 y is 187,000 MT. The low growth case projected in 1977 [Ax77] stretches out the increase in nuclear power capacity (Table 6 - 1). However, as indicated in Table 6 - 2, the accumulated spent fuel for this case reaches 187,000 MT at a reference time of 39 y, or 9 y beyond the previous case.

Table 6 - 1. Projected Nuclear Operating Capacity, GWe

Reference time[a] years	1975 Moderately Low Growth Case[b] LWR	HTGR	LMFBR	TOTAL	1977 Low Growth Case[c] (LWR Only) TOTAL
0	13.7	0.0	0.0	13.7	14.6
5	51.3	0.3	0.0	51.6	51.2
10	112.7	1.1	0.0	113.8	82.3
15	225.6	11.1	0.3	237.0	153.2
20	382.7	35.2	1.1	419.0	227.0
25	547.6	64.3	26.1	638.0	322.1
30	688.4	90.5	141.1	920.0	402.9
35					462.6
40					509.3

[a] A reference time of 0 y corresponds to year 1972.

[b] From Blomeke [Bk76] and ERDA-76-43 [ERDA76].

[c] From Alexander et al. [Ax77].

Table 6 - 2. Projections of Accumulated Fuel Reprocessing or Spent Fuel

Reference time[a] years	1975 Moderately Low Growth Case Accumulated Fuel Reprocessing, MT[b]				1977 Low Growth Case Accumulated LWR Spent Fuel, MT[c]
	LWR	HTGR	LMFBR	TOTAL	TOTAL
0	0	0.0	0.0	0	
5	5.00 E2[d]	1.4	0.0	5.01 E2	3.19 E3
10	9.00 E3	1.25 E1	0.0	9.01 E3	9.84 E3
15	2.69 E4	9.01 E1	1.63 E1	2.70 E4	2.16 E4
20	5.84 E4	5.41 E2	5.74 E1	5.90 E4	4.11 E4
25	1.09 E5	1.87 E3	3.77 E2	1.11 E5	6.93 E4
30	1.79 E5	4.14 E3	3.75 E3	1.87 E5	1.07 E5
35					1.51 E5
40					2.00 E5

[a] A reference time of 0 y corresponds to year 1972 for fuel reprocessing and spent fuel, and year 1982 for 10 y old waste from reprocessing.

[b] From Blomeke [Bk76] and ERDA-76-43 [ERDA76]. Metric tons at rated load equivalent.

[c] From Alexander et al. [Ax77].

[d] 5.00 E2 represents 5.00×10^2.

The first of the above projections is used here for the reference repository inventory, noting that the lower growth rate case reaches the same reprocessing load after an additional 9 y accumulation, assuming the spent fuel accumulation for the low growth case is ultimately reprocessed. The total accumulation of high level waste in the repository is therefore assumed to be from reprocessing of 187,000 MT of spent fuel. This total requires 62,500 canisters at approximately 3.0 MT per canister [Bk76]. For this loading, the average heat generation for 10-year old waste is about 4 kw per canister. Assuming a permissible heat load of 370 kw/hectare [ORNL70] at the time of emplacement and 24 m row spacing (6 m wide rooms and 18 m pillars), the minimum spacing in rows becomes 4.5 m (use 5.0 m). Areal density is then 83.3 canisters/hectare or 8330 canisters/km^2; this corresponds to 7.5 km^2 for all of the canisters. Allowing for ineffectively used areas, the assumed area of 10 km^2 stated earlier is adequate for this waste quantity. The above values are based upon 0.057 m^3/MT (2.0 ft^3/MT) for the solidified waste [ORNL70]. The expected volumes may run as high as 0.94 m^3/MT (3.3 ft^3/MT), in which case larger-diameter canisters and/or closer spacing in rows can be used with no change in the total heat load or repository size.

2. Waste Inventory Input for AMRAW. As described above, the 30 y accumulation period for the moderately low growth case is approximately equivalent to slightly less than 40 y accumulation for the low growth case. The former includes about 2% of the total each from the HTGR (High Temperature Gas Cooled Reactor) and the LMFBR (Liquid Metal Cooled Fast Breeder Reactor). While the future of both of these reactor types is uncertain, the relatively small contribution to the total waste inventory does not greatly affect the waste composition.

Computer printout was obtained [Bk76] for: 1) accumulation of 10-year old waste during a 30-year period, and 2) decay of the total accumulation for a period up to one million years. This data is a blend of ORIGEN output for each of the several reactor types and fuel loadings, obtained at Oak Ridge using the auxiliary computer codes: WASPR for compressing ORIGEN output and KWIKPLAN (Sℓ77] for superimposing numerical values according to projected increases in capacities of several reactor types. Among the fission products, all H, Kr, and Xe are assumed to be

released from the high level waste stream. Most of the I and Br leaves this waste stream but 0.1% is assumed to be retained, along with 100% of all other fission products. Among the heavy metal isotopes, 0.5% of the U and Pu and all of the other heavy metals are assumed to be in high level waste. C-14 is not a fission product but it is produced in LWR fuel by neutron irradiation of N-14, an impurity in the oxide fuel. AMRAW uses as input the grams of each significant nuclide at each time of interest. Activity in curies is obtained by multiplying by the corresponding specific activities.

The waste transportation and repository operations branches of the systems model, when implemented, require waste inventory data for the accumulation period. The terminal storage branch, currently implemented, uses data for the subsequent decay of the accumulated inventory. It is desirable to reference both categories of time to a common starting or "zero" time, as indicated in Table 6 - 2. Also, it is desirable to use smaller increments of time in the AMRAW calculations than used for the ORIGEN output. This adjustment to a common reference time, interpolation for intermediate values and formulating for AMRAW input, is best done with an auxiliary computer program. A cubic spline technique is adopted for this purpose.

Cubic spline functions are a recent methematical development and provide an excellent method for curve fitting. Basically, the technique involves interpolation by cubic splines such that a cubic polynominal function is formulated between each pair of data points. Coefficients are chosen so that the second derivative is continuous across adjacent points.

A cubic spline curve fitting computer program developed by Moler (The University of New Mexico Mathematics Department) and Malcolm was obtained [Fr77] and slightly modified for adjustment of nuclide concentration data. Appendix B lists input and the output is included in Appendix J. Table B - 1 lists the input obtained from ORNL data [Bk76] for the selected radionuclides. The corresponding spline fit (Appendix J) results for the 50 selected times.

A screening process [Lo74b] was applied to eliminate from consideration the many radionuclides which make negligible contributions to

risk, and to thereby select the most significant radionuclides over a time range of 1 year to one million years after irradiation. The originally selected nuclides included 10 fission product isotopes of 8 elements and 16 actinide and daughter isotopes of 7 elements. The selection criteria applied is to select the 3 fission product elements and 3 actinide and daughter elements during each time interval over the full time range of interest which comprise the greatest contribution to the total ingestion or inhalation radiotoxic hazard measure for the waste mixture. The latter is defined [Cℓ75] as the ratio of activity in Ci to the most restrictive RCG (Radiation Concentration Guide, Table II 10CFR20) values in Ci/m^3. The selection criteria then selects the isotopes of each selected element which comprise at least 99% of the hazard for the element. In the current study, waste with a minimum age of 10 y is considered. Radionuclides Ru-106, Cs-134, and Ce-144 have a relatively insignificant hazard contribution after 10 y and are therefore deleted from the original selection. Because of special environmental interest, the activation product C-14 and the fission product I-129 are added. The net list of 25 selected significant radionuclides is given in Table 6-3, and is the basis for the mass tabulations in Appendices B and J.

Table 6 - 3. Selected Significant Radionuclides

Fission products:

C-14[a]	Sr-90	Zr-93	Tc-99	I-129	Cs-135
	Y-90	Nb-93m			Cs-137

Heavy metals:

Thorium Series	Neptunium Series	Uranium Series	Actinium Series
Cm-244	Pu-241	Am-242m	Am-243
Pu-240	Am-241	Cm-242	Np-239
	Np-237	Pu-238	Pu-239
	Th-229	Th-230	
	Ra-225	Ra-226	
		Pb-210	

[a] The activation product C-14 is included with fission products

B. RELEASE MODEL

Implementing the Release Model for the "base" case, or any other release scenario, involves the determination of event probabilities and release fractions for applicable release events and the parameters for leaching by ground water. The following sections first describe the application of Fault Tree Analysis to the model repository site and then the application of ground water leaching calculations to the site.

1. Extended Fault Tree Analysis. Geologic modeling is represented by the Release Model section of the Systems Model. Fault tree analysis is used to represent the various geologic and man-caused events which may combine in various ways and result in release of radioactive material from the waste repository. This technique, which is a systematic method for analyzing interrelated events, need not necessarily be used. Any technique which combines events into sets may be used. The environmental pathway analysis uses input concentrations in four "receptors": air, land surface, surface water, and ground water. It is convenient for calculation purposes to consider the releases from the geologic formation during an interval of time to four corresponding "preliminary environmental input receptors." Release to air represents the initial ejection into an air suspension. Release to land surface and surface water is the initial transport toward these areas, and release to ground water is the transfer by leaching into ground water at the point of ground water contact. Transport through the geosphere to a point of usage is required before release to ground water becomes an environmental input.

Each path through a fault tree which leads to a release represents a set of conditions existing at a given time which together can permit a release to occur. Each such path comprises a "cut set." All of the cut sets can be represented by a series of probability factors. In addition, each cut set has an associated release fraction representing the intensity of the occurrence. Each probability factor, representing some geologic condition or event, may be a function of time. Many geologic processes can be assumed to have a constant probability of

occurrence with time but other processes may vary with, for example, step, ramp, or exponential changes. Time-dependent probabilities may be applied to accommodate increased uncertainties for events further into the future. For example, a specific event may be established as having a zero or low probability for some time into the future but with increasing uncertainty and hence an increasing probability at later times for risk assessment purposes. This flexibility to represent the various events in a fault tree by time-dependent probabilities is an extension of the fault tree technique which is usually applied only with constant values for each component.

The Los Medaños site is under study because it is in a region with predicted long-term stability. The region appears to have been stable since Permian times (225 million years) and has thick deposits of nearly horizontal bedded salt (Salado Formation). The Salado Formation in the vicinity of the model site is more than 500 m thick starting at a depth of about 300 m. This formation consists primarily of halite, and small amounts of anhydrite, polyhalite, and potassium salts. The disposal horizon is assumed to be at a depth of 800 m, near the base of the Salado. The Rustler Formation uncomformably overlies the Salado Formation. This formation, approximately 150 m thick, includes interbedded red and green sandy shale, interbedded shale and dolomite, and local deposits of anhydrite and gypsum. Aquifers in the Rustler are locally recharged directly by precipitation, have very low flow velocities and discharge into salt lakes and the Pecos River about 20 km southwest of the study site. The Castile Formation (anhydrite, >300 m thick) underlies the Salado, followed by the Delaware Mountain Group. Formation water in this sequence of sandstone, shale and limestone has sufficient hydrostatic pressure to rise through the Salado should an open pathway develop. The transmissivity of the deposits is extremely low, limiting the possible water transfer rates.

There are geological events of low probability, which could occur to disrupt a repository. Also, there are man-caused events such as the drilling of holes into a disposal zone. In the fault tree section of AMRAW, estimated probabilities are assigned to the various combinations of such events, along with associated fractions of waste inventory

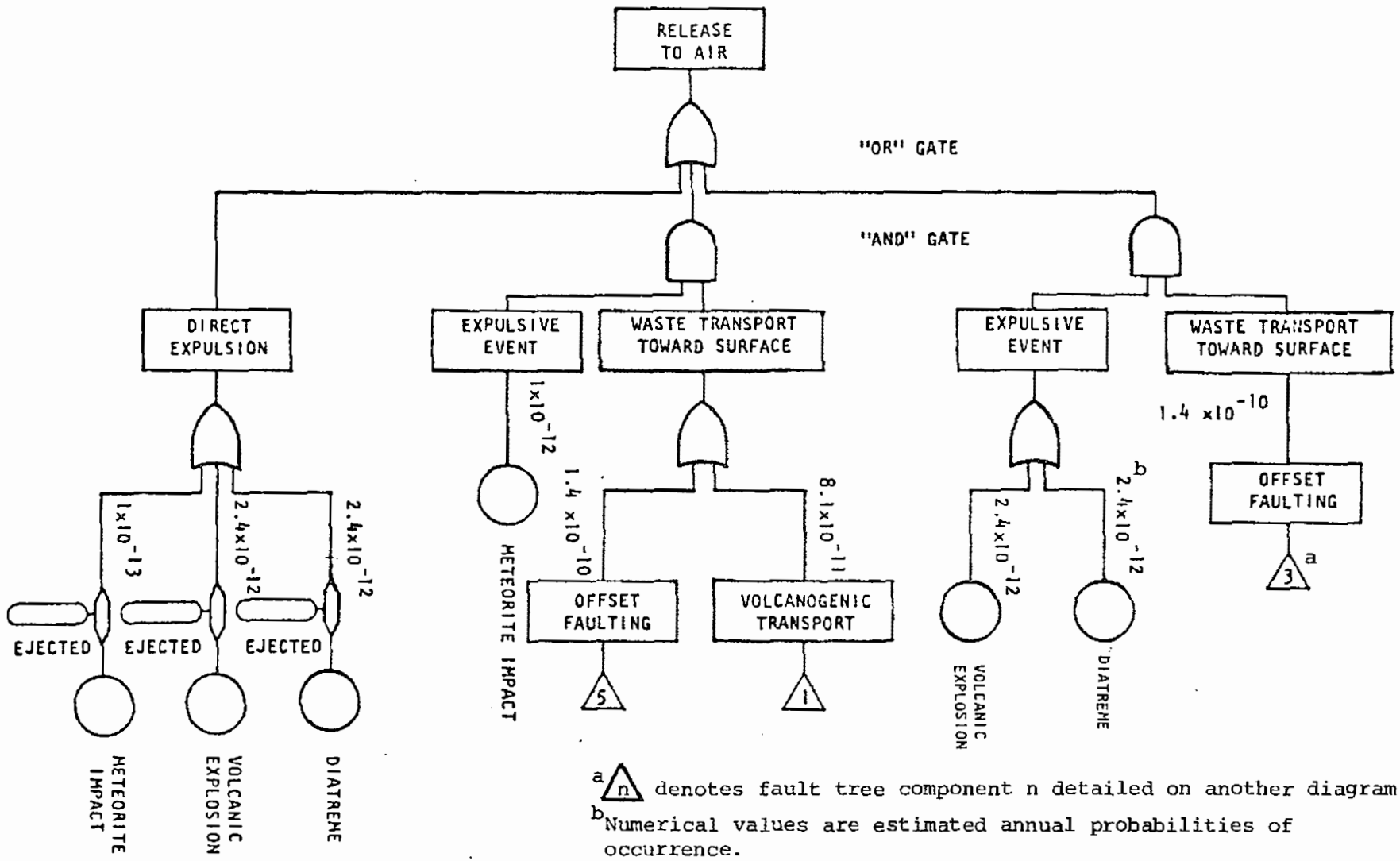
which might be released by these occurrences. Numerical input to accomplish this is obtained with the aid of earth scientists in the interpretation of regional and local geologic data. Where leaching by ground water is involved, AMRAW calculates leach rates, using input parameters also obtained with the aid of earth scientists.

Fault tree diagrams have been developed during this study for the terminal storage phase at the Los Medaños site. Diagrams for potential releases to air, land surface, surface water, and ground water are shown in Fig. 6-1 through 6-4, respectively. Figures 6-5 through 6-7 show fault tree components which are repeated inputs to the main branch diagrams. A general rule in fault tree analysis is that each logic gate should have an event description. In Figs. 6-1 and 6-4, event descriptors are omitted for a few gates to save space. It is appropriate to first describe the component groups, and then proceed to discuss the main diagrams.

(a) Volcanogenic Transport. Volcanogenic transport, detailed in Fig. 6-5, consists of three mechanisms: 1) magma transport, 2) volatile transport, and 3) hydrothermal transport. The first of these involves movement of magma which pushes or entrains and carries repository waste material to a shallower depth, to the surface, or in more extreme cases, into the air. The second mechanism involves movement of volcanic vent gases moving through fractures caused by mechanical disruption of strata or by heat effects, even though the repository is not penetrated by magma. The third mechanism, hydrothermal transport, represents deep ground water contacting magma or other existing hot rock and being propagated upward as with a geyser. Inhibit gates represent conditions which must be met before the event is considered to contribute toward a release. Component probabilities have not been determined and it appears that they are not needed because the probability for the aggregate may be estimated.

The probability of a volcanic disturbance affecting a 10 square kilometer repository at the model site is estimated by a two-step process: 1) determination of the maximum rate of occurrence in the Delaware Basin, and 2) modification by the fraction of the basin associated with the repository.

There have been no volcanos in the Delaware Basin since formation



[a] n denotes fault tree component n detailed on another diagram.

[b] Numerical values are estimated annual probabilities of occurrence.

Figure 6-1. Fault tree for release to air.

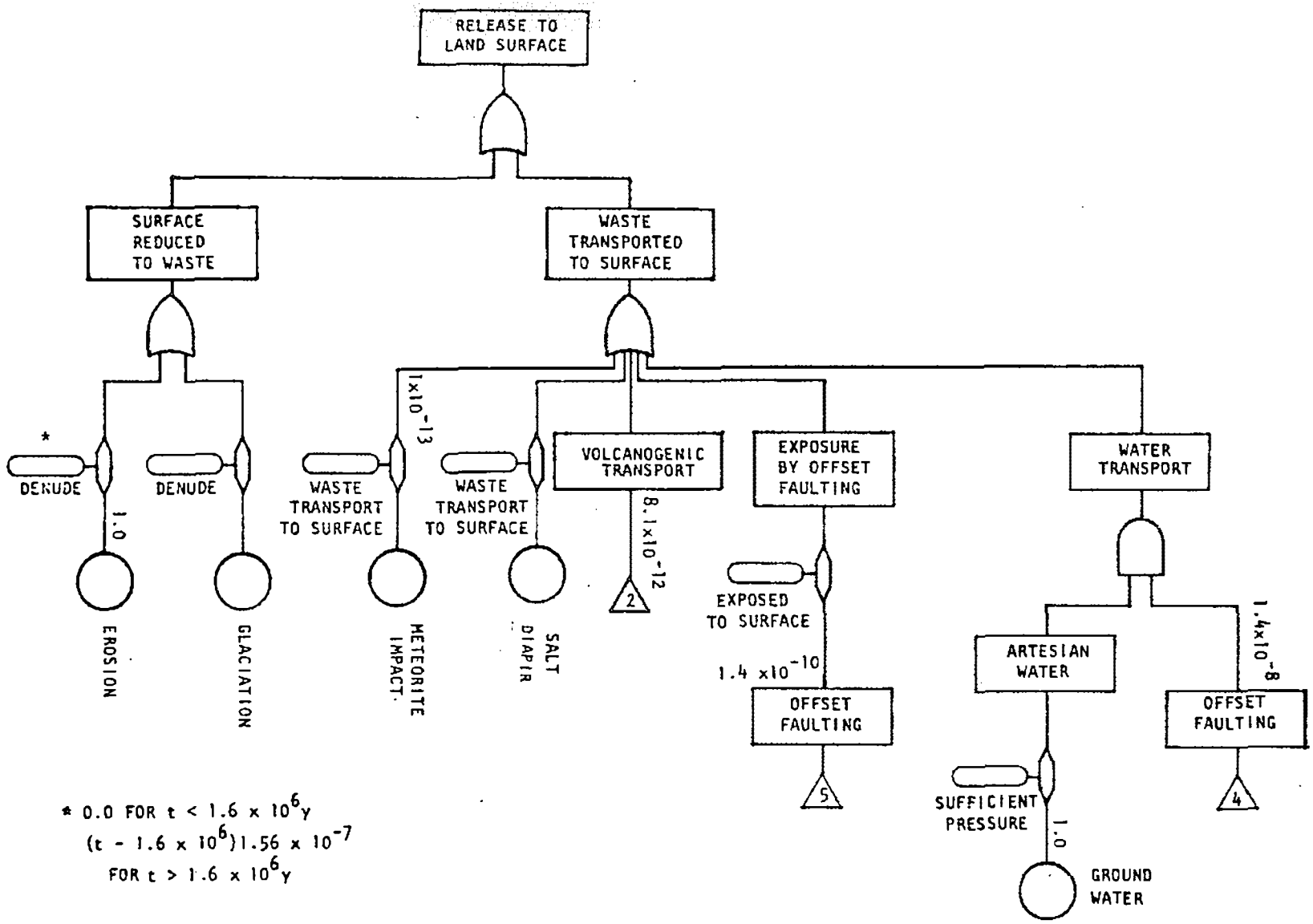


Figure 6 - 2. Fault tree for release to land surface.

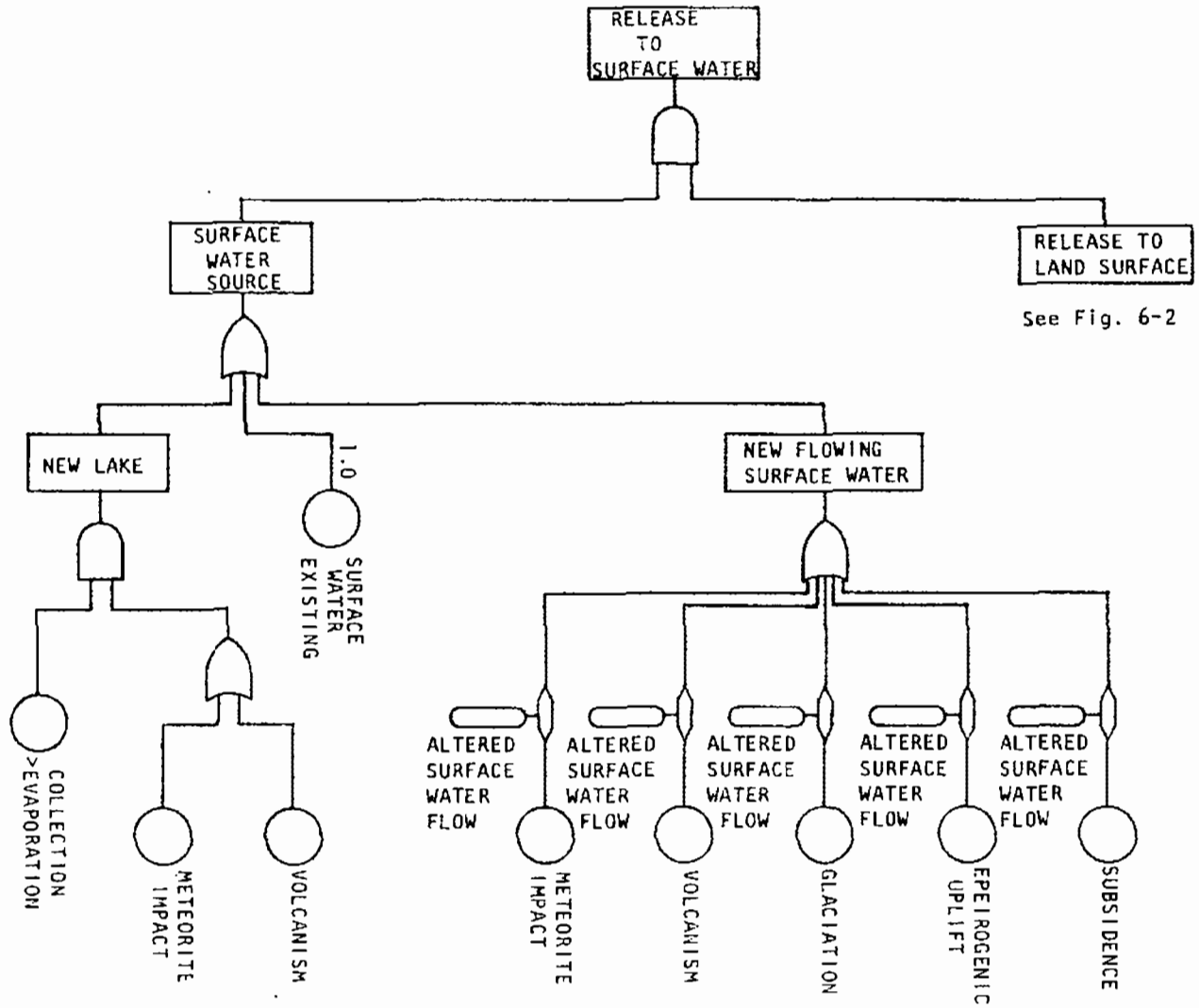


Figure 6-3. Fault tree branch for release to surface water.

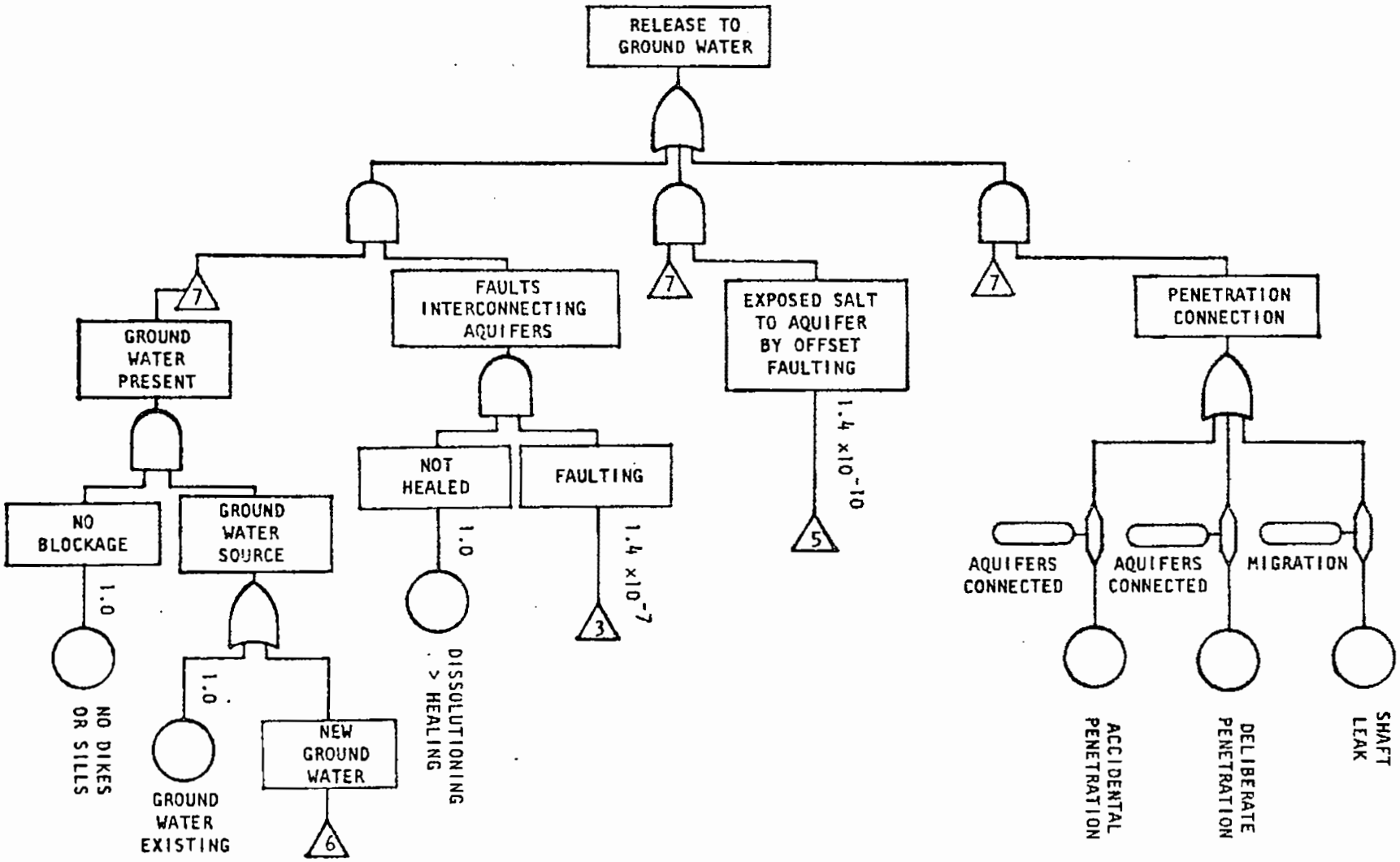
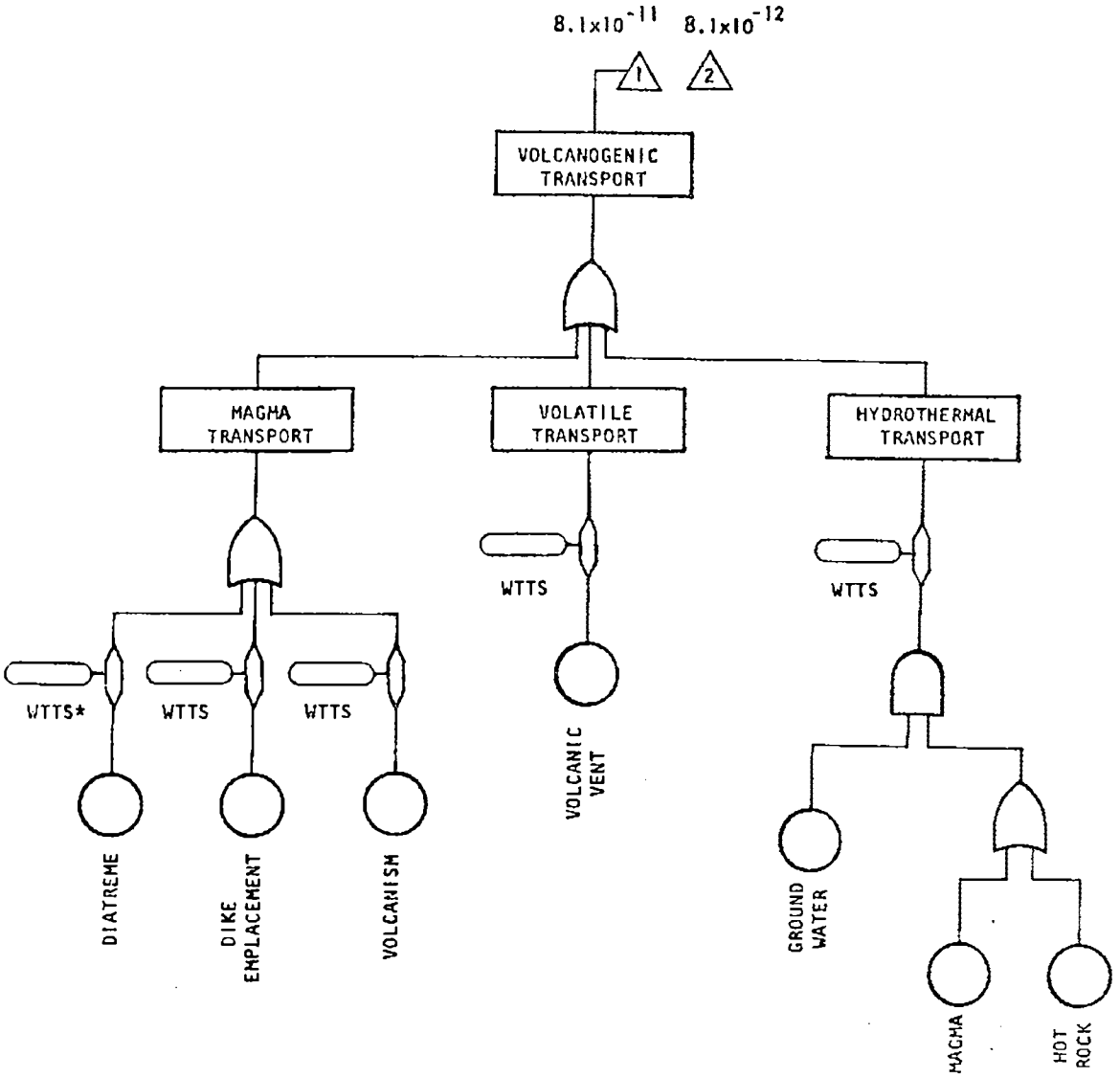


Figure 6 – 4. Fault tree for release to ground water.



*WTTS = WASTE TRANSPORT TOWARD SURFACE, FOR 1

= WASTE TRANSPORT TO SURFACE, FOR 2

Figure 6 - 5. Fault tree component for volcanogenic transport.

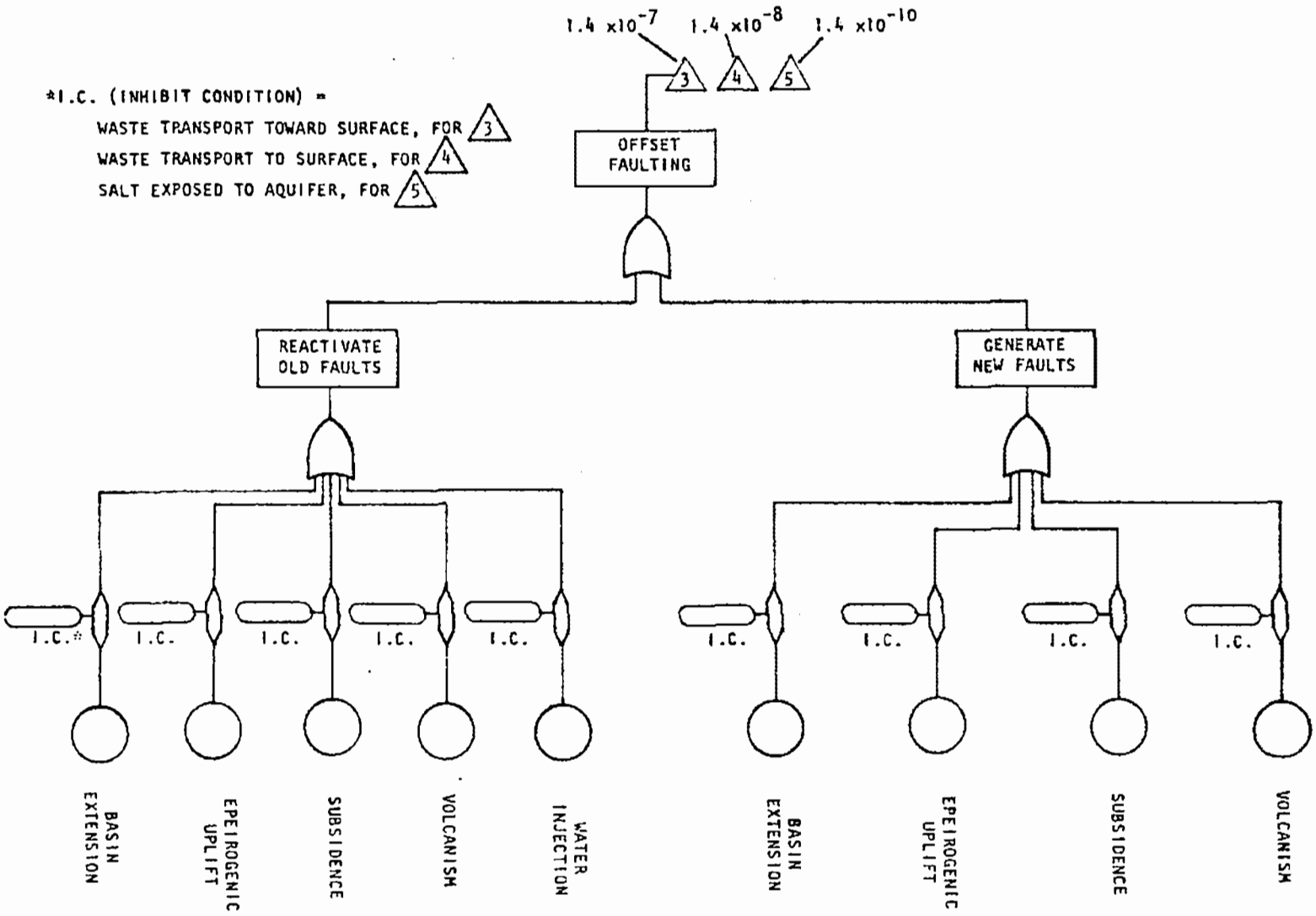


Figure 6 - 6. Fault tree component for offset faulting.

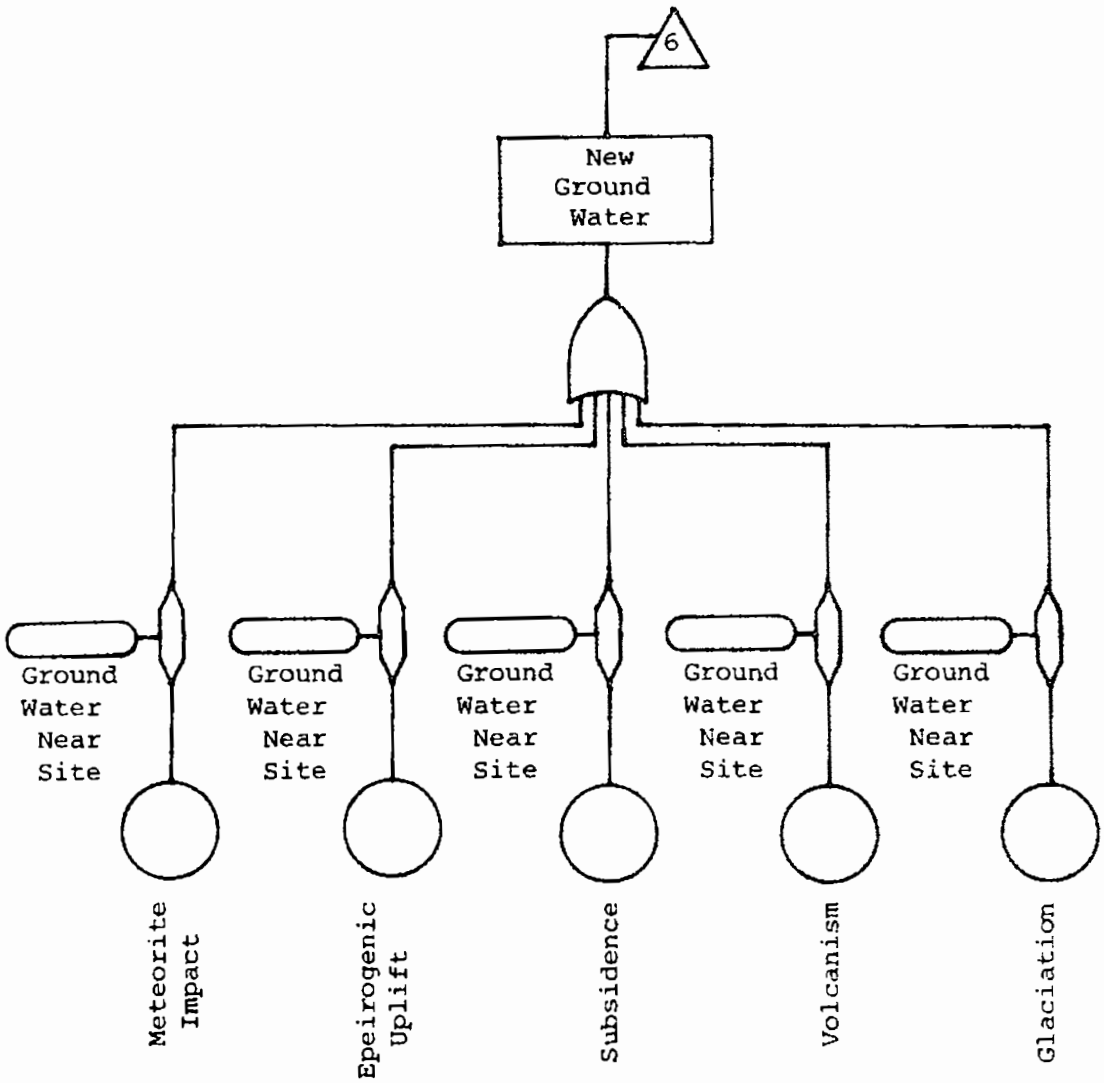


Figure 6 - 7. Fault tree component for new ground water.

during Permian time, though there have been some dike emplacements about 30 million years ago (no published reference available). Assuming the "rate" in the future is no greater than in the past, and using a nominal age of 200 million years for the basin, the volcanism probability is estimated by Kudo [Ku76] to be 5×10^{-9} per year in the Delaware Basin. Appendix C considers the small fraction of the Delaware Basin represented by the repository and estimates the probability for volcanogenic transport of waste to the surface to be $\leq 8.1 \times 10^{-12}$ per year. This is based upon a 10-km^2 repository with a 4 km radius "volcanism effect zone" (Fig. 6-8). This assumes the average diameter of area affected by a volcano is 2.2 km and that the envelope of tangency to the repository represents the effect zone. It can be expected that less severe events such as dike emplacement may occur and transport material to a shallower depth instead of to the surface. Considering the earlier observation that there have been some dike emplacements about 30 million years ago while no volcanos have occurred in over 200 million years, it appears reasonable to assume that the probability of transport merely to a shallower depth is a factor of 10 greater than for transport to the surface. Violent volcanic events such as volcanic explosions or diatremes, which would expel material into the atmosphere, are estimated by Kudo [Ku76] to occur at 0.3 times the rate of the basic volcanogenic transport events, or 2.4×10^{-12} per year. These values are used for the diagrams in Figs. 6-1 through 6-3. The probabilities stated above represent the probabilities of activities within the "volcanism effect zone" in Fig. 6-8. Within this zone, the expected value of the area of intersection by the volcanic process is determined in Appendix C to be 15 percent of the repository area for a volcano, and 1.2 percent for a diatreme. Also discussed in Appendix C are considerations of global plate tectonics. When further work on this concept is completed by geologists, it may be possible to reduce the probabilities from those used in this study. Further, a time-dependent probability may be defined which takes on finite or increased values only after some period of time.

In the absence of available information, the fraction of waste in

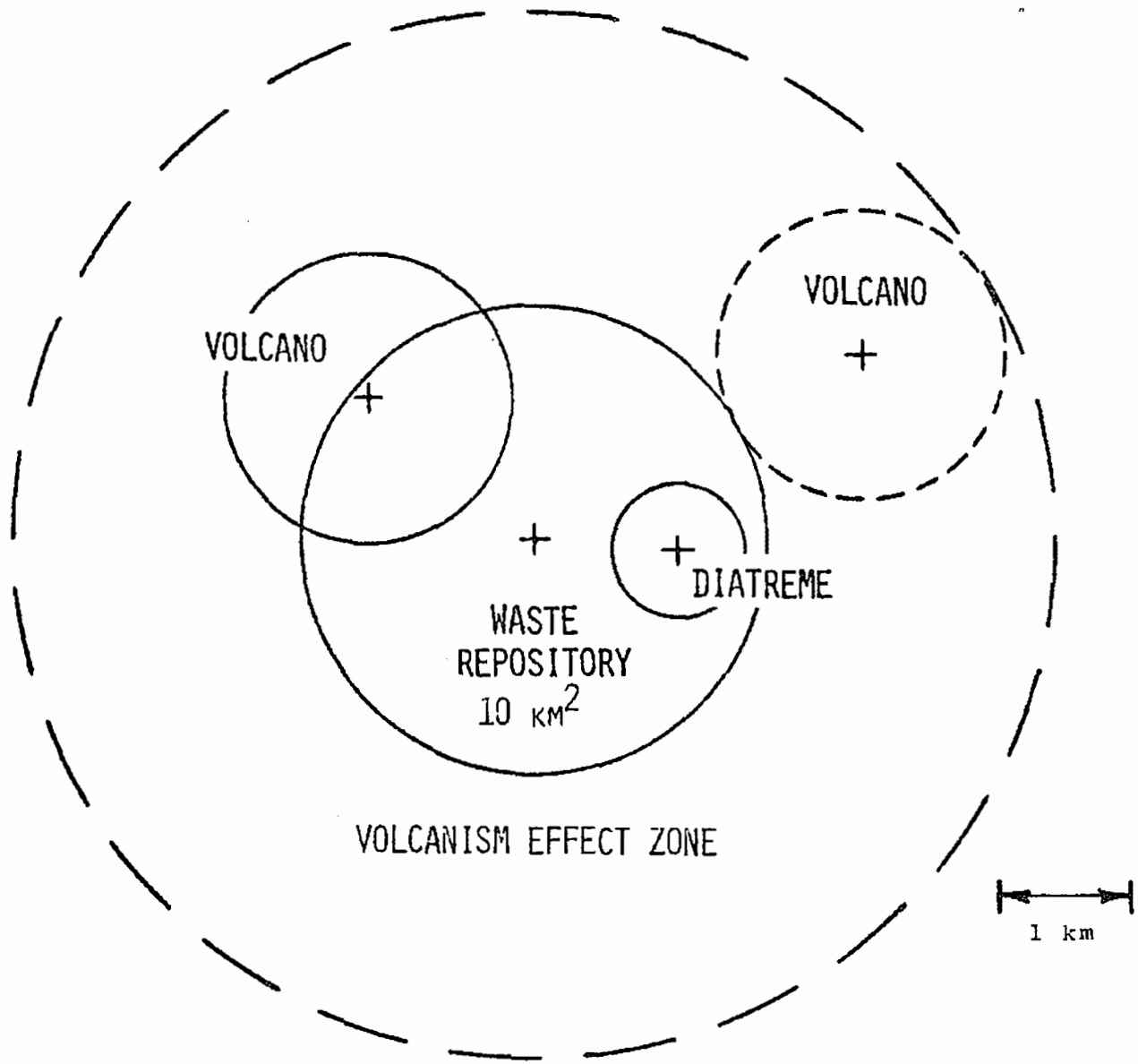


Figure 6 - 8. Volcanic interception of waste repository.

the intersected area transported to an exposed position is conservatively taken to be half of the affected inventory. It can be expected that some of the material in the repository horizon will be entrained, some will be carried only a short distance but much will be merely pushed aside by penetrating magma. On this basis, the fraction of repository inventory transported by a volcanogenic event becomes $0.15 \times 0.5 = 0.075$ for the volcano and $0.012 \times 0.5 = 0.006$ for the diatreme. Actually, much of any such transported material would remain in a buried configuration, or if exposed, would involve delay for leaching before becoming available for biological uptake. It is therefore suggested that the assumptions and estimates used here are conservative.

(b) Offset Faulting. Factors causing offsets by faulting are detailed in the fault tree component diagram in Fig. 6-6 and include the mechanisms of: 1) basin extension if it were to occur, 2) epeirogenic uplift, 3) subsidence, and 4) volcanism. These can lead to reactivation of old faults or generation of new ones, with a much higher probability assigned to reactivation of old faults. Secondly, another mechanism for producing offsets is to reactivate old faults by injection of water for secondary recovery of oil. As with volcanism, it does not appear necessary to predict each contributing event if a means is at hand to predict the aggregate occurrence. The aggregate probability for offset faulting sufficiently severe to fracture the bedded salt formation and interconnect upper and lower aquifers (Fig. 6 - 9) is estimated by Sanford, as described in Appendix D, to be 1.4×10^{-7} per year (output 3 in Fig. 6-6, and input 3 in Figs. 6-1 and 6-4). Fractures extending to the surface and offsets large enough to represent transport of waste toward the surface involve progressively lower probabilities than this basic value. As discussed in Appendix D, the probability for extension to the surface is conservatively taken as one order of magnitude lower (output 4 in Fig. 6-6 and input 4 in Fig. 6-2) and the probability for sufficient offset to expose a significant section of bedded salt to an aquifer is assumed to be at least three orders of magnitude lower (output 5 in Fig. 6-6, and input 5 in Fig. 6-1, 6-2, and 6-4).

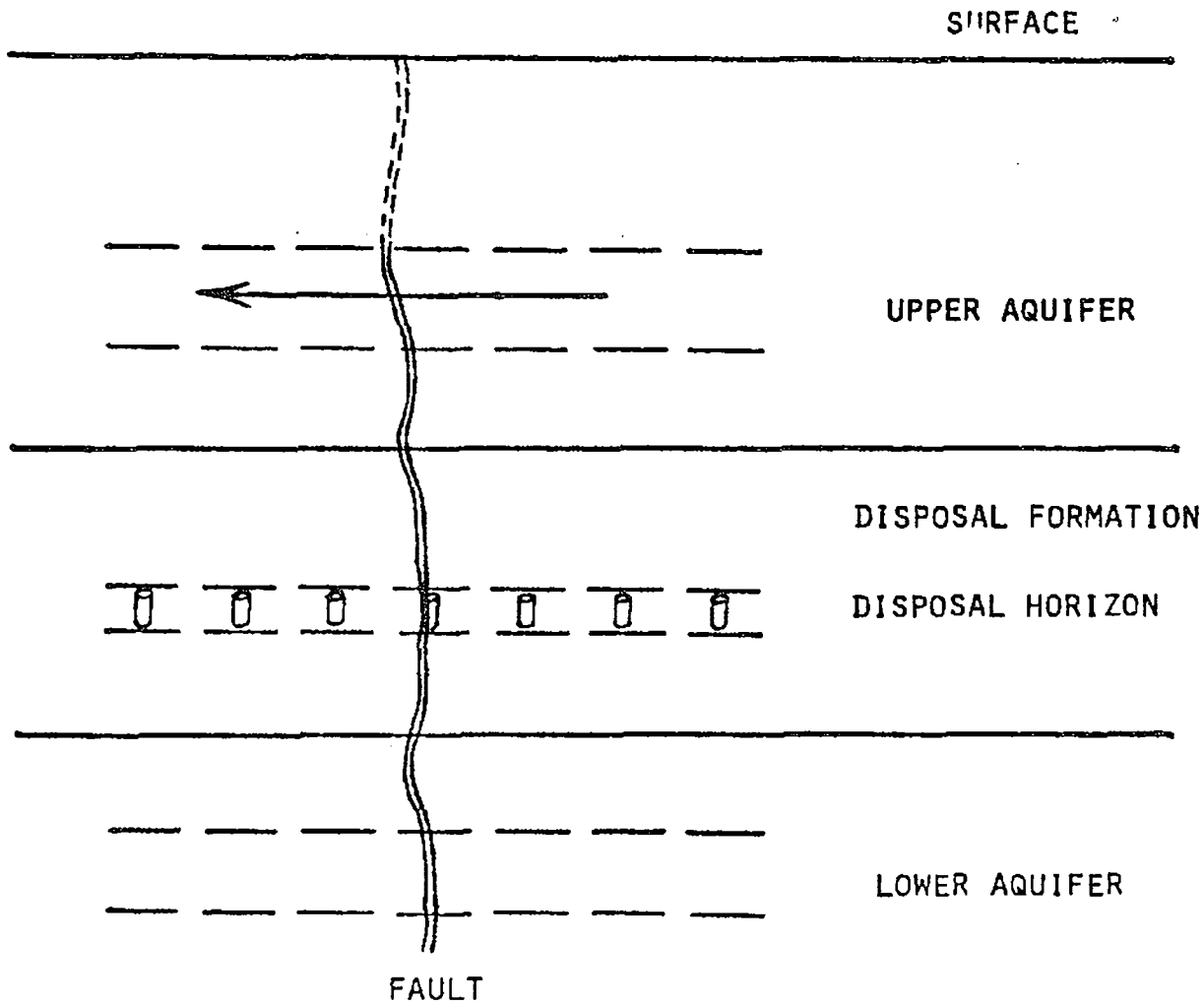


Figure 6-9. Interconnection of aquifers by offset faulting.

(c) New Ground Water. The generalized category of new ground water, Fig. 6-7 (input 6 in Fig. 6-4), reflects altered hydrologic conditions. This can be changed quantities, velocities and directions of flow caused by effects from a number of potential events. These events are quite complex in nature. Data is not available at this time for numerical implementation in AMRAW. This can be studied by parametric runs of the code for various altered hydrologic conditions. For example, the "new ground water" event can be set to a probability of unity and hydrologic input data provided for the correspondingly higher velocity or other changed conditions.

Next, consider the main fault tree diagrams which include the component groups discussed above.

(d) Release to Air. The most prominent member of the fault tree branch for release to air, Fig. 6-1, is direct expulsion due to meteorite impact or violent volcanic activity. The probability of meteorite impact on a 10-km^2 repository sufficient to exhume material from the disposal horizon is estimated in Appendix E to be 1×10^{-13} per year. The fraction of inventory released by such an event is conservatively estimated in Appendix E to be 5 percent to the air and 5 percent directly to land surface in the vicinity. Expulsion by volcanism was discussed earlier. Two other members of the fault tree in Fig. 6-1 express combinations of processes which first transport the waste to a shallower depth, followed by an expulsive event less severe than that required from the original depth. It may be seen that multiplication of annual probabilities in the AND gate in these cases leads to an estimated annual probability of 3×10^{-22} or less, which is an almost non-existent potential for such combined processes.

(e) Release to Land Surface. Release to the land surface, Fig. 6-2, involves either carrying waste material to the surface or reducing the surface by erosional processes to expose the waste. Material released to the surface is assumed to be apportioned between land and surface water according to their respective area fractions in the region considered. Volcanogenic transport and meteorite impact have low probabilities for occurrence discussed earlier. Insufficient data is available to evaluate the other processes. The conditions do not

appear to be present to cause salt diapirism; offset sufficient to expose the disposal horizon at the surface is considered to be exceedingly improbable (inhibit gate much less than unity). Erosion is a likely process, but the rate is so slow that denuding the waste horizon is not likely in less than one million years. This is discussed in Appendix E.

(f) Release to Surface Water. The fault tree branch for release to surface water, Fig. 6-3, includes the release-to-surface diagram discussed above, plus a fault tree member representing the presence of surface water either existing or which may come into existence at some time in the future.

(g) Release to Ground Water. Combinations of conditions leading to disruption of the repository and release of material by leaching to ground water, Fig. 6-4, are generally considered to be more probable than the more drastic events which release material to the surface or into the air, as indicated by the event probabilities presented earlier. This involves faulting which interconnects aquifers (as illustrated in Fig. 6-9), an offset fault severe enough to present the disposal horizon to an aquifer (very unlikely), or a man-caused penetration. In each case, presence of ground water is a necessary AND gate condition. It should be noted that an output from this fault tree does not represent an instantaneous release but instead indicates the start of a slow leaching process into circulating ground water. The leaching implementation is described later in this section. Data has not yet been acquired to evaluate man-caused penetration connections. It should be noted that any single hole drilling incident relates to only a very small fraction of the total repository inventory.

(h) Summary of Release Scenarios Implemented. Each path through a fault tree which leads to release represents a set of conditions existing at a given time which together can permit a release to occur. Each such path is called a "cut set." To illustrate, Fig. 6-10 shows the elements for one cut set in the fault tree branch for release to ground water. This is one of the cut sets used as input to AMRAW at this time for demonstration of the application to the Los Medaños site. The 10 cut sets implemented at this time, their

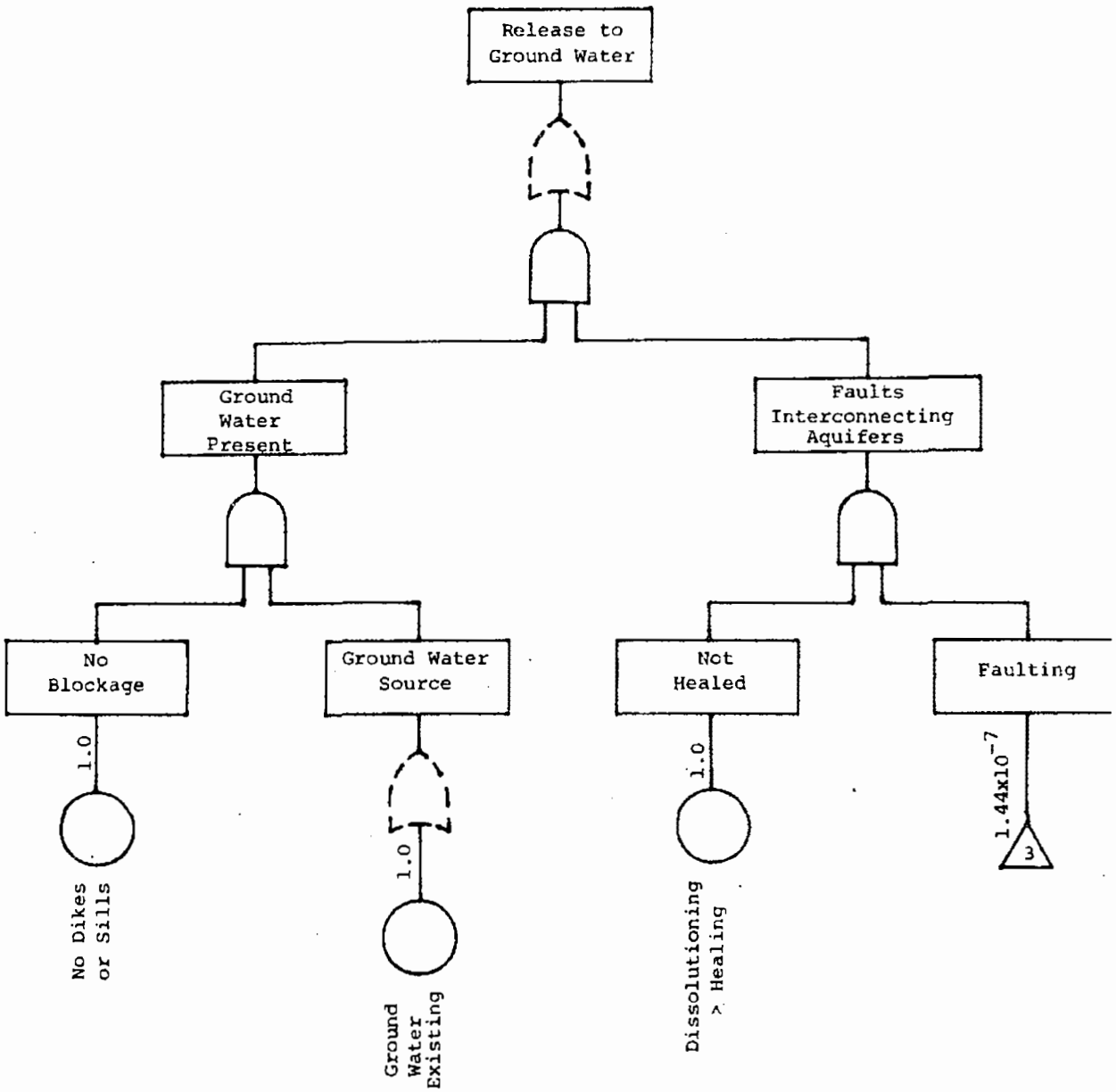


Figure 6-10. Sample cut set for release to ground water.

Table 6-4. Summary of Release Scenarios Included in Base Case

CUT SET	RELEASE TO RECEPTOR	EVENT	ANNUAL PROBABILITY		ESTIMATED RELEASE FRACTION
			FUNCTION	ESTIMATED VALUE	
1	Air (see Fig. 6-1.)	Direct Expulsion by meteorite impact	Constant	1×10^{-13}	0.05
2	Air	Direct expulsion by volcanic explosion	Constant	2.4×10^{-12}	0.075
3	Air	Direct expulsion by diatreme	Constant	2.4×10^{-12}	0.006
4	Land Surface (see Fig. 6-2 .)	Surface reduced to waste by erosion	Ramp	0.0 for $t<1.6\times10^{6}$y; $(t-1.6\times10^{6}) \times 1.56\times10^{-7}$ for $t>1.6\times10^{6}$y	[a]3.3×10^{-5}
5	Land Surface	Transport to surface by meteorite impact	Constant	1×10^{-13}	0.05
6	Land Surface	Volcanogenic transport to surface	Constant	8.1×10^{-12}	0.075
7	[b]Surface Water (see Fig. 6-3).	Surface reduced to waste by erosion	Ramp	0.0 for $t<1.6\times10^{6}$y; $(t-1.6\times10^{6}) \times 1.56\times10^{-7}$ for $t>1.6\times10^{6}$y	[a]3.3×10^{-5}

Table 6-4. Summary of Release Scenarios Included in Base Case (continued)

CUT SET	RELEASE TO RECEPTOR	EVENT	ANNUAL PROBABILITY		ESTIMATED RELEASE FRACTION
			FUNCTION	ESTIMATED VALUE	
8	Surface Water	Transport to surface by meteorite impact	Constant	1.0×10^{-13}	0.05
9	Surface Water	Volcanogenic transport to surface	Constant	8.1×10^{-12}	0.075
10	Ground Water (see Fig. 6-4.)	Faulting; not sealed, interconnecting aquifers	Constant	1.4×10^{-7}	[c]Calculated leach rates

Notes: [a]Release fraction for exposure by erosion assumes vertical canisters eroded at same annual rate as land surface.

[b]The release to surface water corresponds to the same cut sets as for release to land surface plus the presence of surface water.

[c]The release fraction for release to ground water is the inventory fraction leached per year, as calculated by function RLEACH under subroutine FAULT in AMRAW.

overall annual probabilities and inventory release fraction (if event occurs) are summarized in Table 6-4. All of the overall probabilities listed are constant over time except the erosion event which is represented by a ramp function. The exposure by erosion listed for land surface and surface water does not lead here to a release within one million years, but it is used to illustrate input of a ramp function probability (see Appendix E). Input data for the Release Model in AMRAW may be submitted as simply one factor (the overall probability) for each cut set. For the base case demonstrated here, most of the cut sets are represented by several factors (see input data in Appendix J). For example, in Fig. 6-10, the overall probability for the release to ground water is represented by

$$P = (1)(1)(1)(1.4 \times 10^{-7}) \qquad (6\text{-}1)$$

where the unity factors respectively represent: "no blockage," "ground water existing," and (fracture) "not sealed." Should these be determined to have a time dependence for non-unity values, AMRAW flexibility is prepared to receive the more detailed data. Note at this point that the fault trees serve primarily as devices for correlating and displaying scenarios; once the AMRAW input probabilities are determined, it makes no difference whether fault trees or some other logic process was used.

2. Leaching by Ground Water. If access by ground water to the waste deposit occurs (see Figs. 6-4 and 6 - 9), a gradual release by leaching begins. In Section 3.C. of Vol. I a theoretical discussion of waste deposit leaching is presented, in which Eq. 4 - 13 from Vol. I, repeated below

$$L_p = \frac{F_s}{V_s} A_o (\mathcal{D}_e k)^{1/2} \left[\left(t + \frac{1}{2k} \right) \operatorname{erf}(kt)^{1/2} + \left(\frac{t}{\pi k} \right)^{1/2} e^{-kt} \right] \qquad (6\text{-}2)$$

represents the predictor equation for the cumulative amount of radioactive species leached, L_p, in time interval t. The units of L_p correspond to that of A_o, the initial total radioactivity of the species subject to leaching at the time leaching begins.

The derivation of the predictor expression (Eq. 6 - 2) is based on a diffusion transport model [Gd74] that specifically considers diffusion with concentration-dependent dissolution rate. Here, the implementation of that model in AMRAW is discussed.

It is assumed that each waste canister has the dimensions 0.3 m in diameter x 3 m high. Further assumptions include breaching of the container by corrosion and disintegration of the exposed waste matrix into ten cylindrical parts. The total surface area exposed thereby corresponds to $F_s = 4.38 \times 10^4$ cm^2, with the specimen volume equal to $V_s = 2.22 \times 10^5$ cm^3. In Eq. 6 - 2, $\mathcal{D}_e$ is the effective diffusivity for the species in cm^2/d, k is the dissolution rate constant for the species in d^{-1}, and t is the leaching time interval in days.

Clearly, Eq. 6 - 2 shows that the error function term $\mathrm{erf}(kt)^{1/2}$ must also be evaluated before obtaining an explicit solution of L_p at any time interval for a specific radionuclide. Mathematically, the error function term has the form [Kr67]

$$\mathrm{erf}(kt)^{1/2} = \frac{2}{\sqrt{\pi}} \int_0^{(kt)^{1/2}} e^{-\eta^2} d\eta \qquad (6\text{-}3)$$

and its numerical evaluation can be an added computational burden. Because of the computational nature of the AMRAW code itself, the predictor relation (Eq. 6 - 2) is divided into two functions which comprise the algorithm RLEACH. Firstly, at short time intervals, e.g. up to less than one year, Eq. 6 - 2 reduces to

$$L_p \approx 2 \frac{F_s}{V_s} A_o \left(\frac{\mathcal{D}_e}{\pi}\right)^{1/2} \left[\left(1 + \frac{1}{2} kt\right) t^{1/2}\right]. \qquad (6\text{-}4)$$

Secondly, for time intervals equal to or greater than one year, Eq. 6 - 2 becomes

$$L_p \approx \frac{F_s}{V_s} A_o \left(\mathcal{D}_e k\right)^{1/2} \left(t + \frac{1}{2k}\right). \qquad (6\text{-}5)$$

Equations 6 - 4 and 6 - 5 here correspond to Eqs. 3 - 15 and 3 - 16, respectively, in Vol. I. Note that Eq. 6 - 5 above obtains from Eq. 6 - 2 since, for very long time intervals, $\mathrm{erf}(kt)^{1/2}$ approaches unity [Ab70,

Kr67]. Thus, Eqs. 6 - 4 and 6 - 5 are the equivalent of Eq. 6 - 2, and are used in AMRAW in estimating the cumulative amount of radionuclide leached for all time; Eq. 6 - 4 is used in calculating L_p for leach time intervals less than one year, and Eq. 6 - 5 for leach time intervals equal to or greater than one year. (Example plots of calculations for L_p are presented later in this section.)

The leaching routine RLEACH in AMRAW uses Eqs. 6 - 4 and 6 - 5 to calculate the predicted amount of radionuclide species released to solution for all time intervals in units of g and Ci. The latter unit obtains from applying the specific activity factor (SPACT) and is used in the ground water transport calculation (discussed in Section 3.D., Vol. I). However, since most leaching data are reported in terms of mass leach rates [Am72, Bℓ72, Gd74, Gv66, Me72, Me73, Ra72, Sm69], the values in grams calculated by Eqs. 6 - 4 and 6 - 5 are then divided by the product of the leach time interval in days (e.g. the interval 90 y - 100 y, or 10 x 365 d in the case of values calculated by Eq. 6 - 5) and the total surface area exposed to obtain the incremental leach rates in units of g/cm^2-d. Here, incremental leach rates are defined as leach rates calculated for a particular radionuclide at a specific leach time interval and do not include accumulated values at previous leach time intervals. Results of incremental leach rates calculated are described later in this section.

A total of 62,500 canisters are assumed distributed on a 5 m x 24 m spacing within various sections of a 10-km^2 repository area; the number corresponds to an average arrangement of 250 rows of canisters, with each row comprising 250. As discussed in the example leaching calculation in Section 4.C. of Vol. I, one row of canisters is assumed to be subject to leaching at a time by a geologic faulting event. The leached quantity, now expressed as a fraction of inventory in the canister, is then multiplied by the number of canisters assumed to be exposed by geologic events (in this case 250), and subsequently expressed as a fraction of total repository inventory. The example leaching calculational procedure in Section 4.C., Vol. I, also outlines this calculational sequence as performed within AMRAW.

Estimation of the effective diffusivity $\mathcal{D}_e$ is done using the Stokes-

Einstein equation [Bi60] and is discussed in Section 3.C., Vol. I. Appendix J lists input data for the base case, and includes $\mathcal{D}_e$ values (in cm^2/d) approximated for all radionuclides selected for study; the $\mathcal{D}_e$ values are under the variable name "DCl", and are also listed in Table 6 - 5. Subsequently the estimated $\mathcal{D}_e$ is employed in determining the dissolution rate constant k iteratively via a curve-fitting procedure. The value of k is adjusted until the theoretically predicted profile (e.g. L_p vs. t plot of Eq. 6 - 2) adequately coincides with the experimentally measured leach data [Gd74]. Leach data from phosphate-glass by Mendel and co-worker [Me72] is used in this iteration procedure. Values of estimated k are listed in Appendix J under the variable name "DRC" and also in Table 6 - 5.

Examples of leach rates calculated by the leaching routine RLEACH in AMRAW are shown in Figs. 6 - 11 and 6-12. Figure 6-11 represents smoothed plots of Eqs. 6 - 4 and 6 - 5 for the cumulative amount leached as a function of time for Pb-210, Ra-226, and Th-229, while Fig. 6 - 12 depicts the incremental leach rates for Sr-90, and Cm-244. As discussed earlier in this section, the procedure for obtaining the calculated incremental leach rates in units of g/cm^2-d is to divide the amount of radionuclide species leached in g for a specified leach time interval by the product of the leach time interval (in d) and the total surface area exposed (in this case 250 F_s cm^2); the results of carrying out this procedure are the plots shown in Fig. 6 - 12. In Fig. 6 - 11, it is seen that Th-229 leaches more than either Ra-226 or Pb-210 at any leach time interval. It should be pointed out that net radioactive buildup and decay occurs simultaneously with the leaching process; thus, although the estimated diffusivities of Th-229, Ra-226, and Pb-210 are comparatively equal (refer to Table 6 - 5), the inventory of Th-229 available for leaching at various times is the greatest of the three, followed by Ra-226 and Pb-210, as listed in the radionuclides in waste source term in Appendix J. In Fig. 6 - 12, Sr-90 is shown to leach out faster than Cm-244 depending both on differences in diffusivity and inventory available for leaching.

Table 6 - 5. Estimated Values of Effective Diffusivity and Dissolution Rate Constant

Nuclide	Effective Diffusivity, $\mathcal{D}_e$, cm^2/d	Dissolution Rate Constant, k, d^{-1}
C-14	9.55×10^{-10}	4.96×10^{-3}
Sr-90	1.64×10^{-8}	2.90×10^{-2}
Y-90	1.64×10^{-8}	2.90×10^{-2}
Zr-93	6.29×10^{-10}	1.05×10^{-2}
Nb-93m	6.91×10^{-10}	1.11×10^{-2}
Tc-99	1.23×10^{-9}	2.86×10^{-3}
I-129	9.52×10^{-10}	4.95×10^{-3}
Cs-135	1.99×10^{-8}	3.14×10^{-2}
Cs-137	1.99×10^{-8}	3.30×10^{-2}
Pb-210	9.39×10^{-10}	2.75×10^{-3}
Ra-225	7.71×10^{-10}	4.46×10^{-3}
Ra-226	7.71×10^{-10}	4.46×10^{-3}
Th-229	6.64×10^{-10}	1.08×10^{-2}
Th-230	6.64×10^{-10}	1.08×10^{-2}
Np-237	7.51×10^{-10}	4.38×10^{-3}
Np-239	7.51×10^{-10}	4.38×10^{-3}
Pu-238	3.31×10^{-10}	7.19×10^{-3}
Pu-239	3.31×10^{-10}	7.19×10^{-3}
Pu-240	3.31×10^{-10}	7.22×10^{-3}
Pu-241	3.31×10^{-10}	7.25×10^{-3}
Am-241	8.12×10^{-10}	2.49×10^{-3}
Am-242m	8.12×10^{-10}	2.49×10^{-3}
Am-243	8.12×10^{-10}	2.62×10^{-3}
Cm-242	8.10×10^{-10}	2.48×10^{-3}
Cm-244	8.10×10^{-10}	2.48×10^{-3}

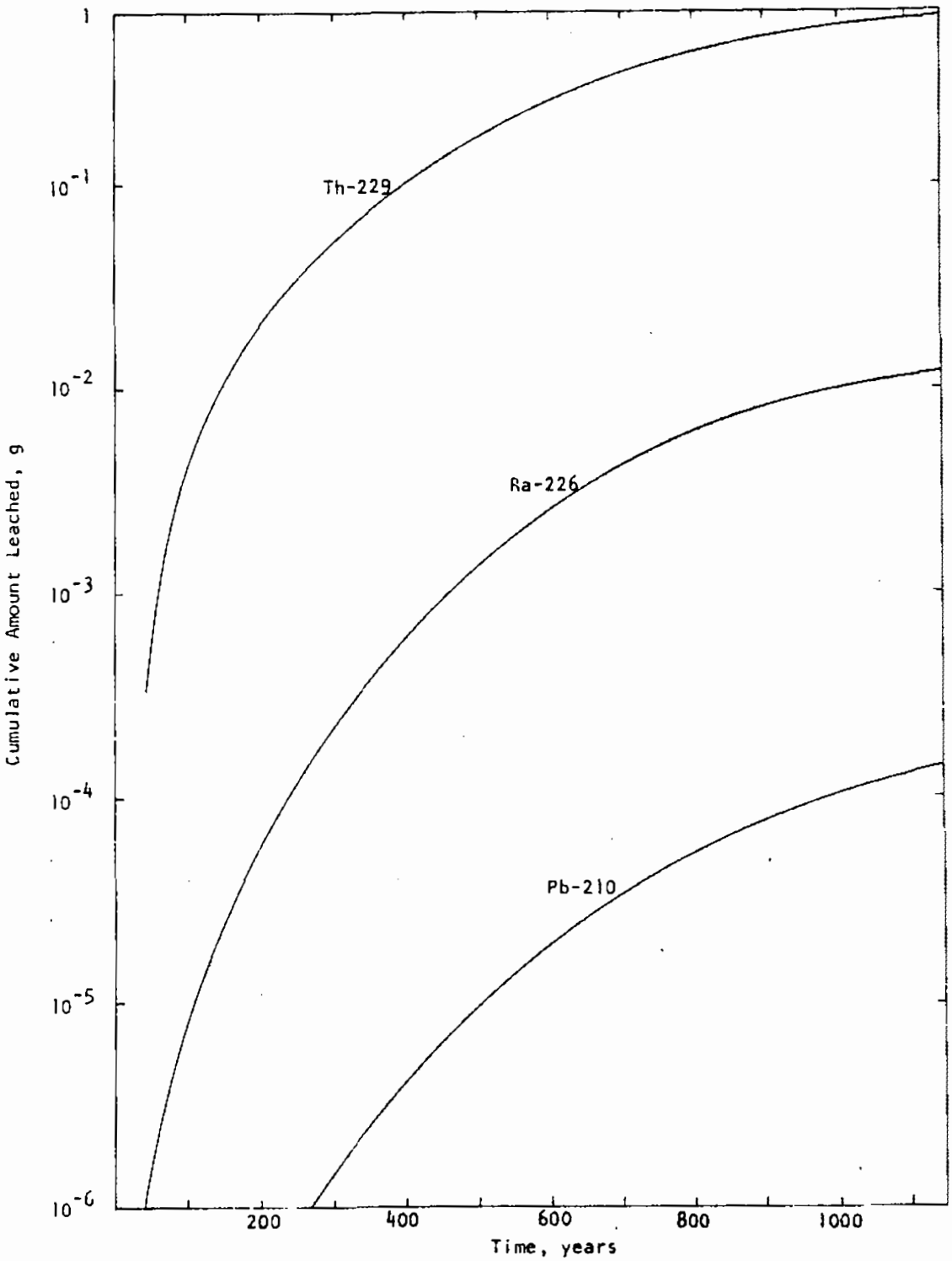


Figure 6 - 11. Calculated cumulative amount leached plotted against time for Pb-210, Ra-226 and Th-229.

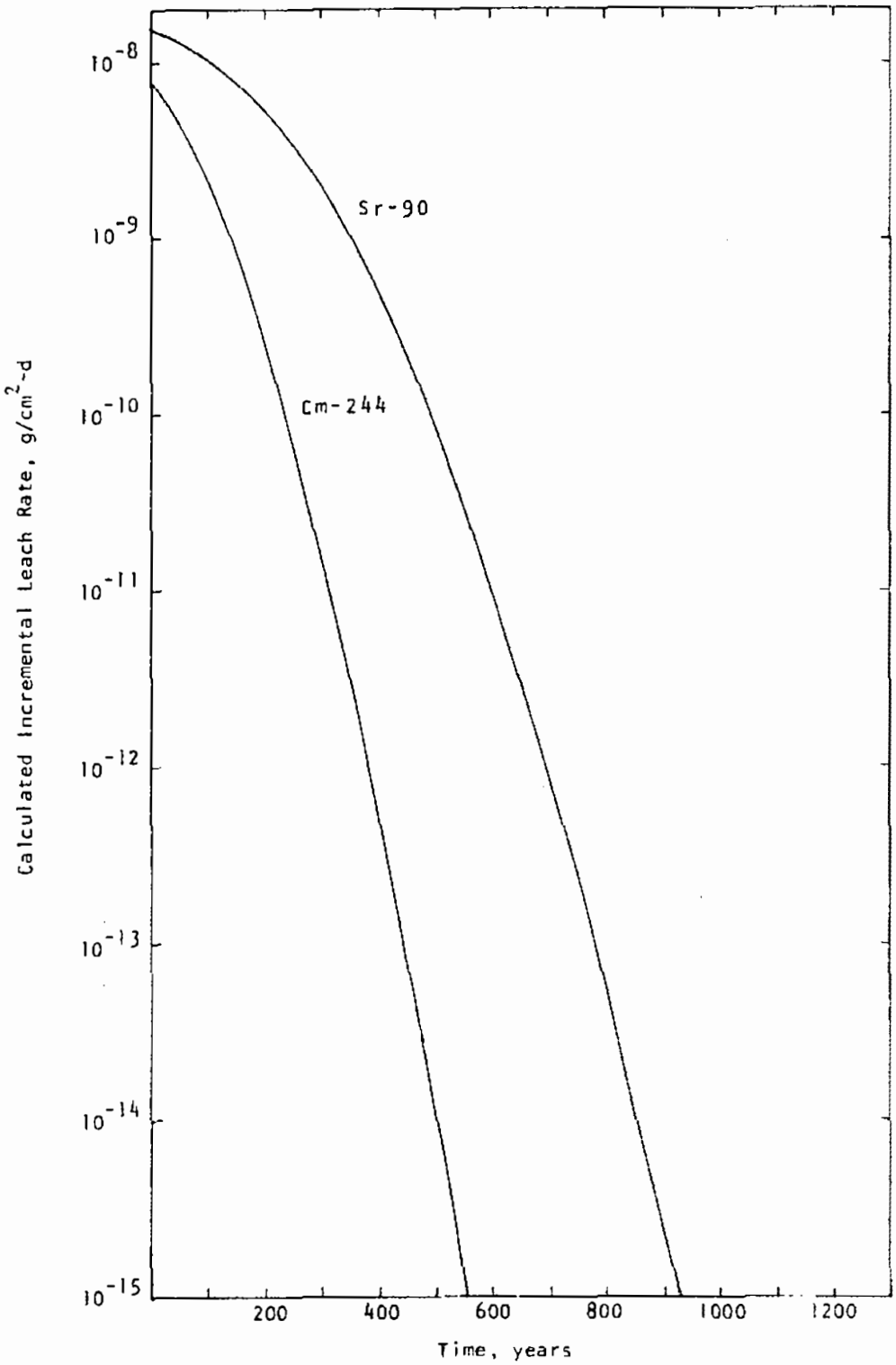


Figure 6 - 12. Calculated incremental leach rate plotted against time for Sr-90 and Cm-244.

C. ENVIRONMENTAL MODEL

Implementing the Environmental Model requires input data for the two parts: 1) Transport to Environment, and 2) Environment to Man Pathways. The following sections describe each of these two parts in turn.

1. Transport to Environment. This part of the Environmental Model uses releases to the four preliminary input receptors from the Release Model matrix and calculates the corresponding concentrations in the environmental input receptors for each of the geographic zones. Categories of input data required are for: 1) dispersion to zones, 2) interreceptor adjustment, and 3) conversion to concentrations.

(a) Dispersion to Zones. Consider first, the dispersion of a release to air to integrated air concentration and surface deposition for each zone. That is, input data is needed for ZONALO for air, and ZONDEP for deposition allocation. See Fig. 4-8 in Vol. I. Several air dispersion codes are available for this purpose. For this implementation, output from the AIRDOS-II code [Mo75, Mo77b] was obtained from the Oak Ridge National Laboratory [Mo77a]. Average New Mexico meteorological data input for AIRDOS is listed in Table 6-6 [Mo77a]. Directional data was averaged and input as directionally uniform. The long term projection of AMRAW calculations does not justify a non-uniform wind rose. AIRDOS output for a unit pulse or acute release (1 μCi) was obtained for three 20 x 20 grids: 80, 200, and 400 square km. The grids were superimposed on the region and zone map and the area weighted averages for the integrated air concentration and ground concentration from air deposition were calculated for each zone. The reader is referred to Section 4.D.1 of Volume I for a discussion of integrated air concentration. The integrated concentration, Ci-y/cm^3, from passage of a contaminated plume following an acute release, in Ci, is numerically equal to the equilibrium air concentration, Ci/cm^3, from a continuous or chronic release, in Ci/y. The resulting integrated air concentration and air deposition factors, input to AMRAW, are listed in Table 6-7. Also listed in this table are the land [USCB69] and water areas estimated for each zone and input to AMRAW. Data is not readily available for water areas and volumes in this arid region. After study

Table 6-6. Average New Mexico Meteorological Data Input to AIRDOS Code

Average Air Temperature, ^{o}K	294.
Average Vertical Air Temperature Gradient, $^{o}K/m$:	
In Stability Class E	0.0728
In Stability Class F	0.1090
In Stability Class G	0.1455
Rainfall Rate, in/y	8.00
Height of Lid, m	2000.
Release Height, m	5.
Fraction of time in each stability class:	
Class A	0.0244
Class B	0.1345
Class C	0.1274
Class D	0.2996
Class E	0.1378
Class F	0.2752
Class G	0.0
Wind speeds for each stability class, uniform wind rose assumed, m/s:	
Class A	1.70
Class B	2.07
Class C	3.50
Class D	6.04
Class E	3.64
Class F	1.70
Class G	0.0
Deposition Velocity, cm/s	1.0
Scavenging Coefficient, 1/s	0.46E-05

of maps, an estimate is made here that the average exposed water surface is 0.25 percent of the area in the more arid zones, 0.5 percent in zones with the Pecos River and reservoirs, and 9.0 percent in Zone 8 (confined to a corridor along the Pecos River).

Consider next the dispersion of direct releases to land surface and associated surface water. As discussed earlier, models for dispersion of material transported to the surface, including ballistic trajectory distributions are not well developed. In the absence of a more detailed model, the simple $1/r^2$ dispersion allocation model described in Appendix F is used, in which dispersion concentrates near the site but some dispersion to all parts of the study region is assumed. Further study of this may support a greater concentration near the site with zero dispersion to the region extremities. Table 6-8 lists areas and the $1/r^2$ factors obtained for each zone in the study region. The fraction of a release allocated to a zone is assumed to be dispersed uniformly within the zone, in proportion to the relative areas of each receptor (land and water) in the zone, also listed in Table 6-8. The zone allocation factor for each receptor and zone is then the product of the $1/r^2$ dispersion factor and the respective receptor area fraction.

The retarded transport of radionuclides in ground water is handled by the factor A2 (see Fig. 4-8, Vol. I) instead of by a zone allotment factor. The input for this calculation is discussed in later paragraphs of this section.

All of the ground water which flows slowly across the repository is assumed to emerge and transfer to surface water in Zone 2 lakes and ponds (20 percent) and in Zone 8 Pecos River (80 percent). The dip of the strata in this region (see Section 5B) causes the Rustler Formation, containing the aquifer of interest, to surface in the vicinity of the Pecos River. Accordingly, ADJ1 is input as 0.20 and 0.80 for Zones 2 and 8, respectively, and ADJ2 is input as 20 (no delay in transfer).

Transfer of surface water from the Pecos River to land surface for irrigation in Zone 8 involves an estimated annual usage of 0.6 m

Table 6 - 7. Integrated Air Concentration and Air Deposition

ZONE	AIR CONCENTRATION Ci-y/ cm^3Ci (ZONALO)	AIR DEPOSITION Ci/cm^2Ci (ZONDEP)	LAND AREA cm^2 (AREAG)	WATER AREA cm^2 (AREAW)
1	1.26E-20	4.04E-13	7.90E+11	0.0
2	5.31E-23	1.93E-15	1.01E+14	5.06E+11
3	5.09E-24	1.94E-16	2.27E+14	1.14E+12
4	2.12E-24	1.05E-16	4.77E+13	1.12E+11
5	3.83E-24	1.79E-16	1.22E+14	3.06E+11
6	3.03E-23	1.17E-15	1.14E+14	2.85E+11
7	3.18E-24	1.50E-16	1.57E+14	7.88E+11
8	3.12E-23	1.25E-15	5.46E+12	5.40E+11

Table 6 -8. Dispersion Factors for Direct Releases to Land and Surface Water

ZONE	TOTAL AREA cm^2	LAND AREA %	WATER AREA %	$1/r^2$ DISPERSION ALLOCATION, %	ALLOCATION FACTOR (ZONALO) LAND	WATER
1	7.90E+11	100.	0.	12.9	1.29E-01	0.0
2	1.01E+14	99.5	0.5	43.3	4.31E-01	2.17E-03
3	2.28E+14	99.5	0.5	9.2	9.15E-02	4.60E-04
4	4.78E+13	99.75	0.25	0.9	8.68E-03	2.18E-05
5	1.22E+14	99.75	0.25	3.6	3.59E-02	9.00E-05
6	1.14E+14	99.75	0.25	24.3	2.42E-01	6.08E-04
7	1.58E+14	99.5	0.5	4.2	4.18E-02	2.10E-04
8	6.00E+12	91.0	9.0	1.6	1.46E-02	1.44E-03
TOTAL	7.78E+14			100.0		

of water on the 22 x 10^3 hectares of irrigated land (see Section 5.C.). Pecos River flow varies over a wide range; it is assumed in this study that the average flow rate through this region is double the average irrigation withdrawal rate. Hence, ADJ1 for transfer of surface water to land surface is 0.50 (and ADJ2 is 20 for step function).

The transfer rate for the above is treated as being rapid, represented by a step function because there is no delay. Slower transfers such as involving leaching or surface erosion would not permit the maximum transfer to be completed within a time increment, particularly for short time increments. It is for such conditions that the transfer rate constant, ADJ2, is provided in AMRAW.

Because of the low rate of rainfall, transfer by wash-off from land to surface water is not evaluated for the application.

(b) Interreceptor Adjustment. After the initial dispersion to receptors in each zone, adjustment for transfer to each receptor in a given zone from each of the other receptors in that zone is calculated by

$$G_m = E_m \left[1-\exp(-0.5\ F_m\ \Delta t)\right] \qquad (6\text{-}6)$$

where E_m (designated ADJ1 in AMRAW) is input data representing the maximum fraction of the radionuclide inventory in one receptor which can be transferred (≤ 1.0), F_m (ADJ2 in AMRAW) is a transfer rate constant, and the average time for transfer of portions of the inventory (average of transfer to the beginning and to the end of the time increment considered) is one-half of the time increment Δt (DELTE in AMRAW). If the rate constant is large ($0.5\ F_m\ \Delta t > 15$), a step function $G_m = E_m$ is used. As mentioned in Vol. I, Section 4.D.1, transfer from air to the land and water surface by deposition is handled directly in the initial dispersion, as the process only involves a few days. Only a few of the many potential transfers in Fig. 4-9, Vol. I, are involved for this application. Data is input for the following assumed transfers:

1. Resuspension from land surface to air in all zones.
2. Ground water intercepting the site geometry discharges 0.20 fraction to surface water in Zone 2 and 0.80 to Zone 8 (Pecos River).
3. Surface water in Zone 8 has fraction of 0.50 transferred annually for irrigation to land surface in Zone 8.

A resuspension factor expresses the ratio of average air concentration above a ground surface to the concentration on the ground surface. The value used here is 100 times the generally used U.S. average, or 1×10^{-7} m^{-1} (1×10^{-9} cm^{-1}), to account for the less consolidated nature of desert soil. Gera reports [Ge75] a somewhat higher value for undisturbed Nevada desert: 7×10^{-7} m^{-1}. The constant ADJ1 is set equal to the resuspension factor. ADJ2 is arbitrarily set at 20, a value which causes a fast rise time for the exponential and provides a constant resuspended fraction. In fact, for this value of ADJ2, the exponential is bypassed, giving a true step function.

(c) Conversion to Concentrations. The adjusted radionuclide activities in each zone are converted to concentrations using appropriate dispersion areas and volumes. The dispersion parameter DISPN (see Fig. 4-10, Vol. I) for air is set within AMRAW to unity to avoid altering air values which already are concentrations. For land surface, the values are listed as AREAG in Table 6-7 (AMRAW obtains AREAG from input values of DISPN). For surface water, DISPN is the estimated water volume in each zone. The average water depth is assumed to be 100 cm, except in zone 8 where average Pecos River volume in Eddy County (including reservoirs) is taken as double the annual irrigation usage (0.6 m water on 22×10^3 hectares of irrigated land). For ground water, DISPN is set equal to a quantity called GNDDIS (ground dispersion), related to ground water velocity and aquifer dimensions, described later under Ground Water Transport. The dispersed concentrations are obtained by dividing each allocated release by the appropriate receptor area or volume.

(d) Environmental Decay. Data for evaluation of environmental decay constants is sparse. The most conservative assumption is to use values of zero, allowing removal by radiodecay only. For AMRAW calculations reported here, a very small token value is used (EDC = 2.30E-05), representing an "environmental half-life" of 30,000 years (factor of 10 attenuation in 100,000 years). Appendix J lists the environmental decay constants as "EDC," by zone, receptor, and nuclide. For ground water, zero values are assigned because removal by sorption processes is separately calculated within the ground water transport routine. For air, complete deposition of material released to air occurs during the release increment. To avoid carrying a residual in the air to a subsequent time increment, EDC is set to an arbitrarily large value (50).

(e) Ground Water Transport. In Section 4.D. of Vol. I a theoretical discussion of ground water transport is presented in which, for a stable geologic isolation repository, the geologic medium itself surrounding the repository can act to impede the rate of migration of radionuclides through the geosphere to the biosphere if the preceding barriers, including the low-leachable solid waste matrix (into which the radioactive species are incorporated) become ineffective and leaching occurs. In considering the migration of dissolved nuclides through the geologic medium, complex physico-chemical interactions such as solid-phase sorption, hydrodynamic dispersion, and diffusion [Br74] can act to control the movement of the nuclides relative to the carrier fluid (in this case water). These interactions cause the movement of nuclides to be generally slower compared to the movement of the water, consequently resulting in the reduction of releases to the biosphere [Bu76].

(1) Simplified Radionuclide Mass Transport Equation. As discussed in Vol. I, a simplified version of the Duguid-Reeves transport model for saturated-unsaturated flow in porous media [Re75] is adapted in AMRAW to predict radionuclide concentrations in ground water at points of usage or discharge to the surface. It is important to list again the following major assumptions described in Vol. I as simplification to the complex radionuclide mass transport and which form an important basis for the simplified Duguid-Reeves model itself: 1) the porous medium is infinite, homogeneous, and isotropic with simple boundary conditions; 2) porous region is fully saturated; 3) sorption of the dissolved radionuclide species is governed by a linear relationship; 4) mechanical dispersion is dominant over molecular diffusion; 5) chemical reactions are rapid such that instantaneous equilibrium exists between the dissolved and sorbed constituents; 6) fluid flow is uniform and steady; 7) the major flow component is parallel to the x-axis; and 8) concentration of the radionuclide species in the soil region is zero at time equals zero.

The simplified analytical solution to the Duguid-Reeves model for one-dimensional flow with two-dimensional dispersion [ANS] which is the basis of the ground water transport model employed in AMRAW to predict radionuclide concentration at usage or emergence points, is obtained as Eq. 4-84 in Vol. I, and is repeated as follows

$$C = \frac{k_1}{v_p t} \exp - \left\{ \frac{(x-k_2 v_p t)^2}{k_3 v_p t} + \frac{y^2}{k_4 v_p t} \right\} \qquad (6\text{-}7)$$

$$k_1 = \frac{M'}{4\pi (a_L a_T)^{\frac{1}{2}}/R_d} \qquad k_2 = \frac{1}{R_d} \qquad k_3 = 4\,\frac{a_L}{R_d} \qquad (6\text{-}7a)$$

$$k_4 = 4\,\frac{a_T}{R_d} \qquad M' = \frac{M}{z_a} \qquad R_d = 1 + \frac{\rho K_d}{\varepsilon}\,. \qquad (6\text{-}7b)$$

where C = radionuclide concentration in ground water at point of usage or discharge, Ci/m^3,

M' = amount of particular radionuclide released by leaching during a release time interval (M in Ci) divided by the thickness of the aquifer in which the waste is released (z_a in m), Ci/m,

R_d = retardation factor, dimensionless,

K_d = distribution coefficient, defined as the ratio of fraction of amount of species that is sorbed on the solid medium per unit mass of medium to amount of species remaining in the solution per unit volume of solution (Eq. 4-71 of Vol. I), cm^3/g,

ρ = solid medium bulk density, g/cm^3,

ε = porosity of solid medium, dimensionless,

v_p = pore or seepage velocity, m/d,

a_L = longitudinal dispersivity, m,

a_T = transverse dispersivity, m

x = distance along aquifer to point of usage or discharge, m,

y = transverse distance from plume centerline, m,

t = time in the environment, d.

With these units used for the parameters listed above, the lumped parameters $k_1 \rightarrow k_4$ will have the respective units: k_1 in Ci/m^2, k_2 dimensionless, and k_3 and k_4 both in m. Following calculation of concentration at usage or emergence point, a decay factor (DECFAC) is applied to account for radiodecay. This DECFAC factor and its application is discussed in Section 4.D.1.e. and illustrated by a sample calculation in Section 4.D.1. of Vol. I. The interpretation of the transverse distance y is discussed in Appendix A of Vol. I and illustrated in the following paragraphs.

Preliminary distances of 10 km (Zone 2) and 20 km (Zone 8) are used in the calculations. The 10 km is a representative average distance between the site and points of possible well withdrawal for use in Zone 2. Since the ground water is considered to surface at or before the Pecos River, the portion of Zone 2 west of the river is not affected. The primary entry of ground water to the river is at Malaga Bend, a distance of about 25 km; a representative distance of 20 km is used to average in some closer sections of the river.

(2) Ground Water Transport Data and Parameters. In the very complex transport of radioactive nuclei through porous media it is necessary to use sorption data and parameters obtained from sorption measurements in the model site [Bu76, Rt73a]. To date, however, sorption measurements have almost exclusively been carried out in the laboratory [Bu76]. In order to generate solutions to the defining governing equations, it is likewise necessary to make assumptions about the data and parameters, even though some of these assumptions could be quite restrictive [EPA75]. The minimum data base requirements upon which a transport model can be developed vary from site to site [EPA75]. Table 6 - 9 gives the data being employed in the implementation of the transport model. For conservation, ground water seepage velocity in initial calculations [Ky75] is increased by a factor of six (as listed) to cover uncertainty (see discussion of site hydrology in Section 5.B. of this volume). The average solid porosity was taken from Hiss [Hi75]. The average aquifer thickness is 100 m, but only the lower half of the formation (50 m) is considered in the analysis. The value of the transverse distance y in Eq. 6-7 which yields the average concentration across the effective plume width, from Eq. 4-84c in Vol. I, is $y = y_y = 2.08\ (a_T x)^{\frac{1}{2}}$. The corresponding effective plume width (width = 2y), where the concentration drops to 0.1% of the centerline value, from Eq. 4-84d in Vol. I is $y_w = 10.5\ (a_T x)^{\frac{1}{2}}$. Compared to the transverse dispersivity, a much higher axial dispersivity is assumed, to account for the predominant bulk fluid flow. Finally, as previously discussed, preliminary distances of 10 km and 20 km from the source to point of usage or discharge are used in the ground water transport analysis.

A very important parameter in the transport analysis is the distribution coefficient (K_d), which is discussed in Section 4.D. in Vol. I.

The K_d is a direct measure of the retention of the species on the porous medium [Gf74, Gv66, Lv72]. Its determination depends on three primary factors [Bu76], namely: 1) pH of the ground water, 2) concentration of dissolved salts (e.g., sodium chloride), and 3) temperature of solution.

Table 6-9. Input Data and Parameters for Ground Water Transport Model

Symbol	Physical Parameter	Estimated Value
v_p	Seepage velocity [Ky75], m/d	4.00×10^{-3}
ε	Porosity of porous media [Hi75], dimensionless	0.15
ρ	Solid bulk density, g/cm^3	2.3
z_a	Aquifer thickness, m	50
y_w	Effective plume width, m	
	Zone 2	2580
	Zone 8	3640
y_y	Transverse distance to average concentration, m	
	Zone 2	520
	Zone 8	730
a_L	Axial dispersivity, m	50
a_T	Transverse dispersivity, m	6
x	Source to point of usage distance, km	
	Zone 2	10
	Zone 8	20

In some cases the concentration of the dissolved nuclide itself may be a significant factor [Bu76].

To date there is a dearth of experimentally-measured distribution coefficients in the literature, except some proposed K_d values as published at Battelle [Rt73a, De73]. These values have been estimated for U.S. western soil, but are applicable only to a non-salt geologic medium. There has been some preliminary work [Bu75b, Ja74a, Ja74b, Rt74b] aimed at considering the effect of salt (e.g. sodium chloride) on the migration of nuclides from an underground waste disposal site. Two studies [Ja74b, Rt74b] have proposed that ions present in the ground water (e.g. sodium ions) can greatly affect the retardation factor R_d (also termed sorption

equilibrium constant [Bu76, Ja74a]) for a specific radionuclide species. It is anticipated that the presence of sodium ions in solution may decrease the retardation factor [Ja74a], i.e. lower the K_d also (Eq. 6-7b). The published K_d values for western soil [Rt73a] are used, but reduced by 30% as an approximate assumed compensation for salinity, in the ground water transport analysis in AMRAW. These estimated K_d values are listed in Table 6 - 10 and also in Appendix J under the variable name "RKD." In Table 6 - 10 a high K_d represents very strong sorption or retention for a particular radionuclide, and conversely; Th-230, for example, with K_d over 10,000 is very strongly sorbed, while Tc-99 (K_d near zero) is sorbed very poorly, if at all. Both Tc-99 and I-129 can generally be considered as simply moving with the ground water since their K_d values are near zero.

Table 6 - 10. Estimated Distribution Coefficients for Selected Radionuclides

Nuclide Number	Nuclide	Distribution Coefficient, cm^3/g
1	C-14	1.4
2	Sr-90	14
3	Y-90	1400
4	Zr-93	1400
5	Nb-93m	1400
6	Tc-99	~0
7	I-129	~0
8	Cs-135	140
9	Cs-137	140
10	Pb-210	2800
11	Ra-225	70
12	Ra-226	70
13	Th-229	10500
14	Th-230	10500
15	Np-237	10.5
16	Np-239	10.5
17	Pu-238	1400
18	Pu-239	1400
19	Pu-240	1400
20	Pu-241	1400
21	Am-241	1400
22	Am-242m	1400
23	Am-243	1400
24	Cm-242	420
25	Cm-244	420

(3) Examples of Ground Water Transport Calculations. The objective in the ground water transport calculations is to obtain the average concentrations at points of water usage during each time increment. After the start of a leach incident, the accumulated quantity of a radionuclide at the end of each time increment is calculated as a release to ground water transport at that time. Thus, the AMRAW calculations consider a sequence of pulse releases. As each pulse moves downflow, the concentration peak broadens in time by axial dispersion. Sensitivity analysis runs on the ground water transport model, discussed in Section 7.A., show that when $K_d = 0$, the width of the concentration peak at half-maximum at distances greater than a few kilometers from the repository site generally is close to 2000 y. When K_d values are non-zero, broadening of the concentration peak becomes more pronounced due to retardation effects; this broadening increases with K_d.

It is important to describe the procedure used in AMRAW (see Vol. I, Section 4.D.) for estimating the average radionuclide concentration in ground water at a specific point of usage or discharge. As presently implemented, 50 times are used in AMRAW from the start of repository operations up to one million years. Shorter time increments of 5, 10, 100, and 1000 y are used near the beginning and longer time increments (10,000 and 100,000 y) are used later. For time increments up through 1000 y (e.g., between times of 2000 and 3000 y), the average radionuclide concentration for each time increment is obtained by averaging the concentrations obtained from Eq. 6-7 at the beginning (e.g., 2000 y) and at the end (e.g., 3000 y) of the time increment. For larger time increments and low values of K_d, this simple averaging procedure would be in error; when time increments under consideration are 10,000 y or higher, the narrow peaks associated with K_d values near zero can be "missed." That is, a peak passes through the location considered at some time within the time increment and is not wide enough to result in a significant calculated concentration at the beginning and/or end of the time increment. Hence, in AMRAW, each time increment of $\geq$ 10,000 y is subdivided into 1000 y sub-intervals if $K_d < 1$; for $K_d \geq 1$, each time increment $\geq$ 100,000 y is subdivided into 20,000 y sub-intervals (allowed by broader peaks when $K_d \geq 1$). The radionuclide concentration is calculated at the

Table 6-11. Predicted Ground Water Concentration as a Function of Time for Tc-99 at a Point 10 km Along Aquifer (K_d = 0.0)

Time, y	[b]Concentration, μCi/cm^3
5,000	1.83×10^{-11}
6,000	1.21×10^{-9}
7,000	[a]2.92×10^{-9}
8,000	8.96×10^{-10}
9,000	6.97×10^{-11}
10,000	2.07×10^{-12}
11,000	3.07×10^{-14}
12,000	2.70×10^{-16}
13,000	1.59×10^{-18}
14,000	6.83×10^{-21}
15,000	2.28×10^{-23}
16,000	6.22×10^{-26}

[a]Calculated peak at 6,850 y (2.98×10^{-9} μCi/cm^3).
[b]Prior to correction for radiodecay.

Table 6-12. Predicted Ground Water Concentration as a Function of Time for Np-237 at a Point 10 km Along Aquifer (K_d = 10.5)

Time, y	[b]Concentration, μCi/cm^3
500,000	4.78×10^{-24}
600,000	7.17×10^{-18}
700,000	4.98×10^{-14}
800,000	1.21×10^{-11}
900,000	3.13×10^{-10}
1,000,000	[a]1.70×10^{-9}

[a]Calculated peak at 1,120,000 y (2.97×10^{-9} μCi/cm^3).
[b]Prior to correction for radiodecay.

Table 6-13. Predicted Ground Water Concentration as a Function of Time for C-14 at a Point 10 km Along Aquifer (K_d = 1.4)

Time, y	[b]Concentration, μCi/cm^3
100,000	2.00×10^{-13}
110,000	9.00×10^{-12}
120,000	1.24×10^{-10}
130,000	6.89×10^{-10}
140,000	1.87×10^{-9}
150,000	[a]2.87×10^{-9}
160,000	2.77×10^{-9}
170,000	1.83×10^{-9}
180,000	8.75×10^{-10}
190,000	3.21×10^{-10}
200,000	9.38×10^{-11}
210,000	2.26×10^{-11}
220,000	4.59×10^{-12}
230,000	8.06×10^{-13}
240,000	1.25×10^{-13}
250,000	1.72×10^{-14}
260,000	2.16×10^{-15}
270,000	2.47×10^{-16}
280,000	2.62×10^{-17}
290,000	2.59×10^{-18}
300,000	2.39×10^{-19}
310,000	2.10×10^{-20}
320,000	1.74×10^{-21}

[a]Calculated peak at 154,000 y (2.978×10^{-9} μCi/cm^3)

[b] Prior to correction for radiodecay.

end of each time sub-interval, and the average radionuclide concentration is obtained by dividing the sum of all these calculated concentrations by the total number of time periods in the increment. Finally, as discussed in Section 4.D. of Vol. I, a decay factor, DECFAC, is applied within AMRAW to account for radiodecay in each of the components for average concentration calculations.

Examples of ground water concentrations prior to accounting for radiodecay predicted by the simplified transport solution in Eq. 6-7 are presented in Tables 6-11 to 6-13 for 1 Ci releases of Tc-99, Np-237 and C-14. Results of calculations indicate that both Tc-99 and I-129 (K_d = 0) emerge at 10 km along aquifer after 9000 y, but only calculated concentrations for Tc-99 are presented in Table 6-11. The Np-237 nuclide (half-life 2.14 x 10^6 y), evaluated with K_d = 10.5, does not peak until after 10^6 years.

In Table 6-13, C-14 (K_d = 1.4 assumed) is found to peak a little after 150,000 years. Plots of these tabulations are shown in Figs. 6-13 and 6-14. Figure 6-13 is a concentration plot for Tc-99 and I-129 while Fig. 6-14 shows the relative emergence of the concentration peaks for Tc-99 and I-129 (coincident in the plot), C-14 and Np-237. Clearly, C-14 appears to travel by a factor of 22 slower compared to Tc-99 and I-129 (peaks at 6800 y). Also, the peak width at half height with K_d = 1.4 is 37,000. (Auxiliary runs external to AMRAW indicate Np-237, for instance, peaks after 1.1 x 10^6 Y.)

2. Environmental Pathways. The second part of the Environmental Model is the Environment-to-Man Pathways Model, in which pathway analysis is performed and dose equivalent rates to man are calculated. This model is entered for each increment of time with the calculated concentrations for each environmental input receptor. These concentrations, as determined in the Transport-to-Environment Model are:

1) Air. Integrated air concentration, R2TOT, μCi-y/cm^3,

2) Land Surface.

   a. Accumulated ground concentration, R2TOT, μCi/cm^2,

   b. Integrated deposition for current time increment, GNDEP, μCi/cm^2,

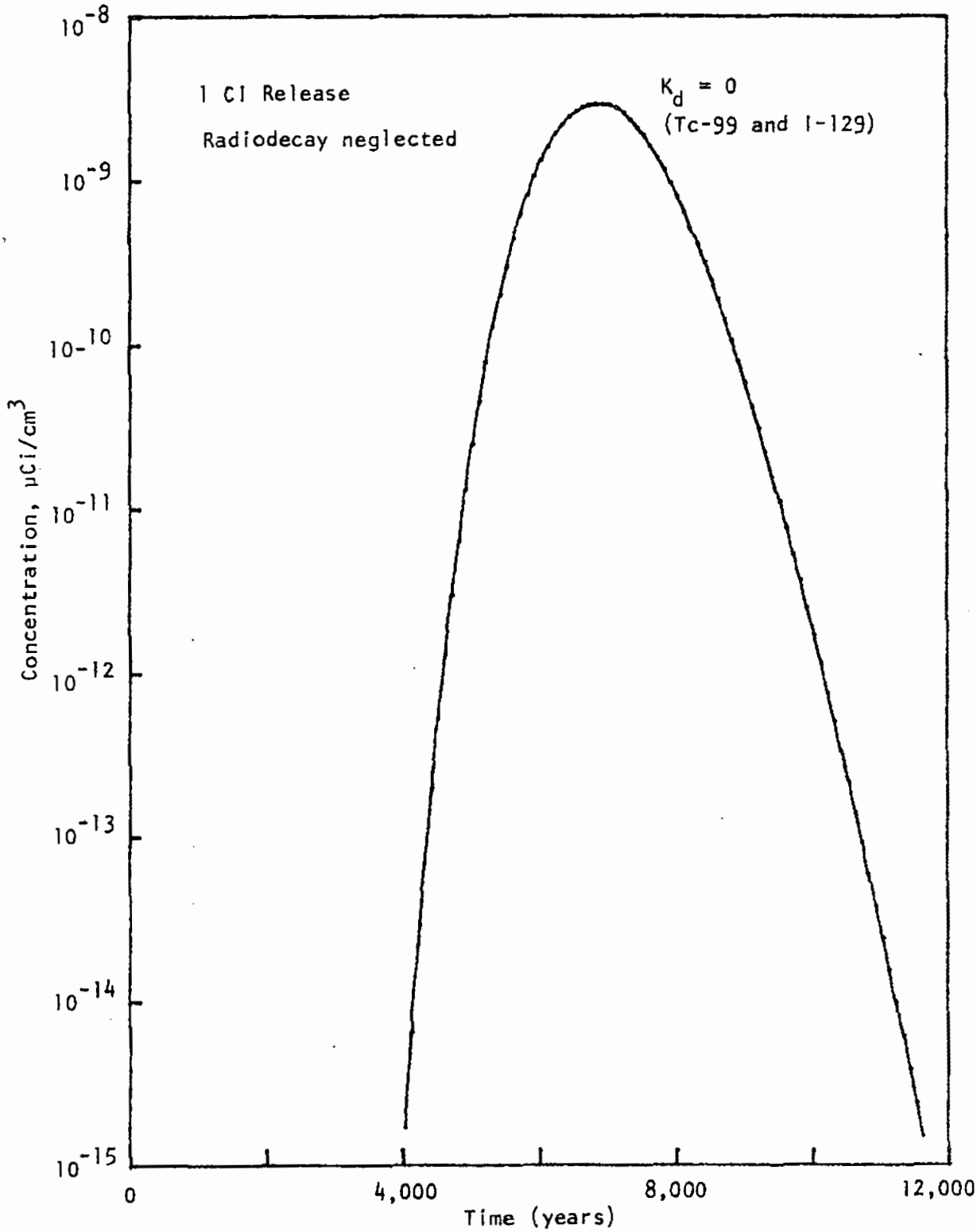


Figure 6-13. Ground water concentration as a function of time for K_d = 0 at a point 10 km along aquifer.

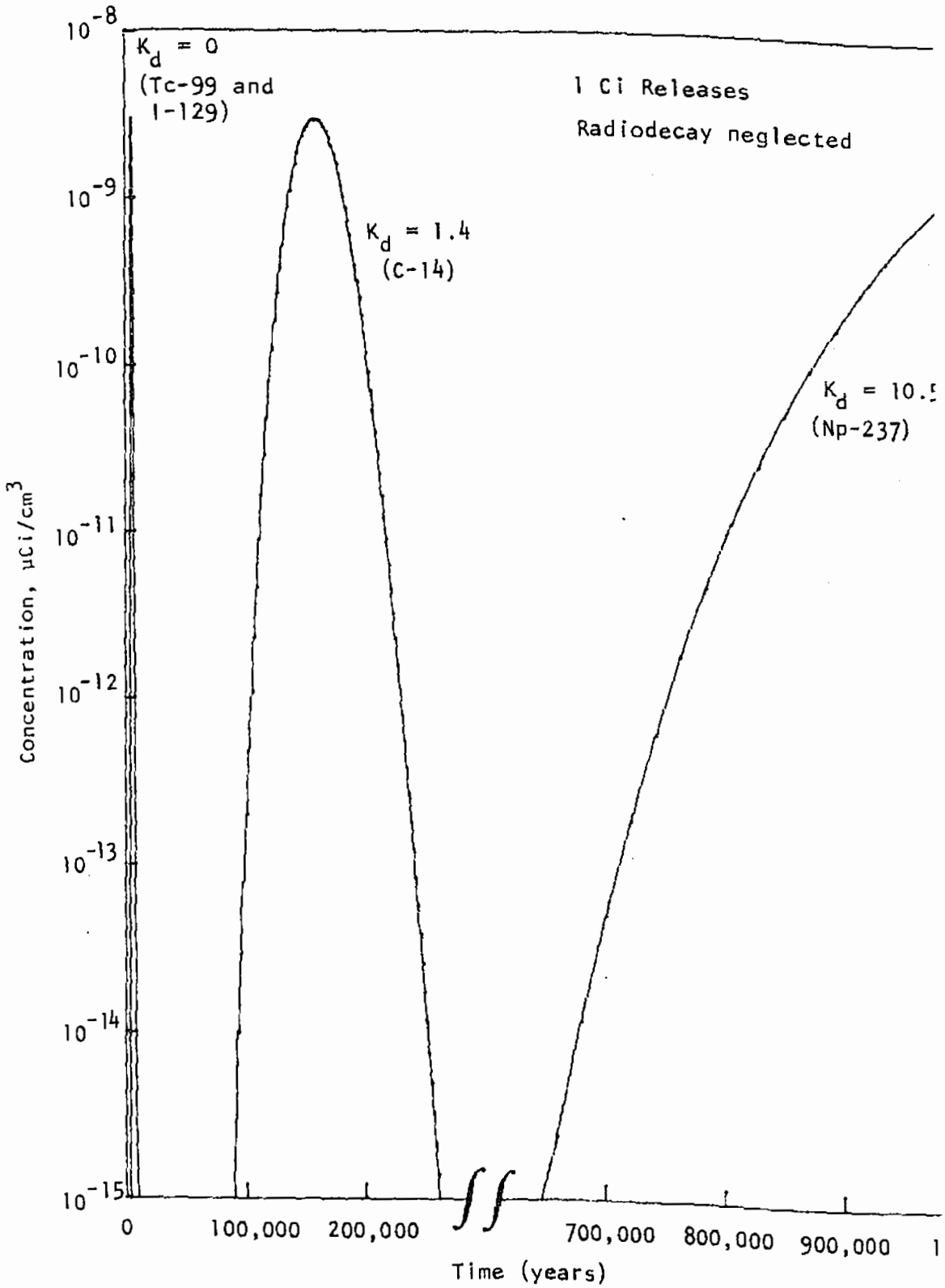


Figure 6-14. Ground water concentration as a functi of time for Tc-99, I-129, C-14, and Np-237 at a point 10 km along aquifer.

3) Surface Water. Accumulated water concentration, R2TOT, $\mu Ci/cm^3$, and

4) Ground Water. Accumulated ground water concentration at point of use, R2TOT, $\mu Ci/cm^3$.

The matrix, R2TOT, contains the net total concentrations accumulated for each of the four environmental input receptors, for each zone of the study region, at the end of each time increment considered. Similarly, GNDEP is the land surface deposition matrix for each current time increment.

Implementation of the last half of the environmental model requires a definition of all the pathways considered significant, and evaluation of input for the three factors which are components of the corresponding transfer coefficients, C: 1) biofactor, BIOFAC, 2) consumption, exposure or food production rates, VOLINT, and 3) dose rate factors, DOSFAC. In Vol. I, Fig. 4-14 illustrates the main pathways and Fig. 4-15 illustrates the relation of transfer coefficient C between receptor concentrations and dose commitment rates. Table 4-3 in Vol. I details the factors comprising the transfer coefficients and their units.

Table 6 - 14 lists 14 subpathways representing the most common pathways between the environment and man in the Los Medaños region. The pathways are grouped for orderly computer calculations. Under each input receptor there are two main pathways or modes, one for external exposure and the other for internal exposure (except for ground water where it is convenient to use both modes for different categories of ingestion). The ingestion mode under the land surface receptor divides into several subpaths representing above surface crops, meat, and milk. Each of these in turn has up to several components. To avoid an unwieldy number of pathways, the components are consolidated external to AMRAW, with consideration of individual concentration factors and consumption, and reduced to equivalent composite transfer coefficients for subpath calculations. There are both fresh water and salt water lakes and ponds in the region, each with a different aquatic food production behavior. Again, in this provision for a single aquatic food subpath, the components are consolidated external to AMRAW. As discussed in a later paragraph, data on production rates in the aquatic food subpath are not

Table 6-14. Environmental Pathways for Los Medaños Region

Environmental Input Receptor	Main Pathway (Mode)	Subpath	Dose Effect*	Component
Air	1. Immersion	1. Immersion	L	
	2. Inhalation	1. Inhalation	L	
Land Surface	1. Direct exposure	1. Direct exposure	L	
	2. Ingestion	1. Above surface crops	N	Corn Sorghum Wheat Soybeans
		2. Meat (range fed)	N	Grazing
		3. Meat (hay fed)	N	Exported hay (feed lots)
		4. Milk	N	Within zone Exported hay equivalent
Surface Water	1. Submersion	1. Submersion	L	
	2. Ingestion	1. Drinking water	L	
		2. Meat from drinking water	N	
		3. Milk from drinking water	N	
		4. Aquatic foods	N	Fish (fresh water) Invertebrates (fresh water) Aquatic plants (fresh water) Waterfowl (fresh water) Fish (salt water) Invertebrates (salt water) Aquatic plants (salt water) Waterfowl (salt water)
Ground Water	1. Ingestion	1. Drinking water (man)	L	
	2. Ingestion	1. Meat from drinking water	N	

*Subpaths contribute to local dose (L) or to nonspecific dose (N), as indicated.

presently available (values for VOLINT input as zero). Each subpath listed in the subpath column of Table 6 - 14 represents a pathway implemented for the application, for a total of 14.

The calculations are linear, permitting superposition of effects. Meat and milk pathway analysis usually considers only the food input to the animals involved. For desert range cattle, there is a heavy intake of drinking water which can also lead to contamination of meat. The superposition calculations are handled in the model by first calculating transfer of radionuclides into meat and milk through food ingesti followed by consumption of meat and milk by man (land surface subpaths). Then the contamination from drinking water is determined and the meat and milk are assumed to be re-consumed by man (surface water and ground water subpaths) and dose effects are added. Note also that meat is divided into two subpaths under land surface. The first subpath represents meat added to animals grazing on contaminated rangeland (does not include weight added in feed lots after export from the region). The second subpath represents meat added to animals feeding on contaminated hay grown on irrigated land in the region. This includes hay exported and used for feed outside of the region.

Each subpath in Table 6 - 14 is labeled to indicate whether the associated dose rate contributes to "local dose" to individuals within each particular zone, or to a "nonspecific dose" to the population consuming exported agricultural products.

Next, implementation for the factors which make up the transfer coefficients is described.

(a) Biofactors. The term "biofactor" is used here to denote the ratio of radionuclide concentration in a food or drink to the corresponding environmental concentration, with units as shown in Table 6 - 15. Biofactors, denoted by the nomenclature BIOFAC, are needed only for the ingestion pathways; this factor is set equal to unity within AMRAW for the other pathway categories (mode 1 for all four receptors and mode 2 for the air receptor).

(1) Terrestrial Biofactors. Terrestrial codes such as

Table 6-15. Factors Comprising Environment-to-Man Coefficients

ENVIRONMENTAL INPUT RECEPTOR CONCENTRATION	AIR $\mu Ci\text{-}y/cm^3$ R2TOT		LAND SURFACE $\mu Ci/cm^2$ R2TOT	GNDEP	SURFACE WATER $\mu Ci/cm^3$ R2TOT			GROUND WATER $\mu Ci/cm^3$ R2TOT
Main Pathway	Immersion	Inhalation	Direct Exposure	Ingestion Terrestrial Food*	Submersion	Ingestion Drinking Water	Ingestion Aquatic Food*	Ingestion
Mode	1	2	1	2	1	2	2	1 or 2
Biofactor BIOFAC	---	---	---	$\frac{\mu Ci\text{-}y/g}{\mu Ci/cm^2}$	---	$\frac{\mu Ci/cm^3}{\mu Ci/cm^3}$ (dimensionless)	$\frac{\mu Ci/g}{\mu Ci/cm^3}$	$\frac{\mu Ci/cm^3}{\mu Ci/cm^3}$ (dimensionless)
X								
Consumption, Exposure, or Food Production Rate VOLINT	y/y	cm^3/y	y/y	g/y	y/y	cm^3/y	g/y	cm^3/y
X								
Conversion of Integrated Value to Average Rate 1/DELTE	1/y	1/y	---	1/y	---	---	---	---
X								
Dose Factor DOSFAC	$\frac{mrem/y}{\mu Ci/cm^3}$	$\frac{mrem}{\mu Ci}$	$\frac{mrem/y}{\mu Ci/cm^2}$	$\frac{mrem/y}{\mu Ci/y}$	$\frac{mrem/y}{\mu Ci/cm^3}$	$\frac{mrem/y}{\mu Ci/y}$	$\frac{mrem/y}{\mu Ci/y}$	$\frac{mrem/y}{\mu Ci/y}$
=								
Transfer Coefficient C	$\frac{mrem/y}{\mu Ci\text{-}y/cm^3}$	$\frac{mrem/y}{\mu Ci\text{-}y/cm^3}$	$\frac{mrem/y}{\mu Ci/cm^2}$	$\frac{mrem/y}{\mu Ci/cm^2}$	$\frac{mrem/y}{\mu Ci/cm^3}$	$\frac{mrem/y}{\mu Ci/cm^3}$	$\frac{mrem/y}{\mu Ci/cm^3}$	$\frac{mrem/y}{\mu Ci/cm^3}$
Dose Rate	mrem/y#	mrem/y#	mrem/y	mrem/y#	mrem/y	mrem/y	mrem/y	mrem/y

*Food pathways divide into sub-paths (not shown).
#Transfer coefficient yields average dose commitment rate during time interval in which integrated dose commitment

TERMOD [Kℓ76] or FOOD [Ba76] may be used to obtain radionuclide concentrations in food per unit deposition rate over the area concerned. It is advantageous to base the terrestrial food on the concept of integrated concentration following an acute deposition, as explained in Section 4.D.2. of Vol. I. There is an equivalence of the ratio of the equilibrium concentration in food (μCi/g) to a unit continuous surface deposition rate (μCi/m^2-day) with the ratio of the integrated concentration in the food (μCi-day/g) to a unit acute surface deposition (μCi/m^2). This equivalence provides for a simple application of terrestrial code output to obtain integrated concentrations. The present implementation makes use of TERMOD output.

First, TERMOD output for a desert grassland environment was needed in addition to the usual output for U. S. average conditions. Table 6 - 16 lists the parameters for which TERMOD input was changed. The desert values are estimates made at UNM by Gosz [Gz76] for the Los Medaños region. The output for desert is used for range grazing meat animals, and the U. S. average data is used for all food categories associated with irrigated agriculture, including above surface food and milk.

Table 6 - 17 lists sample TERMOD output for Sr-90. Consider above-surface food, for example. The equilibrium concentration of Sr-90 corresponding to a unit deposition rate (1 μCi/m^2-day) is 1.92×10^{-2} μCi/g. By the equivalence stated above, this also represents an integrated concentration per unit deposition of 1.92×10^{-2} (μCi-day/g)/(μCi/m^2). Multiplying by 10^4 for m^2 to cm^2 conversion and dividing by 365 for days to y conversion obtains BIOFAC = 0.526 (μCi-y/g)/(μCi/cm^2).

The biofactor for range fed meat production is obtained in the same manner as the deposition component above, using the beef concentrations per unit deposition rate from Table 6 - 17 for the desert condition (0.191 μCi/kg). Similarly, the biofactor for hay fed meat (0.130 μCi/kg) assumes the U. S. average pasture conditions simulate irrigated hay production. Similarly, the biofactor for milk is obtained using the milk concentration per unit deposition rate, 0.672 μCi/liter. The values of BIOFAC for Sr-90 after unit conversions to (μCi-Y/g)/(μCi/cm^2) become:

Table 6-16. TERMOD Input Parameters Changed for Desert Terrain

Parameter	U. S. Avg.	Desert
Pasture area per cow, 10^4 m^2	1.0E+4	2.6E+4
Dry weight areal grass density, kg/m^2	0.15	0.015
Rate of increase in wet muscle mass of steer, kg/day	0.4	0.1
Mass of muscle on steer at time of slaughter (or export), kg	200	100
Density of soil, g/cm^3	1.4	1.6
Deposition fraction to pasture	0.25	0.025
Transfer rates, day^{-1}:		
Above surface food to soil surface	0.0495	0.0243
Grass to soil	0.0495	0.0243
Soil pool to soil sink	1.10E-4	1.0E-5
Pasture soil to soil sink	1.10E-4	1.0E-5
Pasture soil to pasture grass	2.74E-5	5.48E-5

Table 6-17. Sample TERMOD Output, for Sr-90

(Deposition rate: 1 $\mu Ci/m^2$-day)

	U. S. Avg.	Desert
Above-surface food,[a] $\mu Ci/m^2$	1.92	(3.72)[b]
adjusted $\mu Ci/g$	1.92E-2	
Beef, $\mu Ci/kg$	1.30E-1	1.91E-1
Milk, μCi/liter	6.72E-1	(1.97)[b]
Soil surface, $\mu Ci/m^2$	1.31E+3	1.30E+3
Soil pool,[c] μCi	5.11E+6	1.16E+7
adjusted, $\mu Ci/m^2$	5.11E+3	1.16E+4
Soil sink, $\mu Ci/m^2$	1.02E+4	1.75E+3

Notes: a. Dry weight areal density of man's above-surface food is 100 g/m^2.

b. Reference values only; desert not used for man's food crops and milk.

c. Soil pool in μCi in subsurface pool associated with one man's food supply (surface area of 1000 m^2).

Above-surface foods	5.26 E-01
Meat (range fed)	5.23 E-03
Meat (hay fed)	3.56 E-03
Milk	1.84 E-02

The terrestrial biofactor values for the other radionuclides are obtained using corresponding TERMOD output [Wi76].

(2) Water Biofactors. The biofactors for meat and milk contamination from contaminated drinking water are readily calculated. For example, the stable element transfer factor for strontium into meat [NRC76] is 6.0×10^{-4} day/kg which for Sr-90 represents 6.0×10^{-4} (μCi/kg)/(μCi/day). Multiplying this by an average daily water intake per cow, 4.0×10^{5} cm^3/day, and converting from kg to g results in a biofactor of 0.24(μCi/g)/(μCi/cm^3). Similarly, the stable element transfer factor for strontium into milk is 8.0×10^{-4} and a daily water intake per milk cow of 6.4×10^{5} cm^3/day results in a biofactor of 0.512.

The study site in southeast New Mexico contains both fresh water and salt water environments. Available biofactors, obtained for pathways for both of these habitats, are listed in Appendix G. Consumption rates for the several types of aquatic foods (Table 6-14) are not yet known and zero values for this pathway have therefore been entered into AMRAW. However, this is believed here to be a very minor contribution in the Los Medaños area.

(3) Carbon-14. The concentration of C-14 in vegetation is assumed to have the same ratio to the natural carbon in the vegetation as the ratio of C-14 to natural carbon in the atmosphere surrounding the vegetation [Ba76, NRC76, Ng68]. Similarly, the C-14 ratio to natural carbon in animal products is the same as that in the vegetative feed. Table 6 - 18 lists some typical natural carbon fractions [Ba76]. The biofac for C-14 in above-surface foods is then taken to be: air concentration per unit land surface accumulation (approximated by the resuspension factor discussed earlier), divided by the natural carbon fraction in air, and multiplied by the natural carbon fraction F_c in above-surface food. In turn, the resulting value multiplied by F_c for beef and milk yields the corresponding biofactors for C-14 in beef and milk, respectively. The C-14 biofactors for transfer to beef and milk are determined using the stable element transfer factor for carbon, as

Table 6 - 18. Fractions of Natural Carbon in Food and Environmental Media

Food or Fodder	Carbon (Dry)	Carbon (Wet)
	F_c	F_c
Vegetation	0.45	0.090
Grain	0.45	0.40
Beef	0.60	0.24
Milk	0.58	0.070
Poultry	0.67	0.20

Concentration of carbon in water: 0.020 g/liter.
Concentration of carbon in air: 0.16 g/m^3.

described earlier for other elements.

(4) Tabulation of Biofactors. The biofactors obtained for the 25 radionuclides and the 10 mode 2 ingestion subpaths are listed in Appendix J under the variable name "BIOFAC."

(b) Consumption, Exposure and Food Production Rates. This is the second of three factors which make up the environmental pathway transfer coefficients, and is discussed here in the subpath sequence used in Table 6-14. Immersion and inhalation of affected air 100% of the time is assumed. Inhalation rate per individual is 7.30×10^9 cm^3/y (2×10^4 ℓ/d) [Kℓ76]. Direct exposure to contaminated ground by individuals is assumed to average 40% of the time. For the ingestion subpaths associated with land surface contamination, Table 6 - 19 summarizes the production rates for above-surface foods, range fed meat, cultivated land meat (exported hay equivalent), and milk, taken from Appendix H. The latter were developed by the study team, based upon Census of Agriculture [USCB69] data for the area and discussions with Agriculture Economics staff at New Mexico State University [NMSU75].

Submersion in water assumes 10% of the population spends 1% of their time swimming; the corresponding average exposure factor is 0.001. Drinking water for individuals is assumed to be 8.0×10^5 cm^3/y (2.2 ℓ/d)

Table 6-19. Summary of Food Production in Region

(VOLINT input for land surface, ingestion pathways)

	Zone							
	1	2	3	4	5	6	7	8
Above surface food crops, g/y	0	0	1.11E10	3.95E9	2.52E11	1.97E10	5.82E9	2.84E9
Range land meat, g/y	6.30E7	1.18E10	1.81E10	7.60E9	1.02E10	1.38E10	3.27E10	0
Cultivated land meat, g/y	0	0	4.67E8	8.32E8	5.43E9	1.92E9	7.88E9	6.23E9
Milk, cm^3/y	0	0	4.05E9	3.21E9	1.58E10	1.50E10	6.31E10	3.46E10

Notes: Zones 1, 2, and 8 are components of Eddy County; Zone 1 is the repository site and Zone 8 is the irrigated area.

Exported hay is assumed to go 75% to beef conditioning operations and 25% to dairies.

[Kℓ76], divided between surface water and ground water sources as listed in Table 6-20. It should be noted that consumption of ground water in a particular zone can be only partially from a contaminated source. The contaminated plume downflow from the repository lies beneath a surface area equal to an effective plume width multiplied by the distance traveled in the zone. On this basis, the postulated contaminated plume in Zone 2 lies under a fraction of 0.006 times the total area of Zone 2. Assuming a random drilling of water wells, a fraction of 0.006 times the individual intake rate of 8.0×10^5 cm^3/y results in an average of 4.80×10^3 cm^3/y for individuals in Zone 2 from contaminated ground water, as listed in Table 6-20.

Meat and dairy animals are assumed to consume drinking water from surface and ground sources with the same fractions listed in Table 6-20. The "production rate" of meat associated with surface drinking water in a particular zone equals the total meat production rate for the zone, not including meat from exported hay, from Table H-1 (Appendix H), multiplied by the drinking water surface source fraction from Table 6-20. Milk is treated similarly.

Production rates for aquatic foods are not currently available and these are input with zero values.

Ingestion of drinking water by man from contaminated ground water sources is in accordance with Table 6-20; associated meat production is determined in a manner similar to that used with surface water (meat production rate for the zone multiplied by the contaminated ground water source fraction from Table 6-20).

The resulting matrix of factors is listed in Appendix J under the variable name "VOLINT."

(c) Dose Rate Factors. The last of three factors comprising the environmental pathway transfer coefficients is the dose rate factor which converts from external exposure concentrations (mode 1) or nuclide intake rates (mode 2) to annual dose commitments to various organs. Dose commitment from a given intake of a radionuclide is the integrated dose over a period of time subsequent to intake. The integration period is generally taken to be 50 y. For external exposure, dose commitment rates are simply the instantaneous rates as there is no persistence of

Table 6-20. Water Intake Per Person, cm^3/y

Zone	Surface Water		Total Ground Water		Contaminated Ground Water		Noncontaminated Ground Water	
	Fraction	cm^3/y[a]	Fraction	cm^3/y	Fraction	cm^3/y[b]	Fraction	cm^3/y
1	0	0	0	0	0	0	0	0
2	0.50	4.00E5	0.50	4.00E5	0.006	4.80E3	0.494	3.95E5
3	0.25	2.00E5	0.75	6.00E5	0	0	0.75	6.00E5
4	0	0	1.00	8.00E5	0	0	1.00	8.00E5
5	0	0	1.00	8.00E5	0	0	1.00	8.00E5
6	0	0	1.00	8.00E5	0	0	1.00	8.00E5
7	0.50	4.00E5	0.50	4.00E5	0	0	0.50	4.00E5
8	0.50	4.00E5	0.50	4.00E5	0.025	2.00E4	0.475	3.80E5

[a]VOLINT input for surface water ingestion pathway.

[b]VOLINT input for ground water ingestion pathway.

dose rate once the external source is removed. The modes listed in Table 6-15 are summarized in Table 6-21 along with the units for the corresponding dose conversion factors. The modes listed in Table 6-21 are: immersion and inhalation for air, direct exposure to contaminated land surface, submersion in contaminated water and ingestion of contaminated food or water. The eight organs selected for calculation are: total body, GI tract, gonads, liver, lungs, bone marrow, bone, and thyroid. Wherever possible, dose factor values used for this application are taken from ORNL-4992 [Kℓ76]. Internal (inhalation and ingestion) dose factors for Zr-93, Nb-93m, Tc-99, and Cs-135 (and for ingestion of C-14) are from NUREG-0172 [Ho77]. Also, most of the internal factors for thyroid and ingestion for lung are from NUREG-0172. From half to two-thirds of the internal factors (except for GI tract and thyroid) are from ERDA-1541 [ERDA76b]. This latter source uses 70 y dose commitments instead of the 50 y period used in the previous two sources. Also, most of the factors for dose to gonads are from ERDA-1541. Missing data for gonads was approximated by whole body data where deemed appropriate and bone data was used as default data for missing bone marrow values. Appendix J lists the dose factors under the variable name "DOSFAC," for all of the nuclides, exposure modes, and affected organs included in this study. Table 6-21 aids in identifying nomenclature in Appendix J.

(d) Other Potential Pathways. One additional pathway which could be added is that from ground surface to upland birds to man. Biofactors have not yet been found for this pathway. Other minor pathways include other hunted game species, and animal species attracted to human dwellings. Any changes in species populations in response to releases of radioactivity could have some effect on the vegetation types and indirectly shift the potential transfer of radioactivity to man. This is discussed further in Appendix I. Effects of this type may be investigated in AMRAW by input of variables reflecting any projected shift of conditions.

Table 6-21. Summary of Dose Modes and Dose Conversion Factor Units

---

<u>Air</u> (JF = 1)

Mode 1. Immersion, $\frac{\text{mrem/y}}{\mu\text{Ci/cm}^3}$

Mode 2. Inhalation, mrem/μCi

<u>Land Surface</u> (JF = 2)

Mode 1. Direct exposure, $\frac{\text{mrem/y}}{\mu\text{Ci/cm}^2}$

Mode 2. Ingestion, mrem/μCi

<u>Surface Water</u> (JF = 3)

Mode 1. Submersion, $\frac{\text{mrem/y}}{\mu\text{Ci/cm}^3}$

Mode 2. Ingestion, mrem/μCi

<u>Ground Water</u> (JF = 4)

Mode 1. Ingestion, mrem/μCi

Mode 2. Ingestion, mrem/μCi

D. CALCULATED DOSE RATES

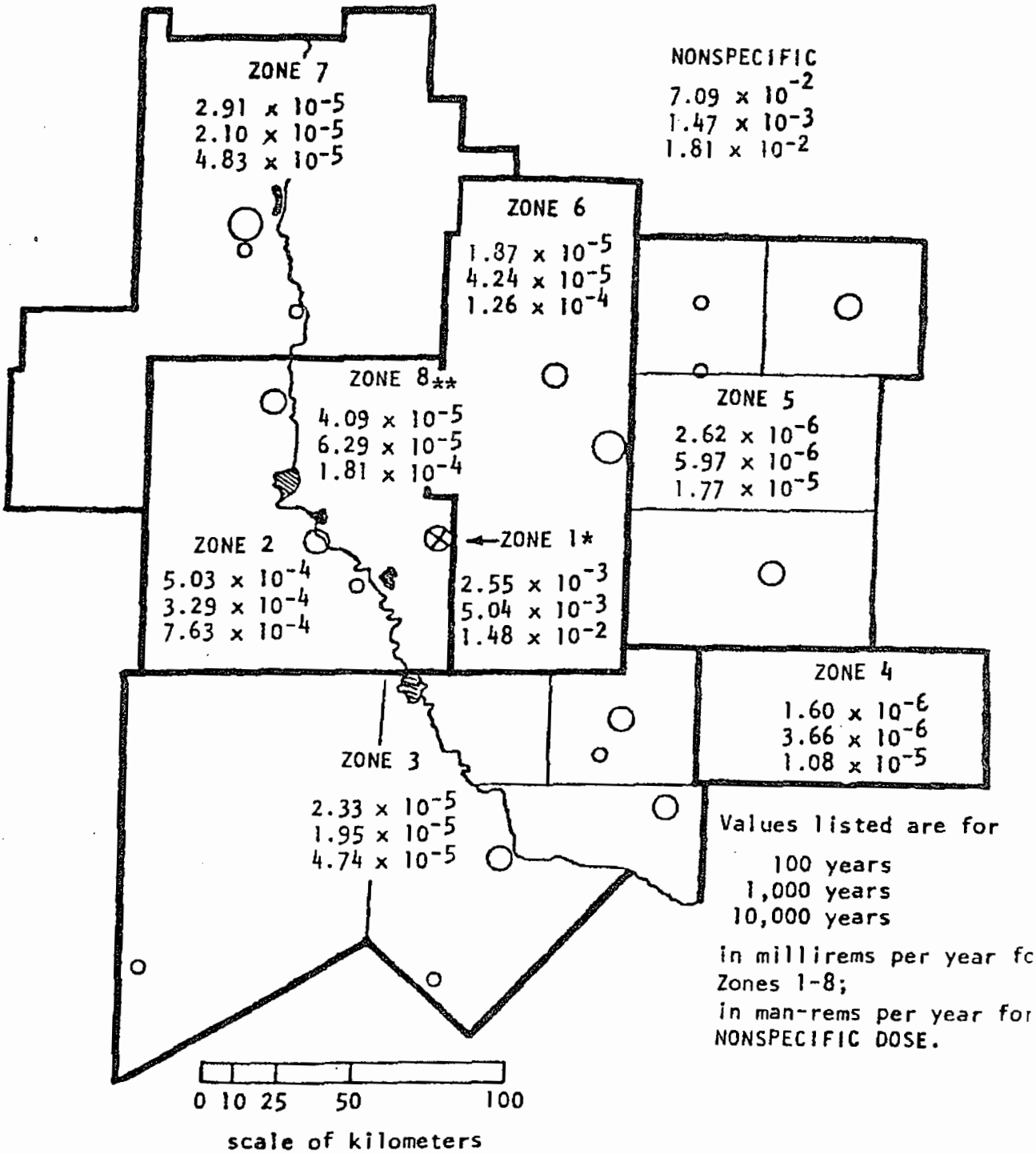
The Base Case AMRAW-A computer run for terminal storage at the Los Medaños site is designated Case 48 and the output calculations for this case are presented here in some detail. This case evaluates the potential releases of radioactivity on a probabilistic basis from all of the release event combinations described earlier in the Release Model Section 6.B.

One computer run with full output option, for 25 nuclides, 8 organs and 8 zones, produces 627 tables of calculated output (see Table J-1 in Appendix J). Several types of summaries are used here to both present sample sets of output and to collect output in a condensed form.

The map in Figure 6-15 indicates total body dose rates totaled for all nuclides, in each zone and for the non-specific category, at times of 100, 1,000, and 10,000 years. Local dose rates in each zone are millirems per year to an individual in the zone, and nonspecific dose rates are man rems to a dispersed population.

Zones 1, 8 (and in one table: Zone 6) and nonspecific are used for sampling the output in more detail. Zone 1 (5 km radius around the site) is of interest because any violent event which transports waste material to the surface results in the highest calculated concentration and associated dose rates in this zone. It should be noted, however, that the only environmental pathways considered for this zone are: air immersion and inhalation, direct ground exposure, and range grazed meat production (site exclusion to grazing is assumed to be only temporary). Zone 8 on the other hand (irrigated corridor along the Pecos River) involves <u>all</u> pathways except range animals and is the zone which ultimately receives surfacing ground water which has passed over the site. The nonspecific category collects effects on agricultural commodities from all of the zones (largely exported to consumers outside of the study region) and partly represents consequences outside of the region as well as within.

Sets of computer output for two radionuclides are in Appendix K. Results for one fission product (Tc-99) and one heavy metal (Pb-210) are presented, with all tables for Zones 1, 8, and the nonspecific category included. Output listing of the corresponding major AMRAW input is in Appendix J.



* Zone 1 is a 5 km radius area centered on the Los Medaños site.

**Zone 8 is a 4 km wide corridor centered on the Pecos River in Eddy County.

Figure 6-15. Calculated total body dose rates for all nuclides.

Figures 6-16 through 6-34 collect sample results in various combinations for comparison purposes.

Figures 6-16 and 6-17 are plots of local dose rates in Zone 1 and nonspecific, respectively, for each organ, totaled for all nuclides. More complete data are listed in Appendix L where summary tables for Zones 1, 8, and "nonspecific" list dose rates to each of the 8 organs considered, from each of the 25 radionuclides, at times of 40 (10 years after closing the repository), 100, 10^3, 10^4, 10^5 and 10^6 years. All of the other figures described in the following paragraphs are for total body dose rates. Results indicate breakthrough of Np-237 in ground water, commencing at about 700,000 y in Zone 2 (downflow from the repository). This causes the steep turnup near 10^6 y in Fig. 6-17 for nonspecific dose (partially from Zone 2). This characteristic result is apparent in some other figures described in following paragraphs. If the time range of calculations were extended beyond 10^6 y, it would be found that these curves would level off above 10^6 y and then decline. A given increment of Np-237 release peaks in Zone 2 after approximately 1.1×10^6 y. It should be recalled that the ground water seepage velocity used in this study was conservatively taken to be 6 times the estimated value; if a less conservative factor of 4 were used instead of 6, the Np breakthrough would not occur within 10^6 y.

Figures 6-18 through 6-23 are plots of total body dose rates in Zone 1. The first two figures are for fission products and the last four are for the heavy metal nuclides, grouped into the four decay series (Th, Np, U, and Ac).

Some irregularity in the curves is related to the sizing of time increments. The size of time increments jumps by a factor of 10 at the beginning of each decade in the time scale. Figure 6-22 for the uranium series, clearly illustrates the effects of sequential buildups of Th-230, Ra-226, and Pb-210 as the precursors Am-242m, Cm-242, and Pu-238 decline.

Figures 6-24 through 6-31 are corresponding plots and additional summaries for the nonspecific category. That is, Figs. 6-24 and 6-25 are for fission products and Figs. 6-26 through 6-29 are for the four decay series. Figure 6-30 is a summary which shows that only six nuclides

comprise almost all of the total nonspecific dose rate. Cs-137 and Sr-90 are virtually the total up to 400 years; Am-241 and Am-243 are the major contributors from 400 years to 5000 years; Tc-99 and Ra-226 take over for times after 5000 years, and Np-237 moves in as 10^6 y is approached. Figure 6-31 presents contributions from minor heavy metals

Figures 6-32 through 6-34 are plots of total body dose rates, totaled for all radionuclides, broken down by contributions from each o the four environmental receptors: air, ground surface, surface water, and ground water, and their total. Figure 6-32 is local dose rates in Zone 2; here, a prominant Np breakthrough appears in ground water after 700,000 y as Zone 2 is downflow from the repository. Fig. 6-33 is loca dose rates in Zone 6. These two zones are of comparison interest as their centers are roughly the same distance from the repository site an they are both primarily desert terrain. However, 50% of drinking water in Zone 2 is assumed to be from surface water and 50% from ground water while no surface sources of drinking water is assumed in Zone 6 and gro water in this zone is in a direction which cannot become contaminated. Figure 6-34 is the corresponding plot of nonspecific dose rates (accumulated from all zones). Note that air is not a contributing receptor fo the nonspecific category. Ground water begins to show a significant contribution after 10^4 y as Tc-99 breaks through in Zone 2, followed by Np-237 breakthrough after 700,000 y.

Chapter 7 describes other cases in which selected parameters are varied in the probabilistic mode for sensitivity analysis purposes and discrete events at specific times provide for consequence analysis.

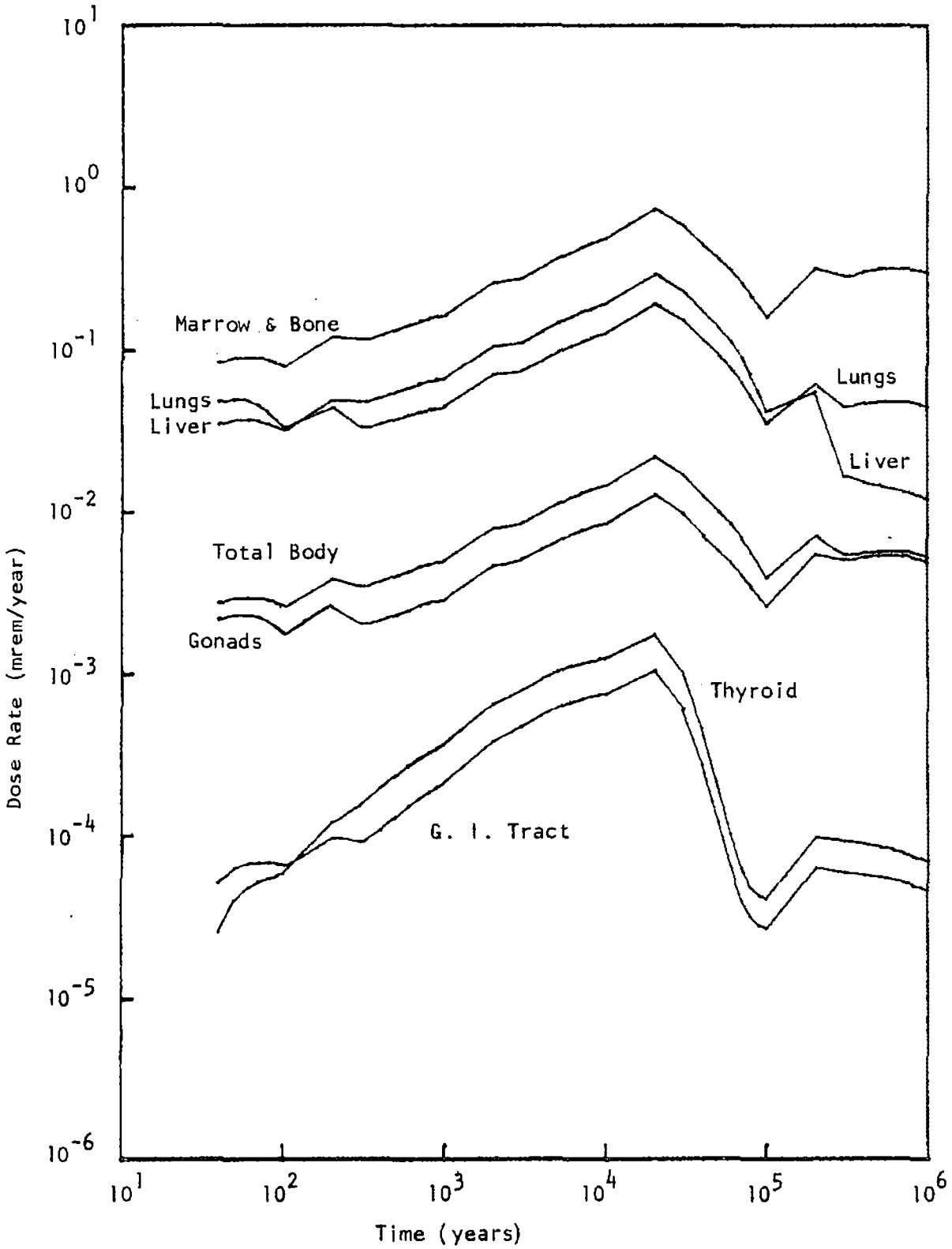


Figure 6-16. Average annual local dose to individual for each organ in Zone 1 from all nuclides.

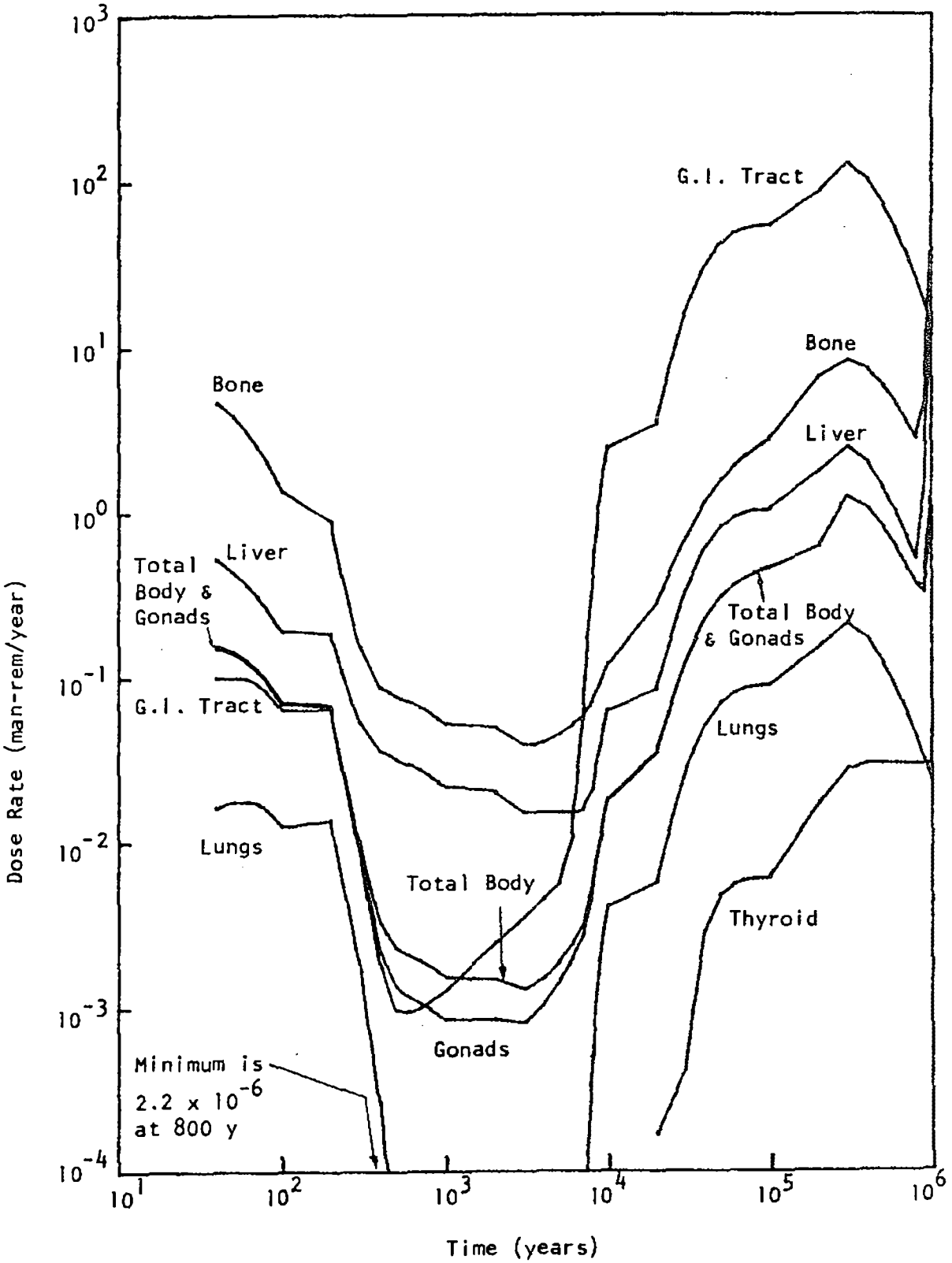


Figure 6-17. Average annual nonspecific dose to population for each organ from all nuclides.

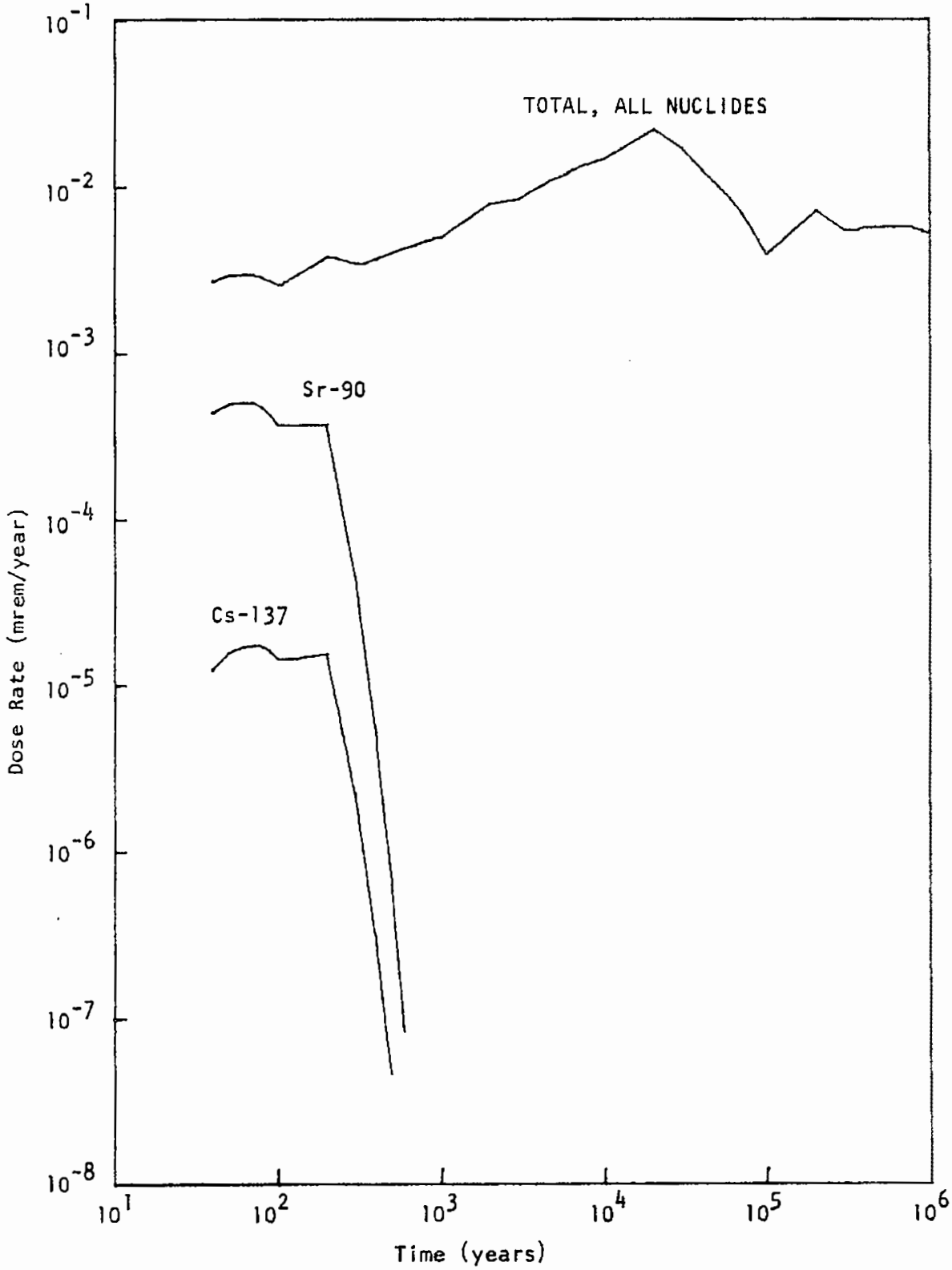


Figure 6 - 18. Average annual local total body dose to individual in Zone 1 from fission products.

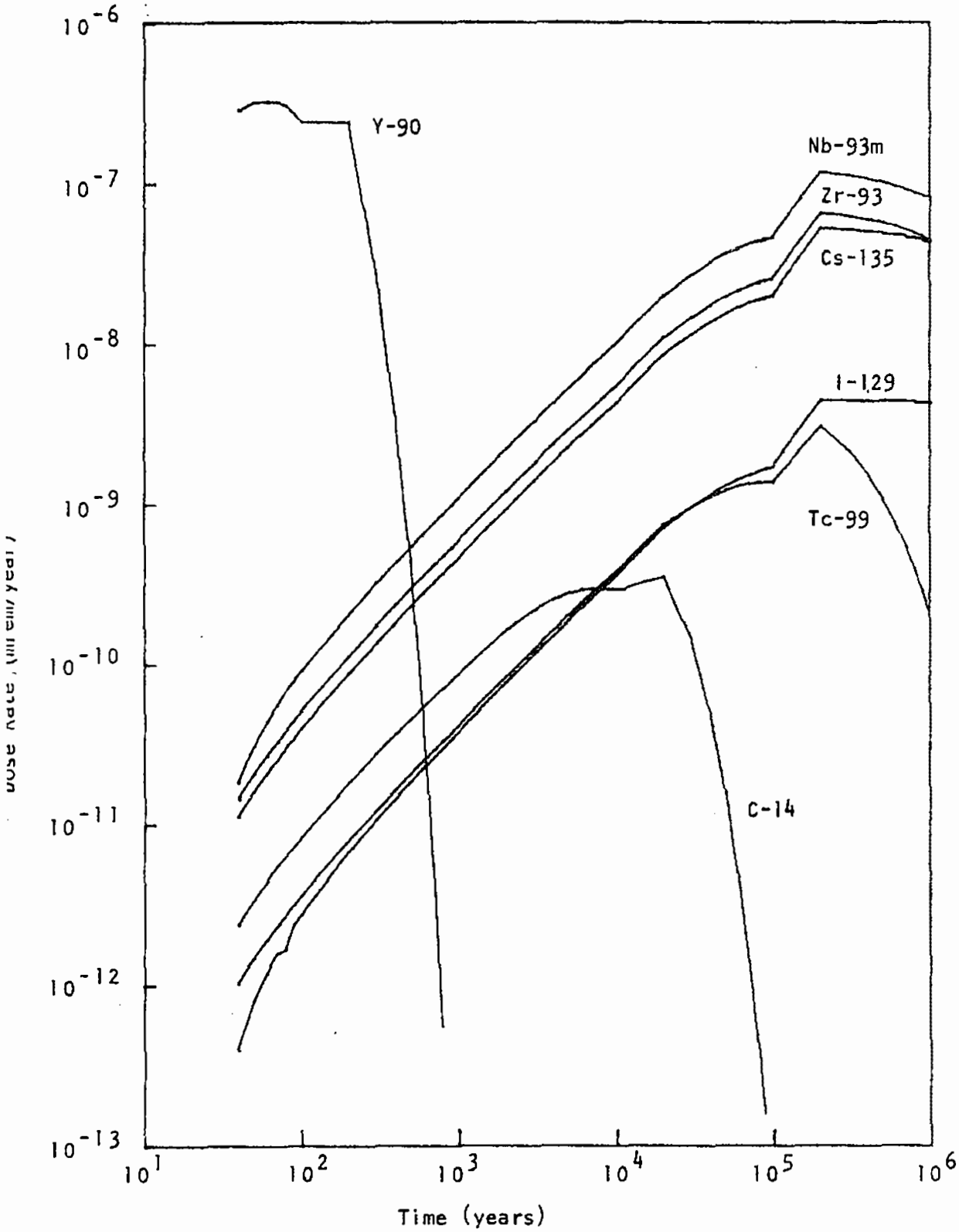


Figure 6-19. Average annual local total body dose to individual in Zone 1 from minor contributing fission products.

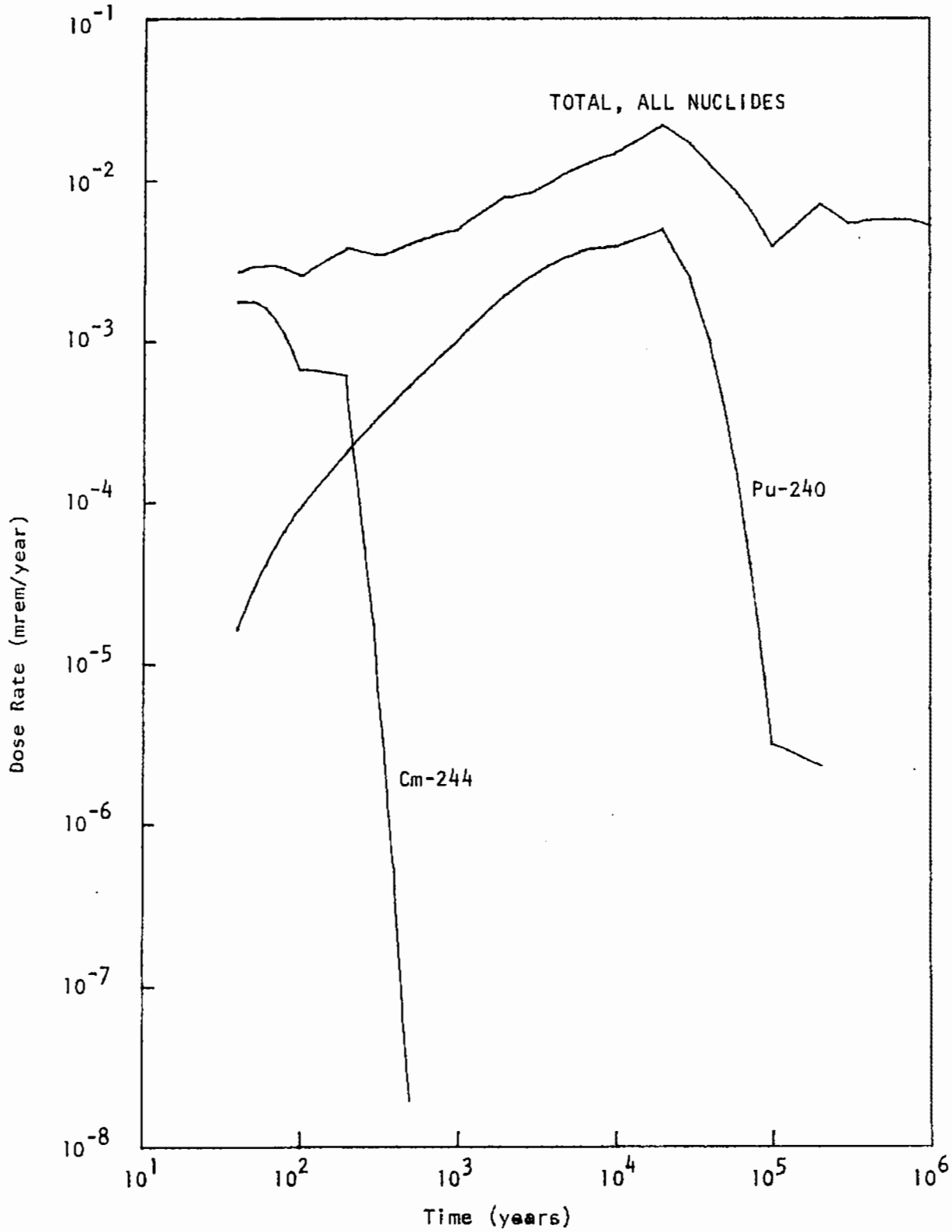


Figure 6-20. Average annual local total body dose to individual in Zone 1 from thorium series.

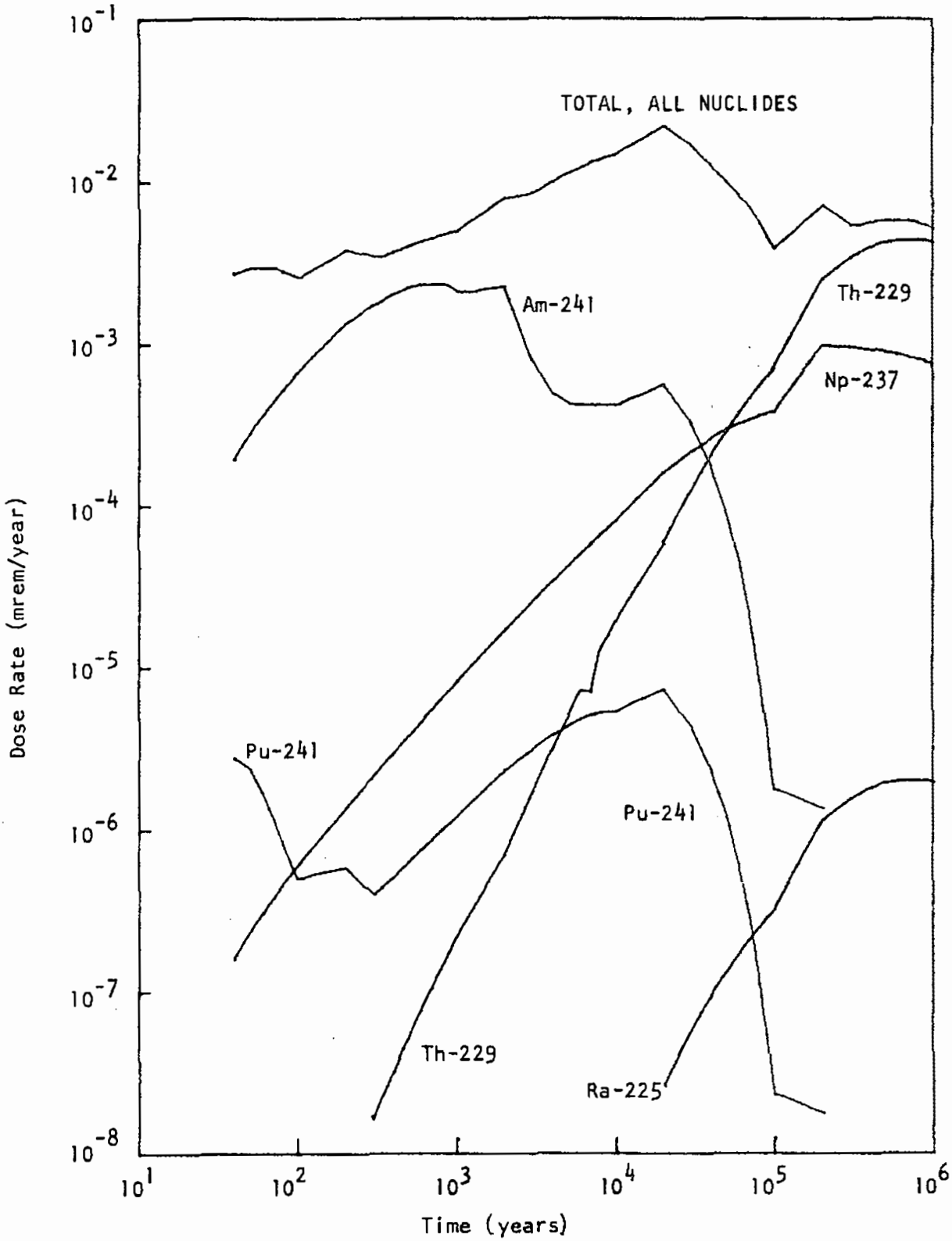


Figure 6- 21. Average annual local total body dose to individual in Zone 1 from neptunium series

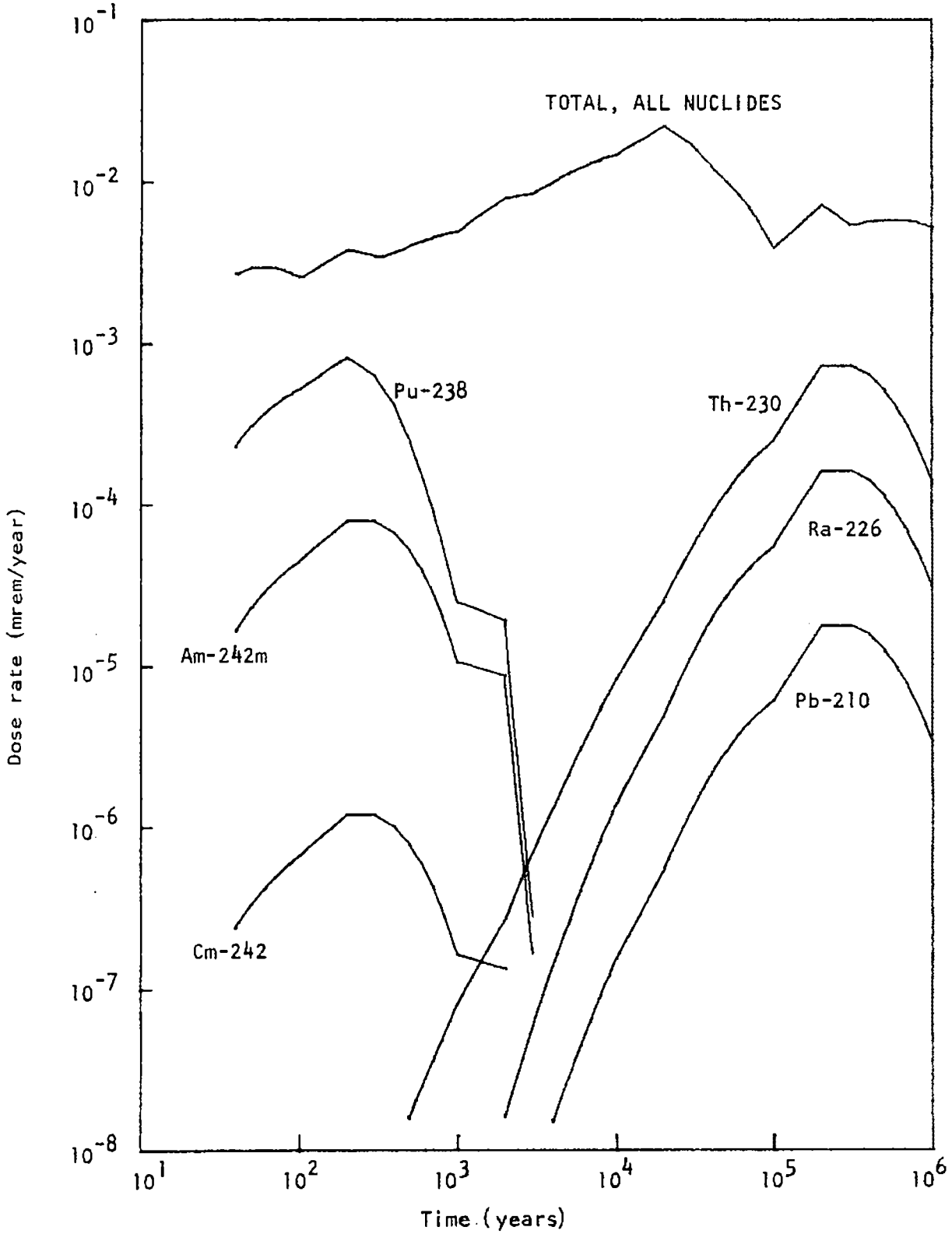


Figure 6 - 22. Average annual local total body dose to individual in Zone 1 from uranium series.

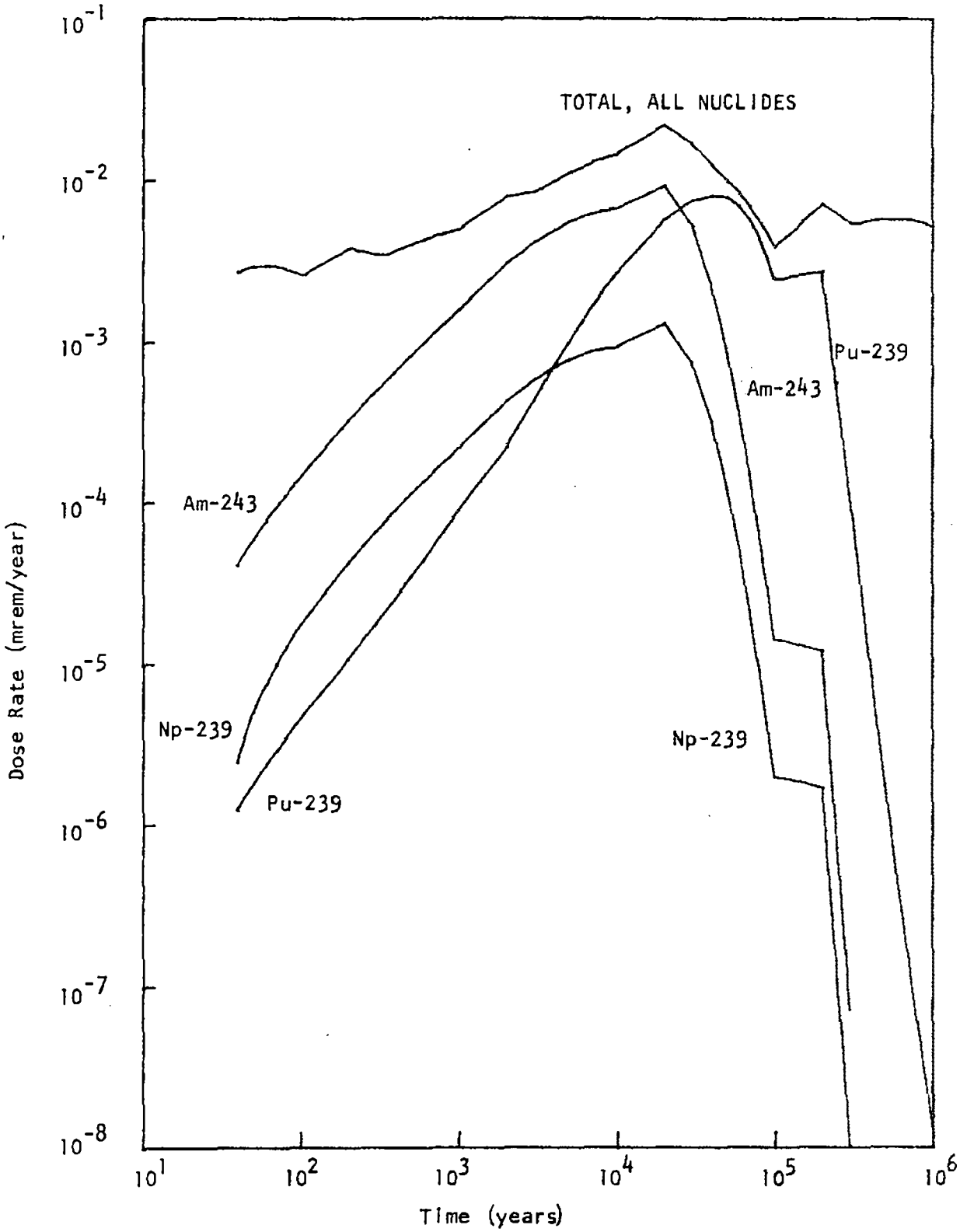


Figure 6 - 23. Average annual local total body dose to individual in Zone 1 from actinium series.

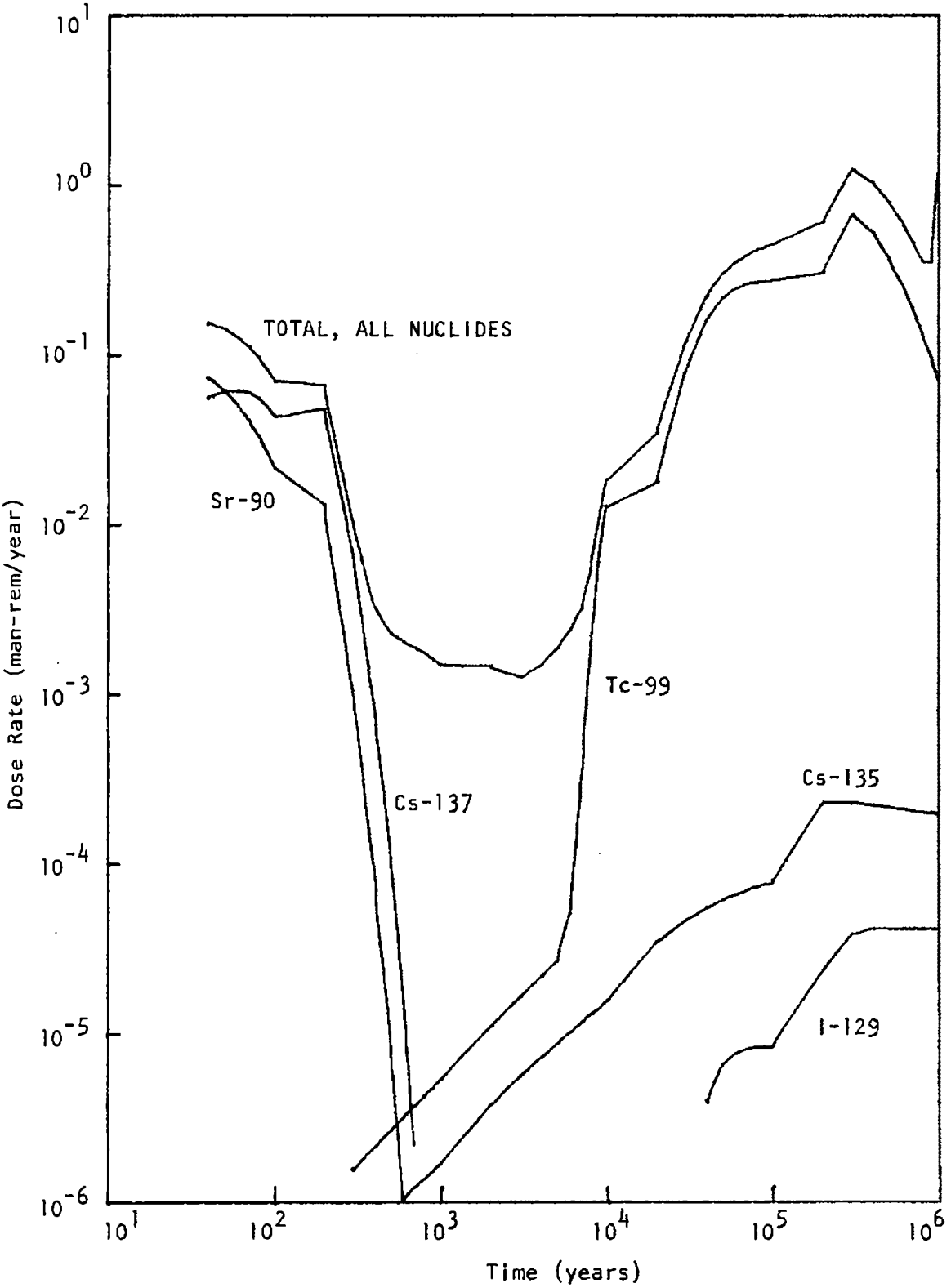


Figure 6-24. Average annual nonspecific total body dose from fission products.

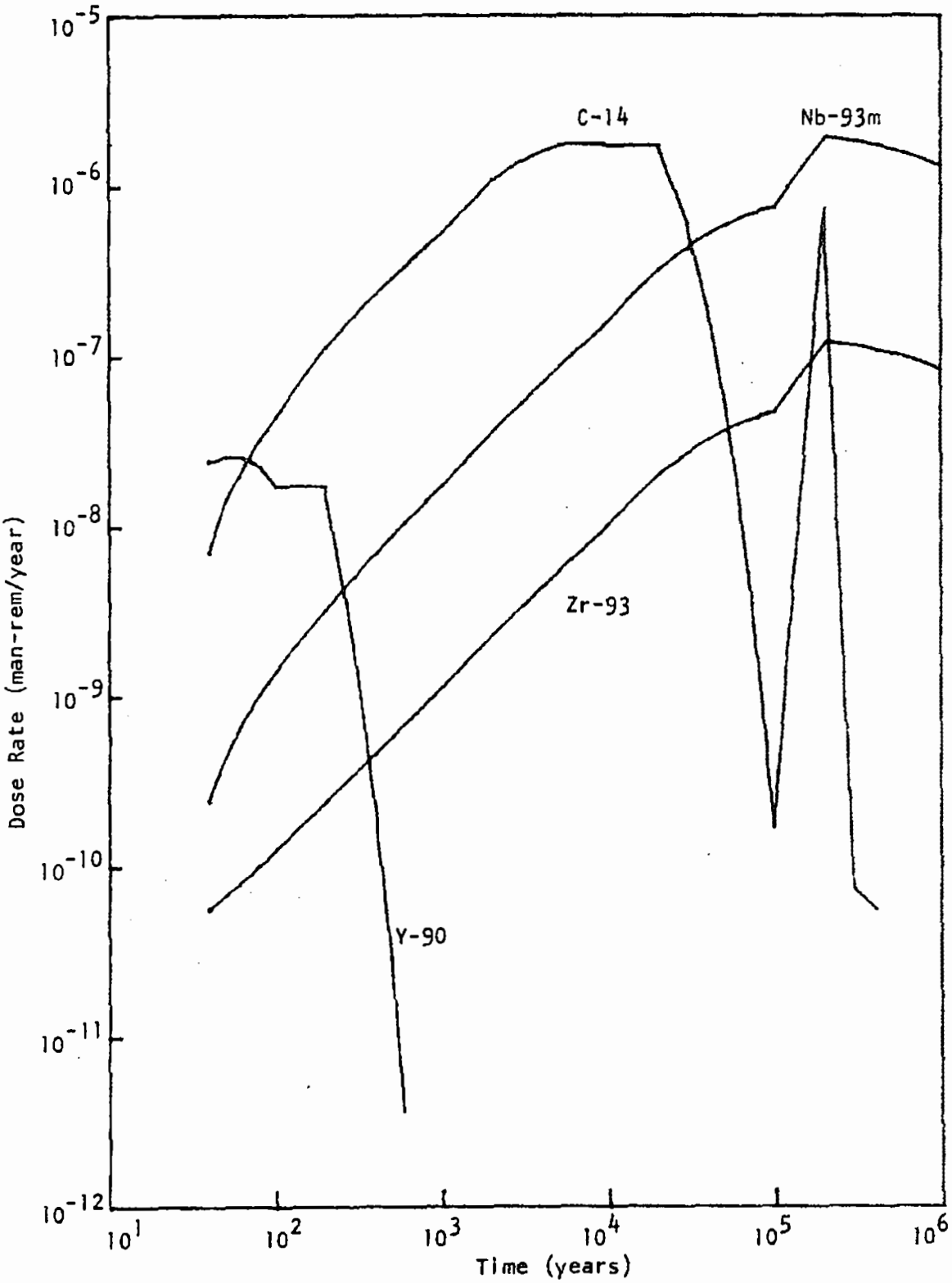


Figure 6 - 25. Average annual nonspecific total body dose from minor contributing fission products.

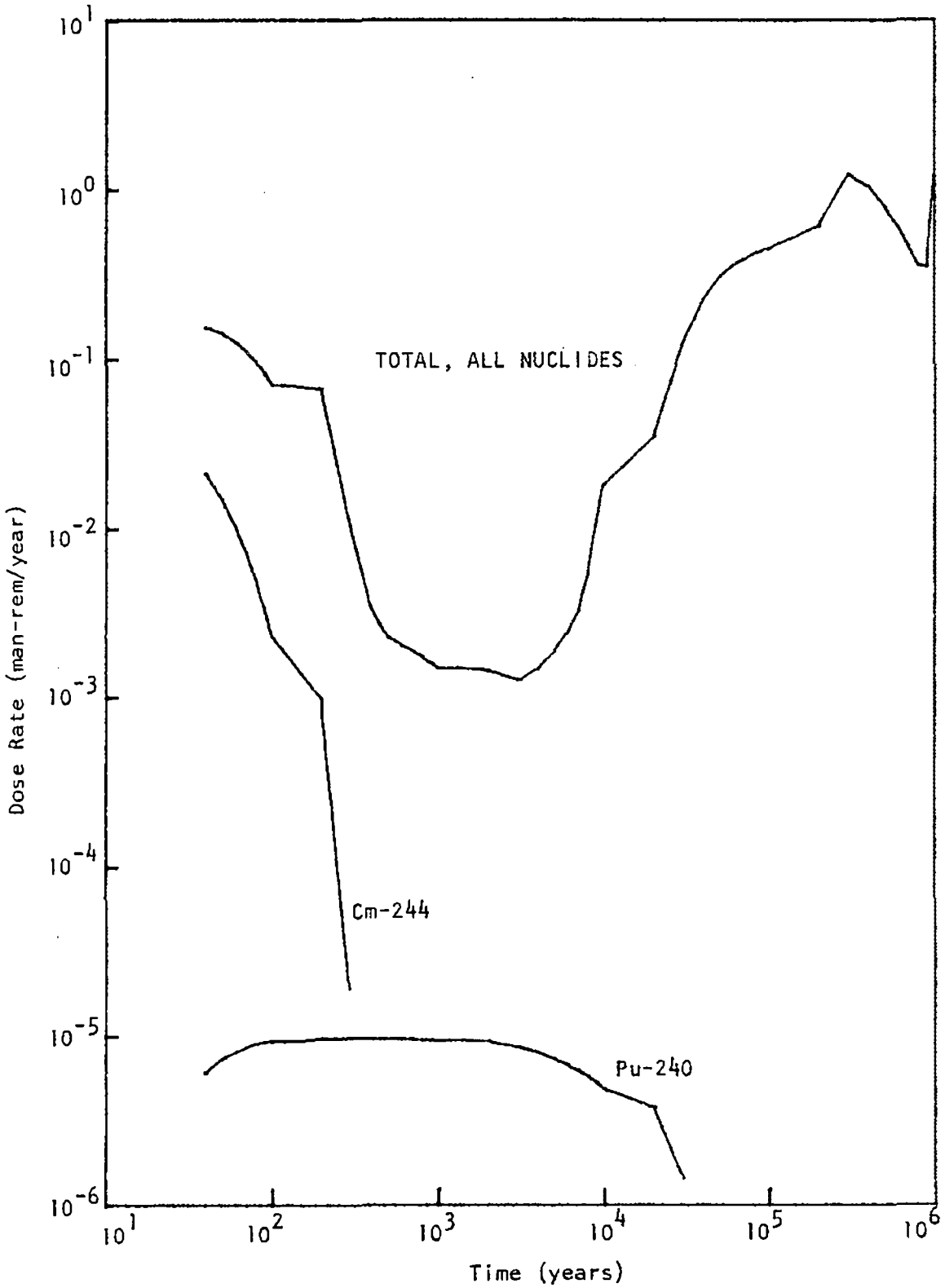


Figure 6 - 26. Average annual nonspecific total body dose from thorium decay series.

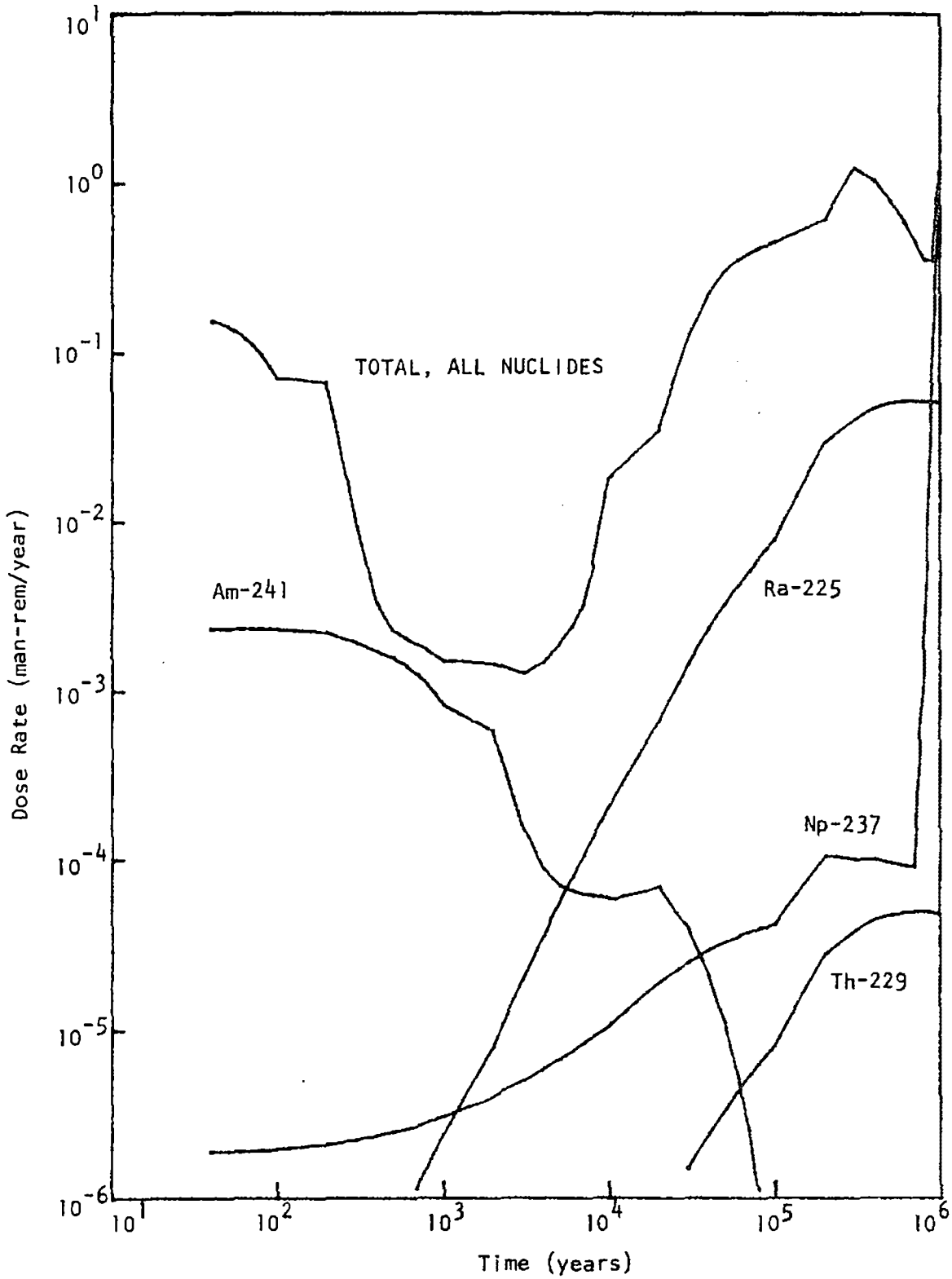


Figure 6 - 27. Average annual nonspecific total body dose from neptunium decay series.

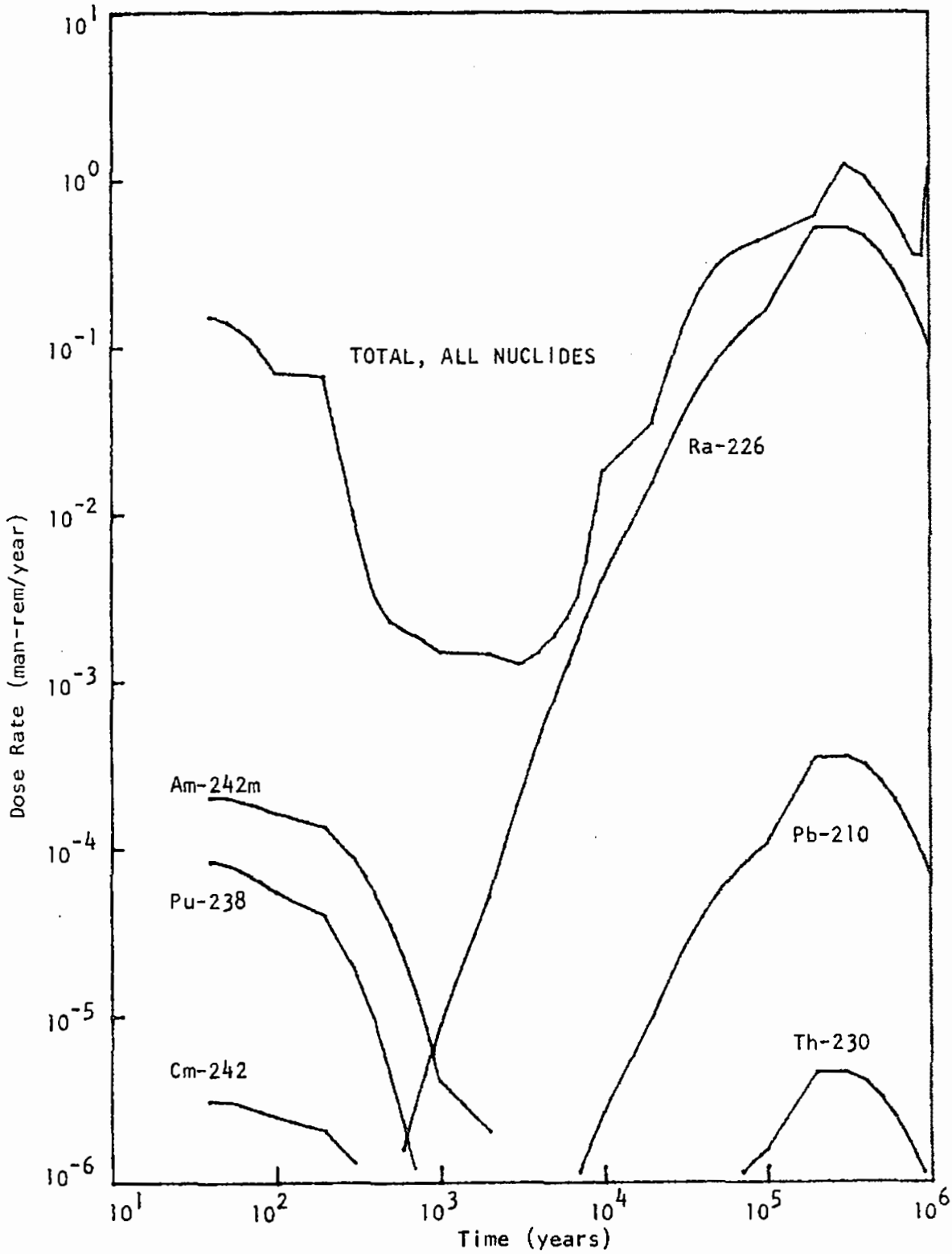


Figure 6-28. Average annual nonspecific total body dose from uranium decay series.

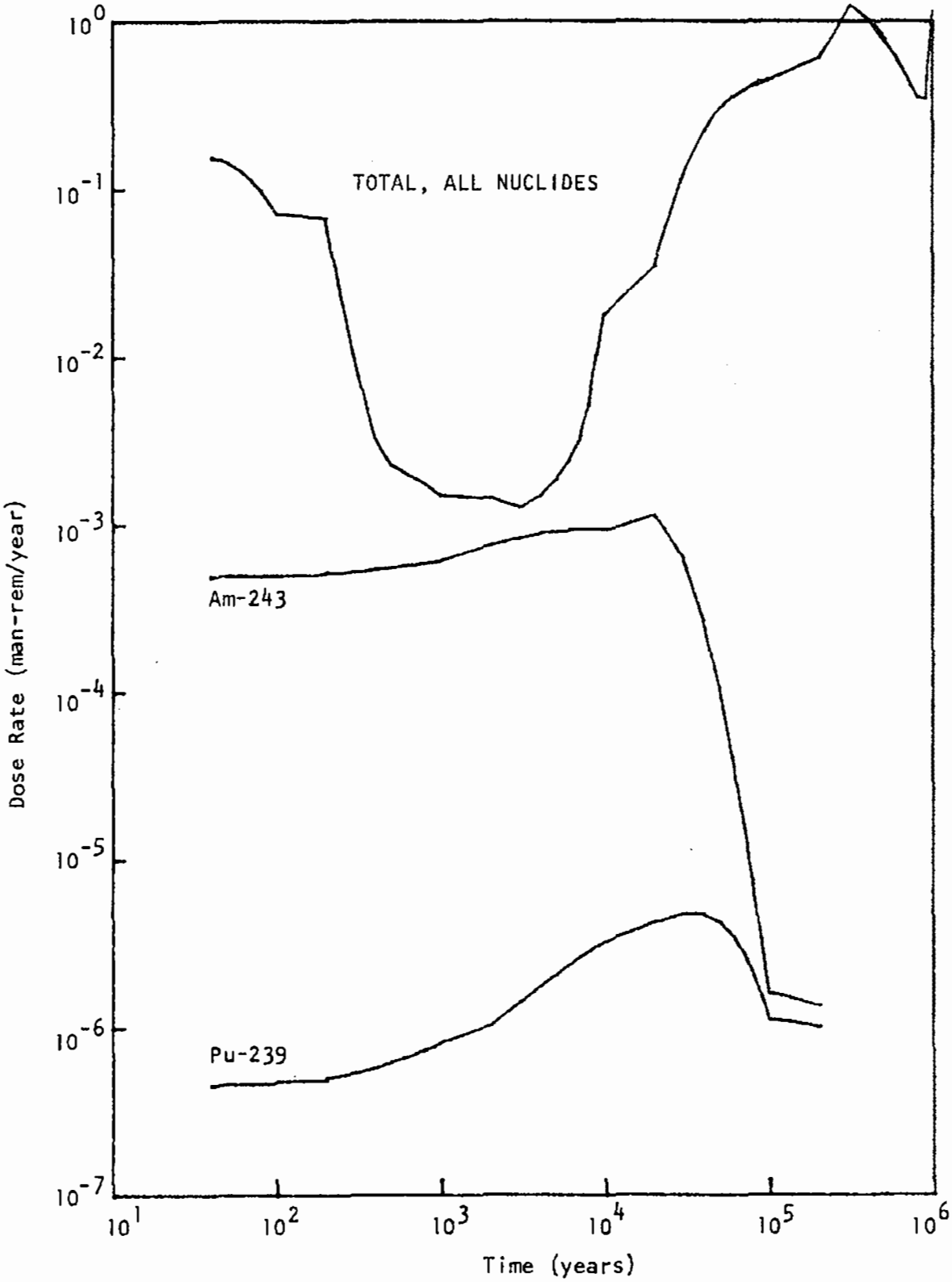


Figure 6 - 29. Average annual nonspecific total body dose from actinium decay series.

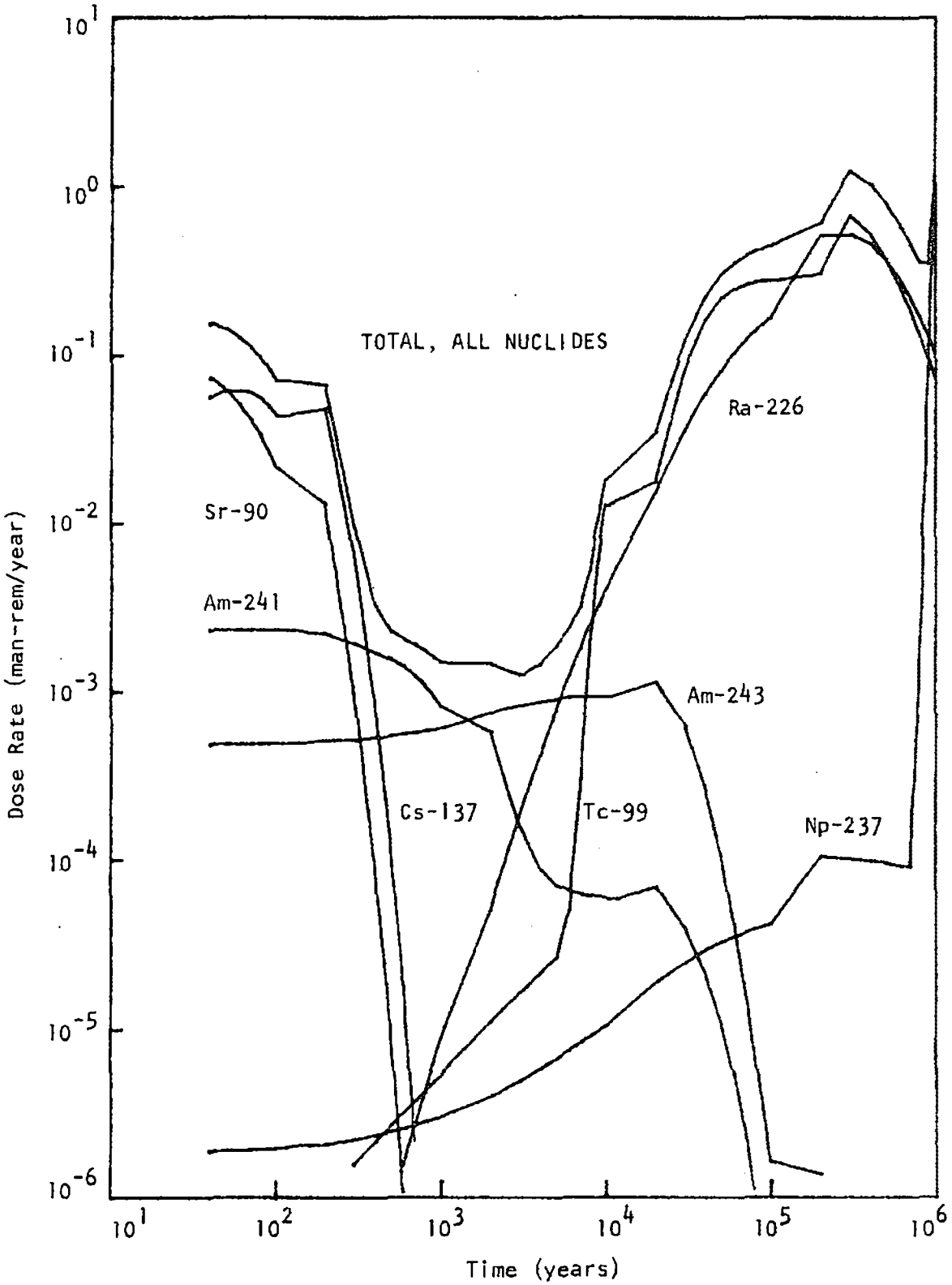


Figure 6 - 30. Average annual nonspecific total body dose from major contributing nuclides.

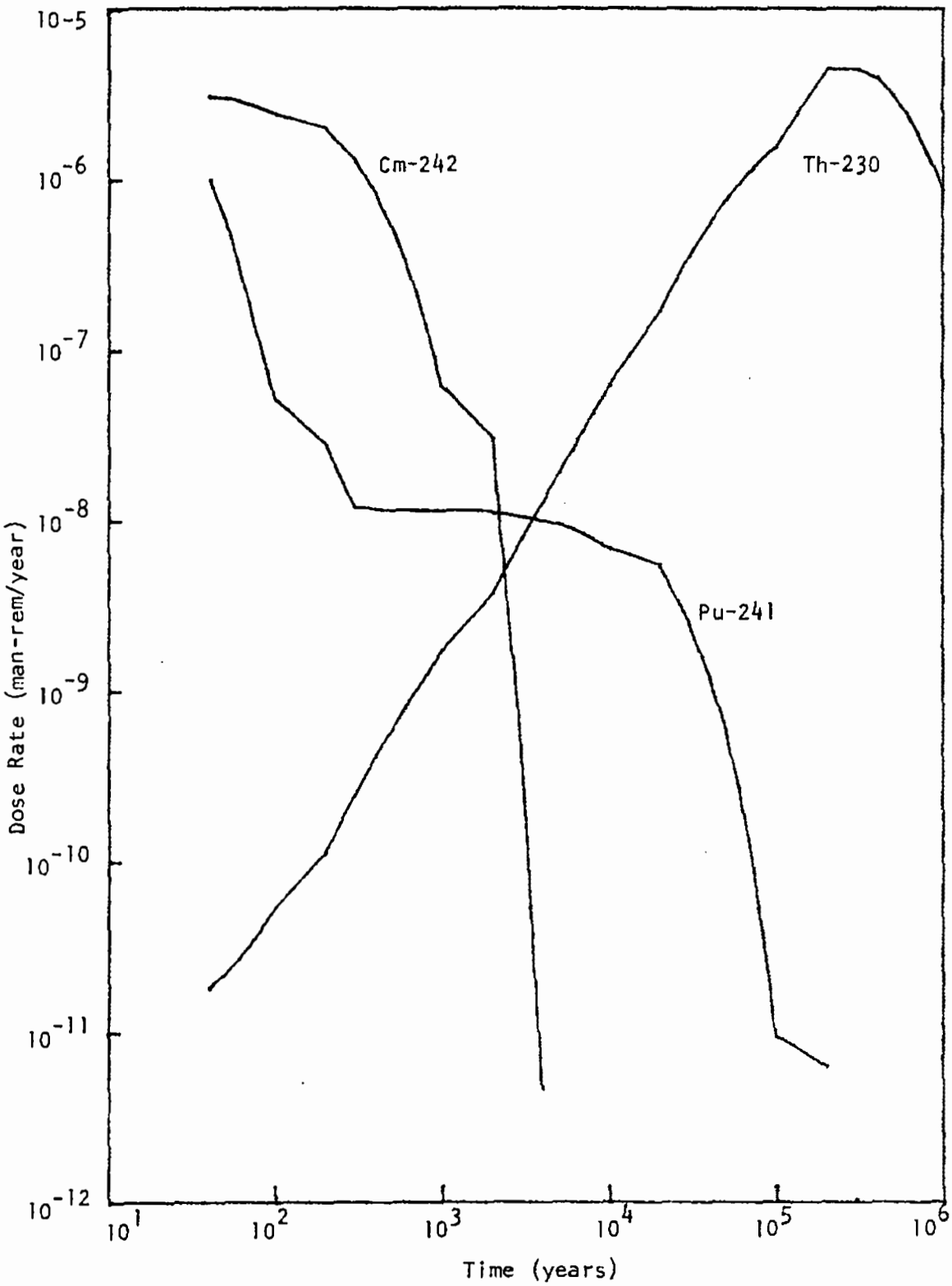


Figure 6 - 31. Average annual nonspecific total body dose from minor contributing heavy metals.

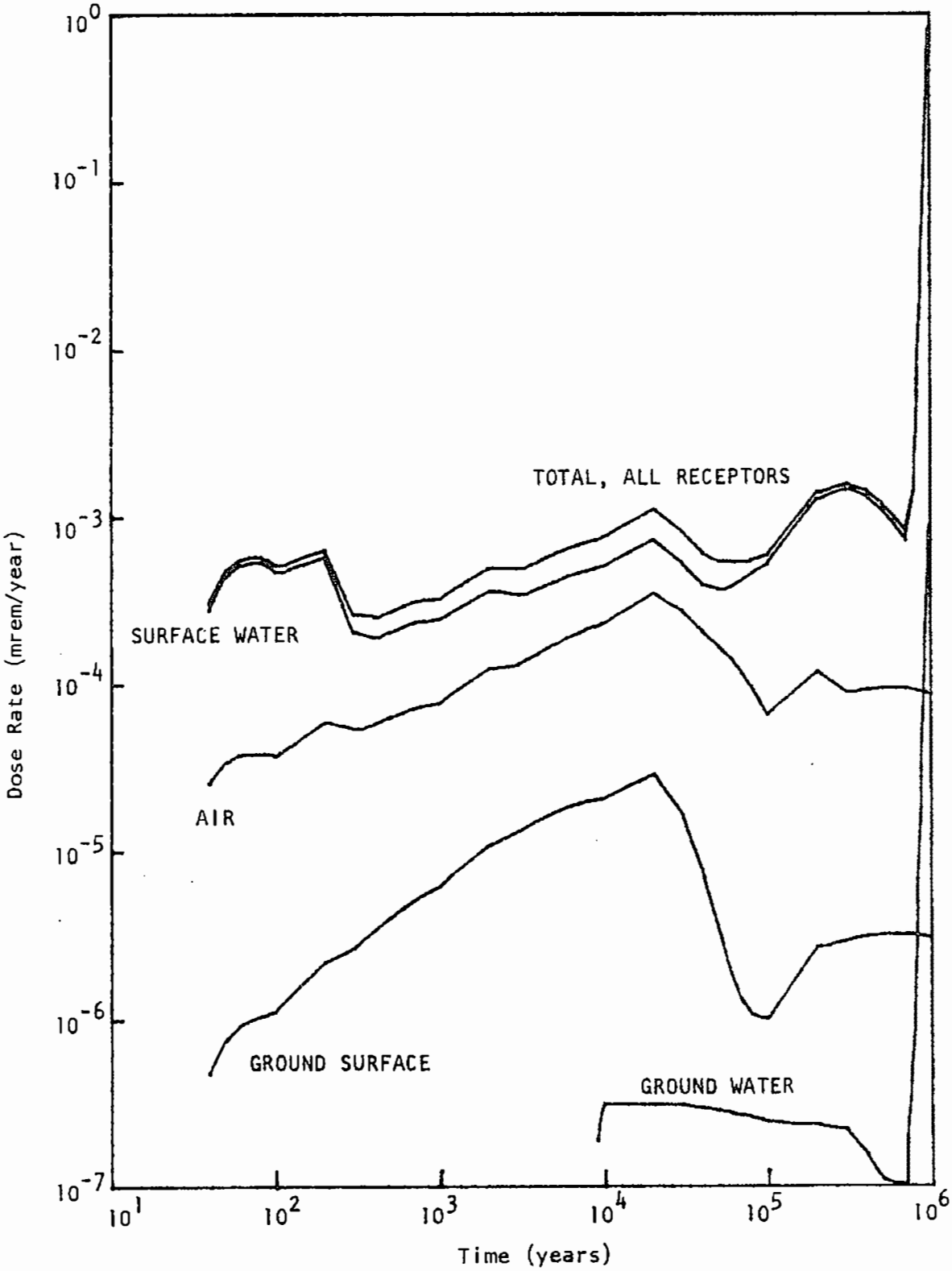


Figure 6 - 32. Average annual total body dose in Zone 2, total all nuclides by receptor.

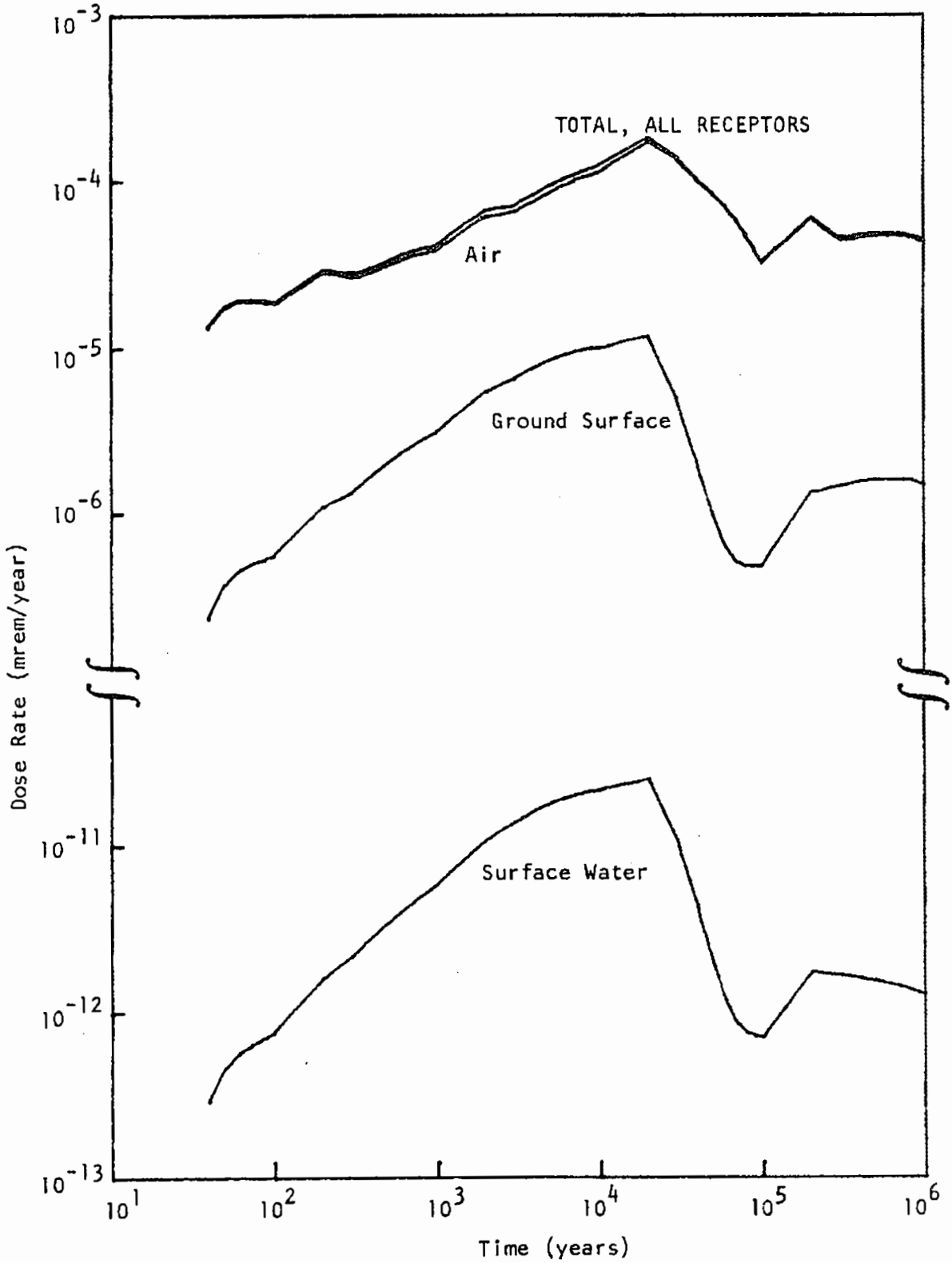


Figure 6-33. Average annual total body dose in Zone 6, total all nuclides by receptors.

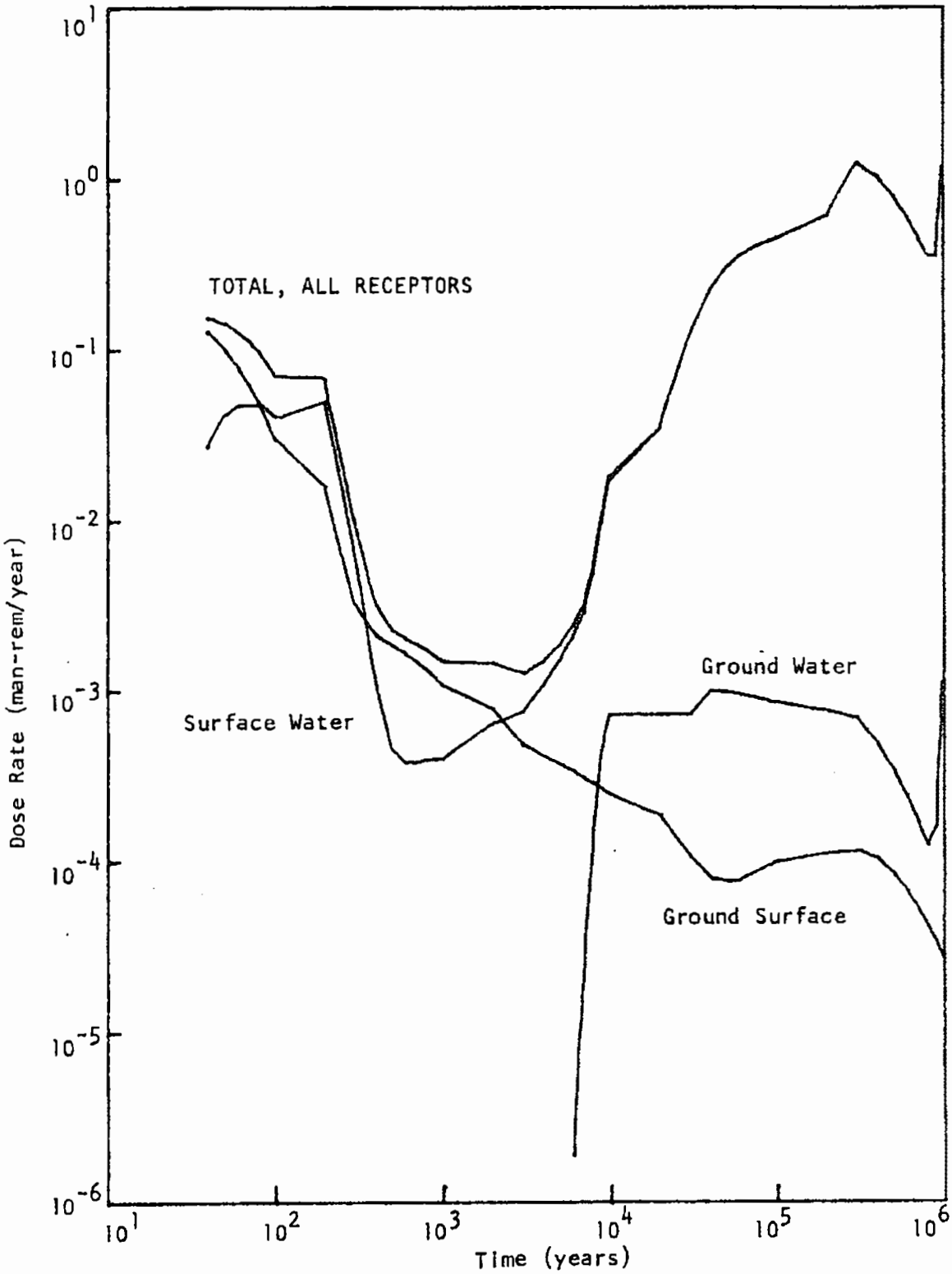


Figure 6-34. Average annual nonspecific total body dose, total all nuclides by receptors.

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CHAPTER 7

IMPLEMENTATION OF MODEL: OTHER CASES

The base case described in Chapter 6 is a computer run in the probabilistic mode in which several geologic disturbance events are considered. The probabilistic distribution represents operation of AMRAW in a risk mode. Additional cases which consider individual release scenarios or which use different values for one or more of the parameters input to the code are helpful in identifying the more important contributors to risk. These additional cases comprise a sensitivity analysis, presented in this chapter.

Another category of cases described in this chapter considers discrete release events occurring at various times, comprising a consequence analysis. This mode can also be considered to be sensitivity analysis in that the consequence response to various times of initiation and to changes in certain parameters is studied.

A. SENSITIVITY ANALYSIS

The sensitivity analysis is done using two approaches: 1) operation of the complete AMRAW-A code with varied input, and 2) operation of an auxiliary program, consisting of the leaching and ground water transport sub-programs from AMRAW-A, with varied input. Each of these approaches is described in the following paragraphs. A structured sensitivity analysis requires agreement on the output parameter to be used as an indicator. With approximately 600 output tables for each computer run, it is possible to demonstrate only with a few important parameters. With a selected indicator, output can be reduced to keep a structured analysis within reasonable bounds.

1. AMRAW Sensitivity Analysis Cases. The 10 release scenarios considered by the base case (Case 48) described in Chapter 6 are summarized in Table 6-4. A first step for sensitivity analysis purposes is to conduct computer runs for different single release scenarios (cut sets) or combinations to determine relative contributions by each to the total. The cases selected here are summarized in Table 7-1.

Table 7-1. Summary of Sensitivity Analysis Cases for Volcanism and Meteorite Impact

Case No.	Cut[a] Set(s)	Release to Receptor	Event
48	1-10	All	All (Base Case)
22	2	Air	Direct expulsion by volcanic explosion
23	6	Land Surface	Volcanogenic transport to surface
24	9	Surface Water	Volcanogenic transport to surface
25	2,3,6,9	Air, Land Surface & Surface Water	All volcanism (including diatreme)
26	1,5,8	Air, Land Surface & Surface Water	Meteorite impact: Direct expulsion to air and transport to surface
54	10	Ground Water	Faulting, leaching to ground water

[a]Cut set numbers refer to Table 6-4.

The only difference in AMRAW input for these various cases is in Release Model input. Inclusion of all cut sets comprises the base case, while one or several cut sets comprises each of the other cases. It is not necessary to run all of the cut sets separately. For example, 2 cut sets (4 and 7 in Table 6-4) for surface reduction to the waste by erosion do not result in a release during the 10^6 y study period. Direct expulsion to air by a diatreme is minor compared to other volcanic releases but may be obtained as the difference between Case 25 (total of all volcanic releases) and the sum of Cases 22, 23, and 24 (all volcanic releases except diatreme). Releases due to meteorite impact comprise only 1% of those from volcanism and the 3 cut sets (1, 5, and 8) are therefore combined in one run (Case 26).

Figure 7-1 and 7-2 show graphs of sample results for the 6 cases identified in Table 7-1. Figure 7-1 is local total body dose rates in Zone 2 summed for all nuclides. Zone 2 (see Fig. 5-6) is a desert area surrounding the repository zone (Zone 1), in which 50% of drinking water is assumed to be from surface water and 50% from ground water sources. The total of all volcanism cut sets (Case 25) contributes virtually all of the total for the base case (Case 48) until about 20,000 y (see coincident plots); leaching and ground water transport (Case 54) begins to affect the total after Tc-99 breakthrough, followed by ground water domination after 700,000 y due to Np-237 breakthrough. Meteorite impact (Case 26) is 2 orders of magnitude below the base case total, and therefore contributes only 1% of the total. During the first 20,000 y, the most significant environmental receptor for releases is surface water (Case 24) (60 - 80% of the total), followed in turn by land surface (Case 23) and air (Case 22). After 20,000 y, the ground water receptor overtakes the other receptors as stated above and becomes dominant. The reader is reminded that calculated releases to one receptor also involves subsequent contamination of other receptors as interreceptor transfers are made. For example, the case for a cut set giving release to air (Case 22) also includes consequences of deposition onto land surface and surface water and resuspension from land surface back into the air. If irrigation were involved in Zone 2 (it is not), there would also be sequential transfer from surface water to land surface and corresponding additional resuspension. Figure 7-2 shows the nonspecific total body

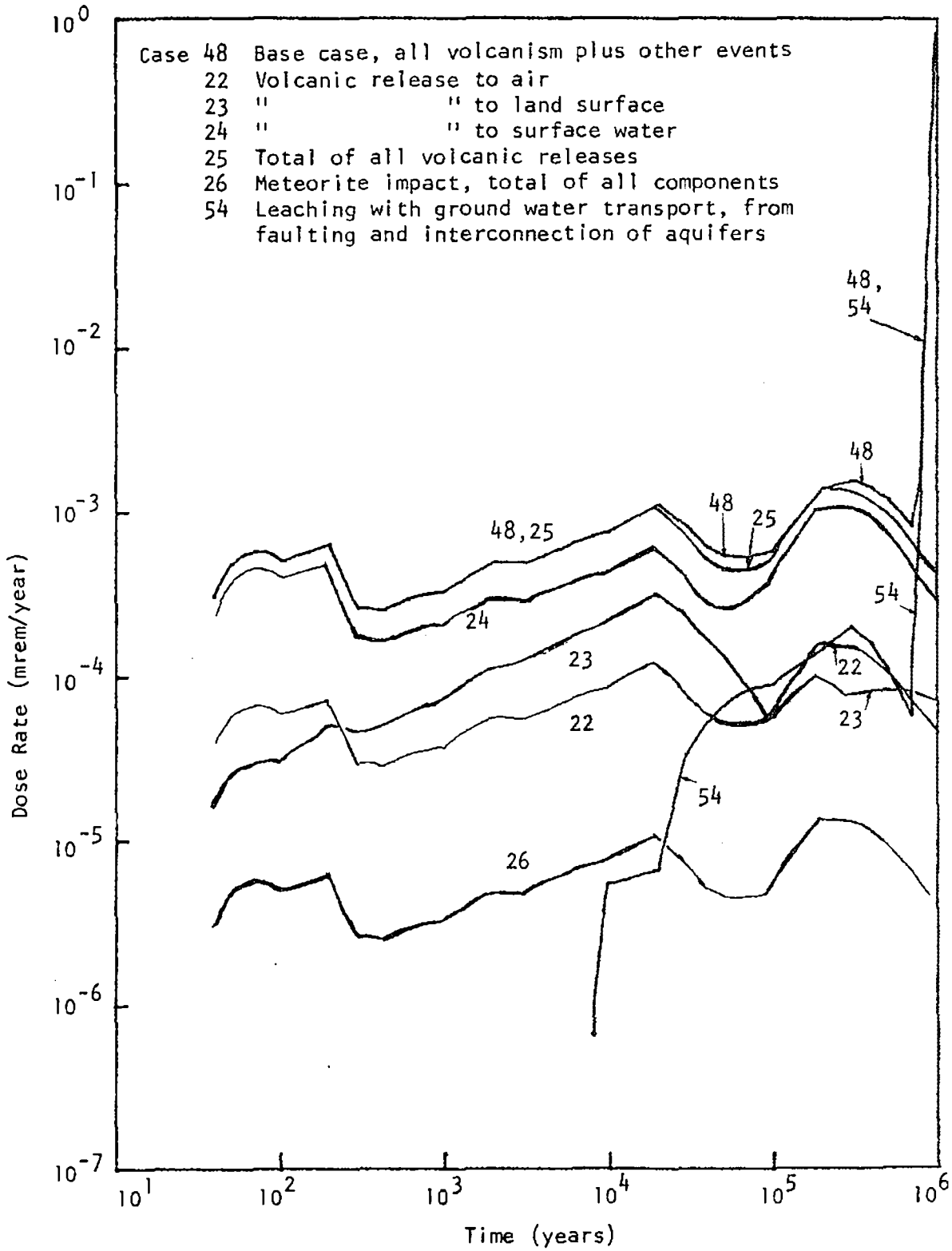

Figure 7-1. Components of average annual local total body dose to individual, in Zone 2 from all nuclides for violent volcanic, meteorite, and faulting events.

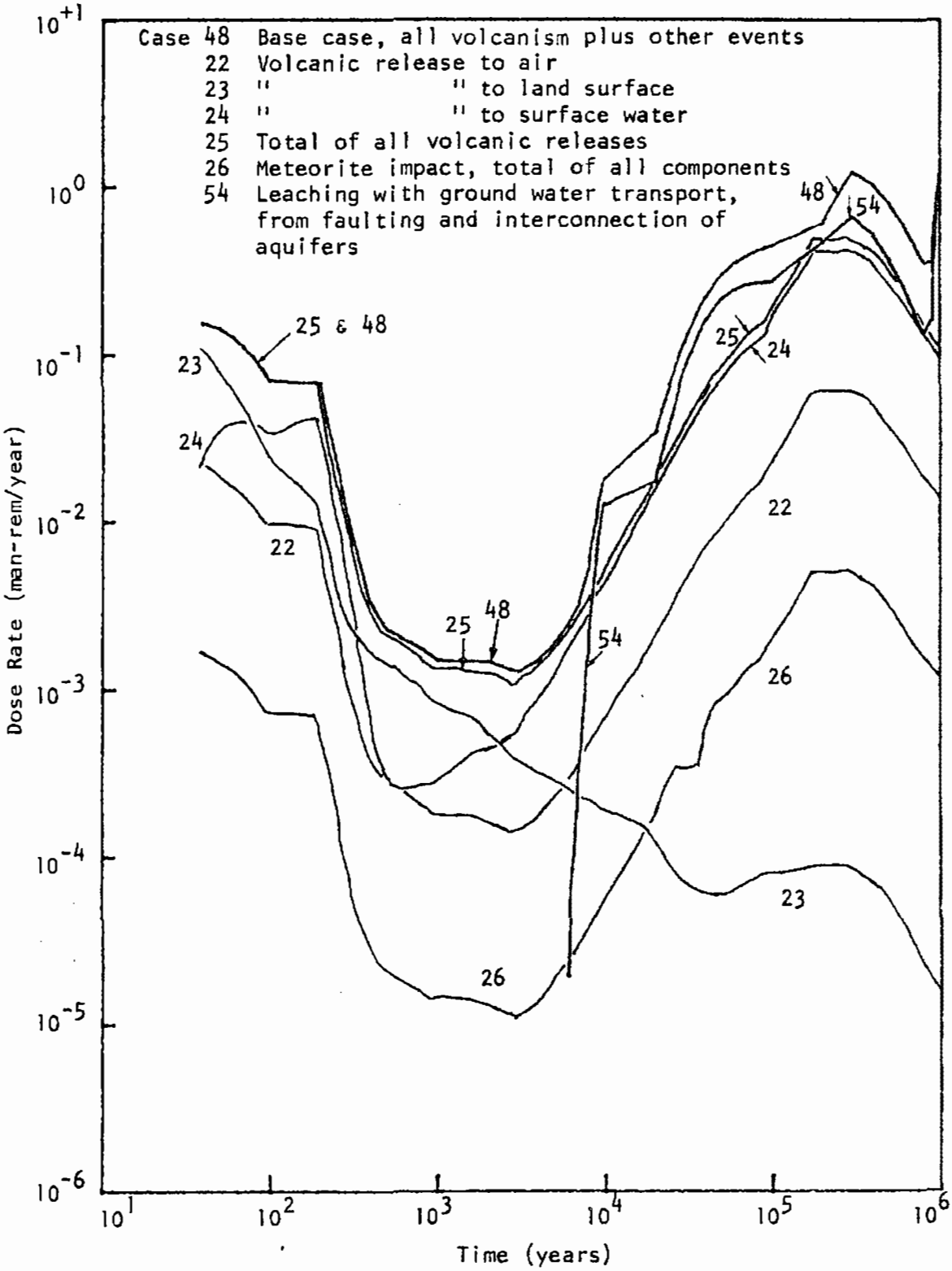

Figure 7-2. Components of average annual nonspecific total body dose from all nuclides for violent volcanic, meteorite and faulting events.

dose rate summed for all nuclides. Recall that the nonspecific category refers to agricultural products which are largely exported from the region. The relative ranking of components is the same as for local dose except that the relative importance of release to land surface (Case 23) decreases at later times and ground water begins to dominate at 10^4 y. The characteristic dip in the middle of these curves is due to dominance by Sr-90 and Cs-137 at times less than 300 y, and dominance by Tc-99 and Ra-226 at times greater than 10,000 y. Integration of dose rates over 7×10^5 y and the entire study period of 10^6 y (areas under each curve in Figs. 7-1 and 7-2) gives a measure of long-term risk from all events and from each contributing event. Results of integration (performed externally with AMRAW output) are listed in Table 7-2 for local dose in Zone 2 as a sample, and for nonspecific dose (includes components from all zones). The two ranges of integration show the changes in relative contributions by the various events after Np breakthrough occurs. Before Np breakthrough, volcanism comprises 90.5% of the total local dose in Zone 2 with 8.6% from ground water, but Np breakthrough in the 10^6 y time range moves ground water to 99% of the total. On the other hand, nonspecific dose is close to equally divided between volcanism and ground water for both time ranges. The reader is reminded that the ground water velocity is conservatively taken to be 6 times the estimated value; a less conservative velocity assumption or a slightly higher K_d (e.g., instead of 10.5) would defer Np breakthrough to times > 10^6 y.

The relative importance of surface water depends upon its use as drinking water. For example, in Zone 6 (a desert area near the repository in which no drinking water is assumed to be from surface sources and ground water flow from the repository does not occur) local total body dose rate from volcanic release to surface water (Case 24) is more than 7 orders of magnitude below the total for all events (Case 48), representing a negligible contribution from swimming.

The next step in the sensitivity analysis is an investigation of a parameter which applies after release. A very small token value for the environmental decay constant (EDC) is used for most of the cases in this study (see Section 6.C.1.d), corresponding to an environmental half-time of 30,000 y. Case 49 has EDC for land surface and surface water increased by a factor of 100, corresponding to an environmental half-time of 300 y.

Table 7-2. Summary of Integrated Total Body Dose for Base Case and Release Scenario Components[a]

Case No.	Description	7×10^5 y Integrated Dose[b]				10^6 y Integrated Dose			
		Local, Zone 2		Nonspecific		Local, Zone 2		Nonspecific	
		mrem	% of Total	man-rem	% of Total	mrem	% of Total	man-rem	% of Total
48	Base case, all events	7.96×10^2	100	4.97×10^5	100	8.83×10^4	100	6.86×10^5	100
22	Volcanic to air	8.32×10	10.5	3.04×10^4	6.1	1.03×10^2	0.1	3.66×10^4	5.3
23	Volcanic to land surface	6.73×10	8.5	6.03×10	0.01	9.07×10	0.1	6.86×10	0.01
24	Volcanic to surface water	5.63×10^2	70.7	2.35×10^5	47.3	6.85×10^2	0.8	2.84×10^5	41.4
--	Diatreme to air[c]	6.50	0.8	1.54×10^3	0.3	8.00	0.01	2.33×10^3	0.3
25	Volcanic, total	7.20×10^2	90.5	2.67×10^5	53.7	8.87×10^2	1.0	3.23×10^5	47.1
26	Meteorite impact, total	7.51	0.9	2.85×10^3	0.6	9.24	0.01	3.43×10^3	0.5
54	Faulting, leaching to ground water	6.82×10	8.6	2.27×10^5	45.7	8.74×10^4	99.0	3.60×10^5	52.5

[a]Cases run in probabilistic mode.

[b]7×10^5 y is prior to breakthrough of Np in ground water discharged in Zone 2.

[c]Diatreme release to air is Case 25 (total of all volcanic) minus sum of Cases 22, 23, and 24.

Table 7-3 summarizes results. Significant reduction of dose rates occurs for the increased EDC, up to a maximum reduction of 87%; a two orders of magnitude increase in EDC results in less than a one order of magnitude reduction in total dose rates. The effect of varying EDC is moderated in the probabilistic mode by continual feed in of new calculated releases.

Other examples of sensitivity analysis are discussed under the topic of consequence analysis in Section 7.B. Additional discussion is also presented in Chapter 8.

2. Ground Water Transport. The sensitivity analysis work in the leaching and ground water transport models similarly uses the present site-specific application of AMRAW to the Los Medaños site as the basis. Here, however, the leaching and ground water transport routines, which include analytic expressions that are functions of a number of parameters, are run separately from AMRAW as a combined auxiliary program. This is an economical step since only portions of AMRAW are used instead of the entire code.

(a) Border Values of K_d. An important parameter in ground water transport is the retardation factor, R_d, discussed in Section 4.D. of Vol. I and in Section 6.C. of this volume. Burkholder [Bu77a] uses the term: "adsorption equilibrium constant" for this parameter. From Eq. 6-7b (or Eq. 4-72 in Vol. I), R_d is defined as

$$R_d = 1 + \frac{\rho K_d}{\varepsilon} \tag{7-1}$$

where ρ is the density of the solid medium, K_d is the distribution coefficient, and ε is the porosity of the aquifer. Simply, Eq. 7-1 shows that the retardation factor increases with K_d. In Vol. I (Eq. 4-80), the pulse velocity U is the approximate rate of travel of a dissolved radionuclide, defined as the ratio of the seepage velocity (or pore velocity) v_p to R_d, i.e.

$$U = \frac{v_p}{R_d} . \tag{7-2}$$

For a given distance x corresponding to a point of discharge or usage, the pulse velocity in Eq. 7-2 can be used to estimate the approximate

Table 7-3. Reduction of Total Body Dose Rate from Increase in Environmental Decay Constant

Time y	Base Case No. 48	Comparison Case No. 49[a]	% Dose Rate Reduction
Zone 1 local dose rates, mrem/y			
100	2.55×10^{-3}	2.41×10^{-3}	5
1,000	5.04×10^{-3}	2.32×10^{-3}	54
10,000	1.48×10^{-2}	1.85×10^{-3}	87
100,000	3.91×10^{-3}	8.94×10^{-4}	77
1,000,000	5.12×10^{-3}	4.61×10^{-3}	10
Zone 2 local dose rates, mrem/y			
100	5.03×10^{-4}	4.70×10^{-4}	7
1,000	3.29×10^{-4}	1.49×10^{-4}	55
10,000	7.63×10^{-4}	9.68×10^{-5}	87
100,000	5.90×10^{-4}	1.36×10^{-4}	77
1,000,000	8.19×10^{-1}	8.14×10^{-1}	0.6
Nonspecific dose rates, man-rem/y			
100	7.09×10^{-2}	6.85×10^{-2}	3
1,000	1.47×10^{-3}	1.25×10^{-3}	15
10,000	1.81×10^{-2}	8.75×10^{-3}	52
100,000	4.57×10^{-1}	1.26×10^{-1}	72
1,000,000	1.19	1.16	3

[a]Case 49 has the environmental decay constant for land surface and surface water increased by a factor of 100.

transport time t_t for a specific radionuclide. Thus

$$t_t = \frac{x}{U} = \frac{x}{(v_p/R_d)} = \frac{x}{v_p} R_d. \qquad (7\text{-}3)$$

This approximation of the travel time indicates that as the value for K_d, and therefore for R_d, increases, the transport time to a given point of discharge for the associated nuclide increases. For each set of ground water seepage velocity, distance, other rock properties, and radionuclide half-life, there is some value of K_d above which: 1) the transport time exceeds the length of time studied, or 2) radiodecay diminishes nuclide activity to insignificant levels during transport. In such cases, risk analysis may be considered insensitive to K_d values greater than this border value.

Using Eqs. 7-1 and 7-3, the approximate transport time versus K_d for a distance of 10 km and several velocities is obtained and shown as curves in Fig. 7-3. It should be noted that these curves neglect radiodecay. The top curve, for a velocity of 4×10^{-3} m/d, represents the velocity used for the AMRAW cases. The other two curves are for higher velocities by factors of 10 and 100 respectively. The top curve indicates that for $K_d > 10$, the transport time for 10 km is $> 10^6$ y. Thus, for these conditions, if K_d is determined to be, for example, approximately 100, a precise value need not be obtained as the value of 100 is an order of magnitude greater than the border value of 10. Similarly, if the assessment time is limited to 100,000 y, $K_d = 1.0$ becomes the border value. Actually, a small margin above these K_d values should be allowed to provide for the leading edge which begins to arrive before the peak concentration.

An auxiliary program containing the leaching routine, the ground water transport routine (which solves the equivalent of Eq. 6-7), and the decay factor (DECFAC), was applied to two radionuclides having long half-lives. Representative points for the peak concentration travel times for the two nuclides are shown in Fig. 7-3. The results indicate that travel times calculated by AMRAW programming lie on or close to curves obtained by the approximate calculations. Shorter half-lives would skew the concentration curve toward shorter times because of

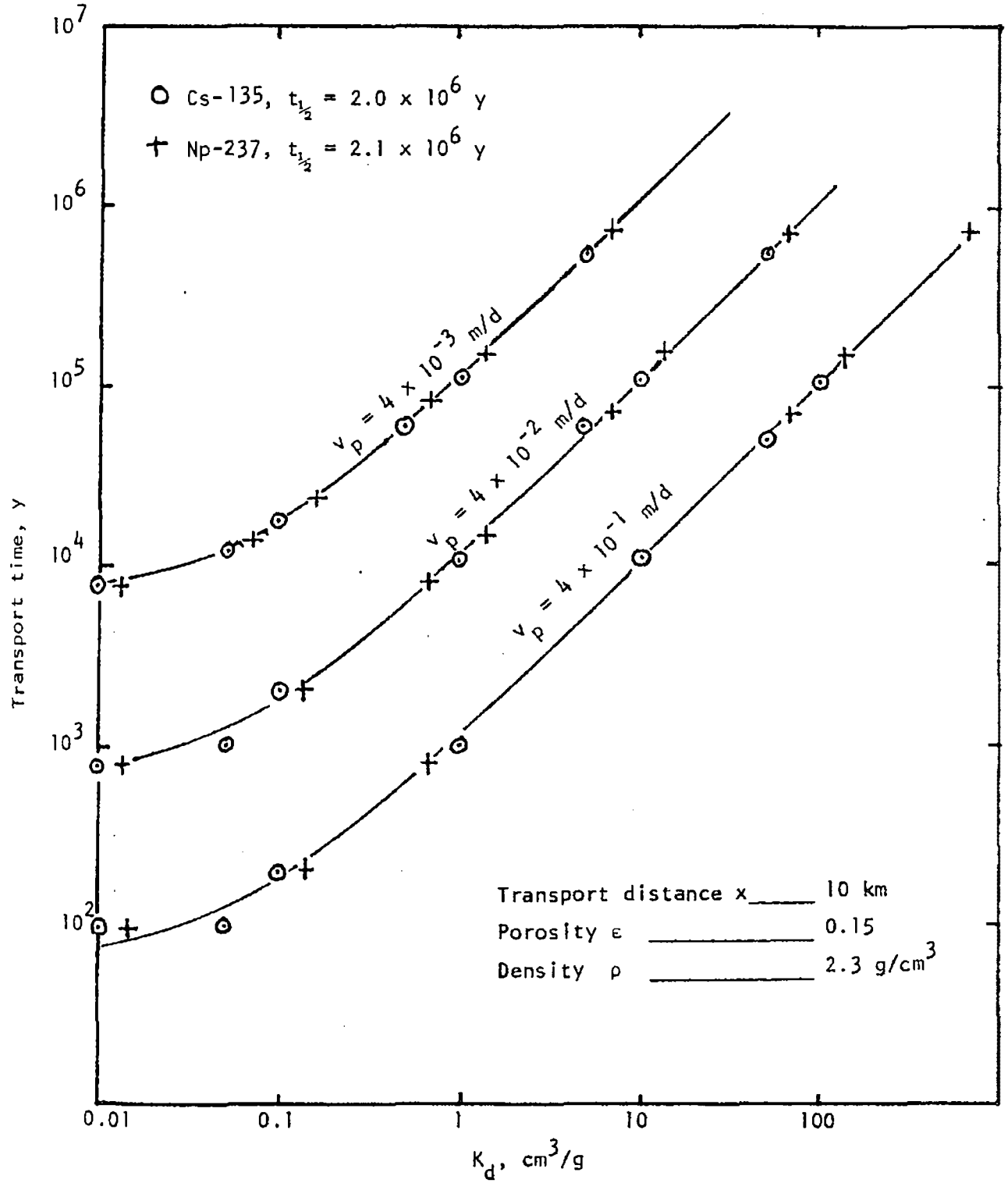

Figure 7-3. Transport time versus K_d at several ground water velocities.

removal of later "arrivals" by decay.

Extension of the approximate calculations with Eqs. 7-1 and 7-3 obtain the families of data listed in Table 7-4. It should be pointed out that the R_d values involved in these calculations are based upon a density to porosity ratio of $\rho/\varepsilon = 2.3/0.15 = 15.3$. Hence, the results also apply to higher density rock with greater porosity, and visa versa. Definition of the appropriate assessment time period, distance to ground water discharge and ground water velocity determines the border value of K_d. There is no advantage in expending effort to obtain precise values of K_d when they are substantially greater than the border value. A general relationship becomes apparent. The border value of K_d is

$$(K_d)_{border} \sim v_p \, T/x \tag{7-4}$$

where v_p is the seepage velocity, T is the limiting transport time, and x is the applicable distance to discharge. A nominal combination which fits the conditions reported here is:

$$\left.\begin{aligned} (K_d)_{border} &\cong 10.\ cm^3/g \\ \text{for } v_p &= 4 \times 10^{-3}\ m/d \\ T &= 10^6\ y \\ x &= 10^4 m. \end{aligned}\right\} \tag{7-5}$$

Variations for other values of v_p, T, and x vary the border value on the base of Eq. 7-4 as follows:

$$(K_d)_{border} = A(v_p \, T/x) \tag{7-6}$$

where A is the proportionality constant

$$A = \frac{(K_d)_{border} \, x}{v_p \, T} = \frac{10 \cdot 10^4}{4 \times 10^{-3} \cdot 10^6} = 25. \tag{7-7}$$

(b) Widths of Concentration Peaks. The widths of the concentration versus time peaks at a distance of interest following a pulse release need to be examined to make certain that adequate calculation

Table 7-4. Border Values of K_d for Transport in Ground Water

Distance x, m	Velocity v_p, m/d	Time T, y	K_d cm^3/g	R_d
5,000	0.004	10^6	19.	290.
	0.04	"	190.	2900.
	0.4	"	1900.	2.9×10^4
	0.004	10^5	1.8	29.
	0.04	"	19.	290.
	0.4	"	190.	2900.
10,000	0.004	10^6	9.5	2800.
	0.04	"	95.	1500.
	0.4	"	950.	1.5×10^4
	0.004	10^5	0.89	15.
	0.04	"	9.5	150.
	0.4	"	95.	1500.
20,000	0.004	10^6	4.7	73.
	0.04	"	47.	720.
	0.4	"	470.	7200.
	0.004	10^5	0.41	7.3
	0.04	"	4.7	73.
	0.4	"	48.	70.

resolution is provided. An auxiliary computer program is applied to Eq. 6-7 to define the tops of the curves previously shown in Figs. 6-14 and 6-15. The results are shown in Fig. 7-4 for K_d = 0, 1.4, and 10.5. These values correspond to nuclides Tc-99 or I-129, C-14, and Np-237 respectively. As these graphs neglect radiodecay, they also apply to other nuclides having the same K_d values. For reference purposes, the widths at half-maximum are indicated.

These are summarized in Table 7-5, and are the basis of the subdividing of time increments for ground water transport calculations, described in Section 6.C.1.e. This discussion applies to the procedure for calculating the average ground water concentration during each main time increment by averaging the calculated concentrations at each subinterval and superimposing the results for the sequence of pulse releases which simulate a band release. At times greater than 10,000 y, the current application uses main time increments of 10,000 y and then 100,000 y. These are subdivided into 1000 y sub-intervals when K_d < 1.0 to accomodate the indicated widths as narrow as 1600 y. The 100,000 y main increments are subdivided into 20,000 y intervals for $K_d \geq 1.0$, which appears to be adequate for the much broader peaks.

Table 7-5. Effect of Distribution Coefficient on Width of Concentrations Peaks

Distribution Coefficient, K_d cm^3/g	Peak Width at Half Maximum, y
0	1,600
1.4	37,000
10.5	2.7×10^5

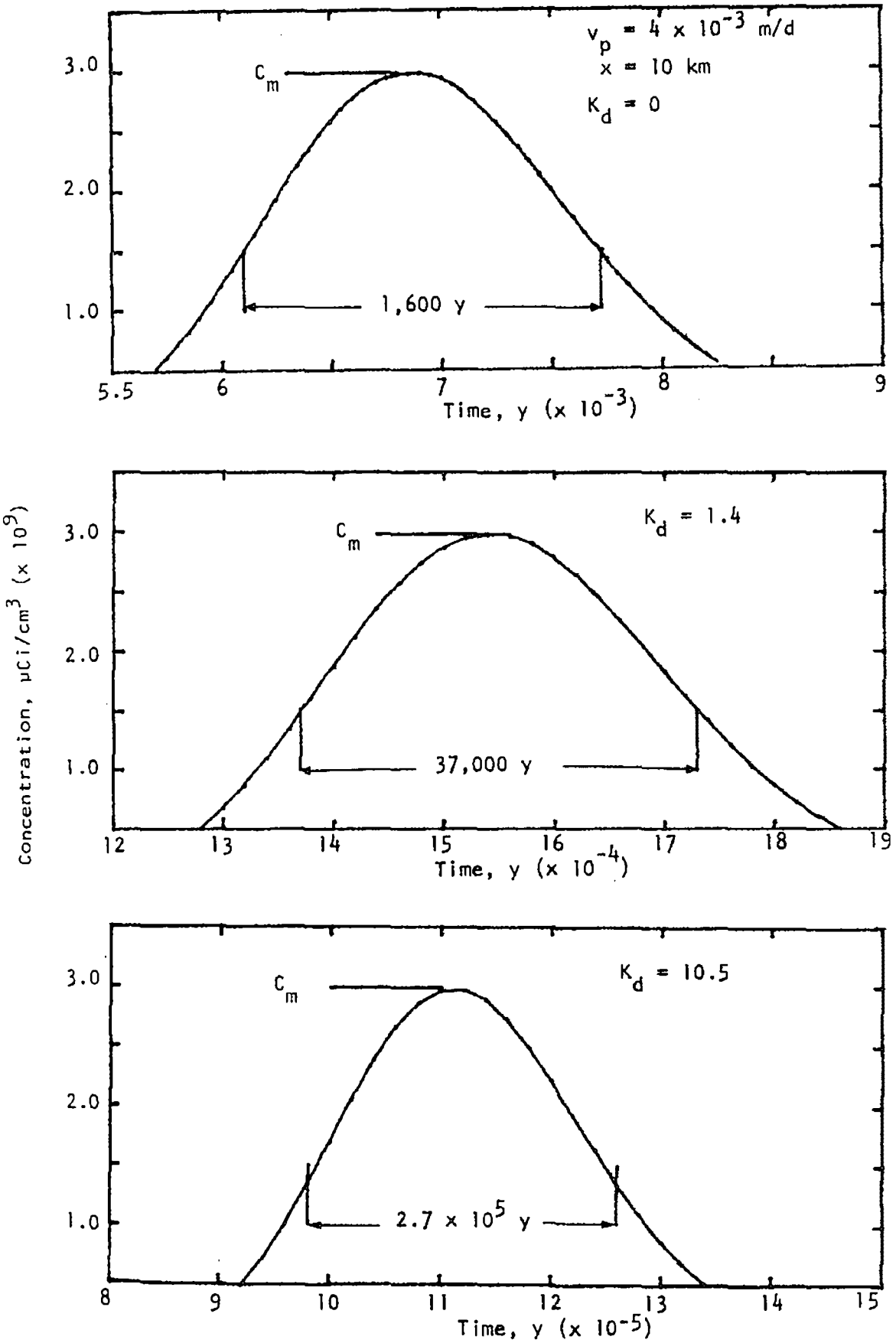

Figure 7-4. Widths of concentration peaks for various values of K_d.

B. CONSEQUENCE ANALYSIS

Computer runs for discrete release events occurring at various times comprises a consequence analysis. The various potential release events have very low probabilities of occurrence. It is of interest to calculate the consequences following any such occurrence, but the low probabilities should be kept in mind when evaluating the calculated results. Also, violent events such as volcanic explosions have serious consequences independent of a radiological increment.

Table 7-6 summarizes two series of computer runs: 1) volcanic explosion release to air, and 2) leach incident release to ground water. The first series considers volcanic explosions occurring at 1,000, 10,000, and 100,000 y. This corresponds to cut set 2 (Table 6-4) described earlier, except that instead of a probabilistic distribution (2.4×10^{-12}/y), a probability of unity is input as a delta function in the time increment of interest. Occurrence of the event means erupting within the volcanism effect zone (Fig. C-1). On this basis, the expected repository fraction intersected is 0.15 (see Appendix C) and assuming one-half of the intersected inventory is expelled to the air, the expected fraction of repository inventory expelled is 0.075. The reader is reminded that this is a generous assumption. Further, as before, it is assumed that all expelled radioactive material, subsequently deposited, is not covered by other deposited material, and is available immediately for environmental uptake without first requiring leaching or chemical modification. Additionally, population distribution and agricultural activity is assumed to continue unaffected by the volcano, and no cleanup or evacuation occurs after the eruption. Figure 7-5 shows the local total body dose rates in Zone 2 for the several cases. The decrease in dose rate following the release in each case is due to radiodecay and the token value for the environmental decay constant (EDC) corresponding to an environmental half-time of 30,000 y. Case 33 assumes the rate of environmental decay is increased by a factor of 100 (half-time of 300 y), resulting in a much more rapid decline in dose rate following a release at 1,000 y. Fig. 7-6 gives the corresponding nonspecific dose rates. The hump at later times is due to buildup of Ra-226 (see earlier Fig. 6-31).

Table 7-6. Summary of Consequence Analysis Cases for Volcanism and Leaching Incidents

1. Volcanic explosion release to air.

Case No.	Occurrence Time, y	Other Description
32	1,000	
33	1,000	Environmental decay rate increased, x 100.
34	10,000	
35	100,000	

2. Leach incident release to ground water.

Case No.	Initiation Time, y	Other Description
50	100	
51	1,000	
52	10,000	
53	100	Distribution coefficients, K_d, reduced, ÷ 20.

Table 7-7. Summary of Integrated Doses for Discrete Events of Volcanic Explosion Release to Air

		10^6 y Integrated Dose	
Case No.	Occurrence Time, y	Local, Zone 2 (mrem)	Nonspecific (man-rem)
32	1,000	9.77×10^7	3.81×10^9
33	1,000 (EDC x 100)[a]	5.42×10^6	6.92×10^7
34	10,000	5.76×10^7	4.49×10^9
35	100,000	2.37×10^7	8.66×10^9

[a]Environmental decay constant increased by factor of 100.

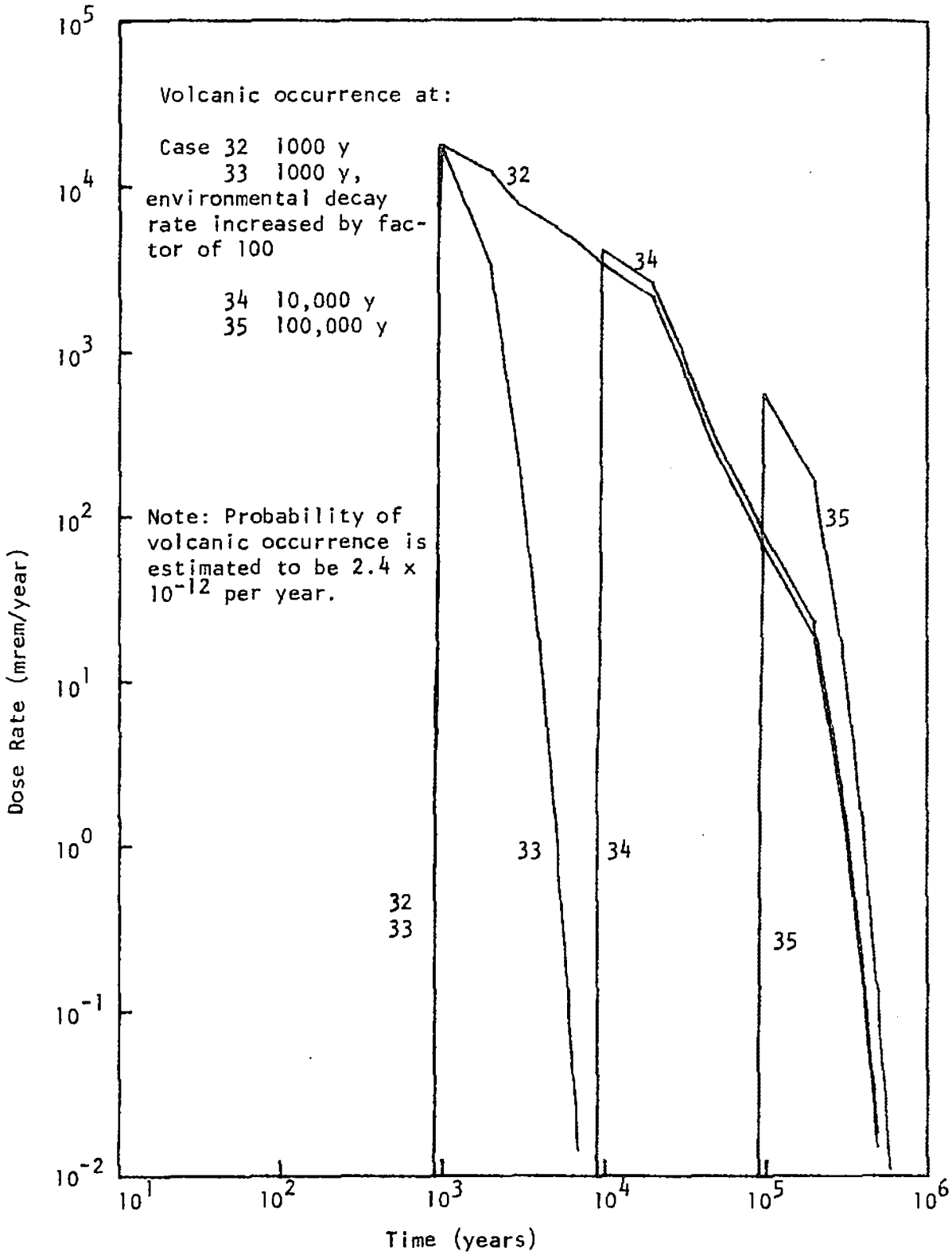

Figure 7 - 5. Average annual local total body dose to individual in Zone 2 from all nuclides following discrete violent volcanic events occurring at various times.

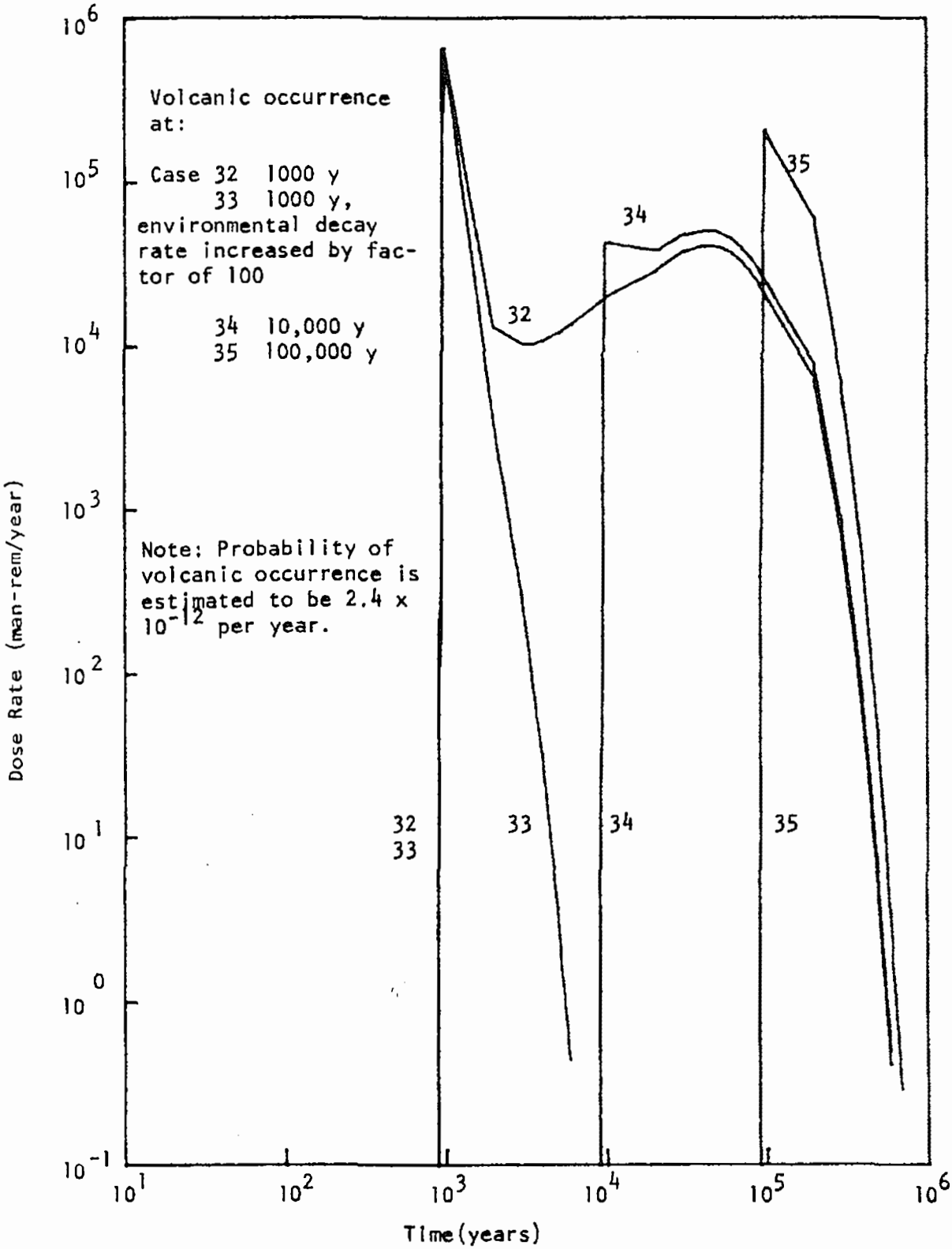

Figure 7 - 6. Average annual nonspecific total body dose from all nuclides following discrete violent volcanic event occurring at various times.

Table 7-7 lists the values from integration of dose rates over the entire study period of 10^6 y (area under each curve in Figs. 7-5 and 7-6). It is seen that the total impact of local dose decreases as the time of assumed occurrence becomes later. On the other hand, later occurrences have greater total nonspecific dose impact as a result of greater inventories of Ra-226 at times of release. An increase of EDC by a factor of 100 reduces the total local dose impact by a factor of 18 and nonspecific close impact by a factor of 55 (Case 33 versus Case 32). Appendix M presents summary tables of dose rates from Case 32 for Zones 1 and 8 and nonspecific, by organ at several times.

The second series of consequence analysis runs (Table 7-6) considers initiation of leach incidents from interconnection of aquifers by offset faulting at times of 100, 1,000, and 10,000 y. This corresponds to cut set 10 (Table 6-4) described earlier, except that instead of a probabilistic distribution (1.4×10^{-7}/y), a probability of unity is input as a step function with the step occurring in the time increment of interest. The step function is used to cause the leach incident to continue indefinitely (fracture pathway for water flow remains open). This assumes that closure or healing of the fracture does not occur or is offset by dissolution of salt. Figure 7-7 shows plots of local dose rates in Zone 2. The curves for Cases 50, 51 and 52 become nearly coincident after 10^5 y. Similarly, Fig. 7-8 shows plots of nonspecific dose rates. The contributors to dose are 4 radionuclides having estimated distribution coefficients, K_d (Table 6-10), less than approximately 15 and relatively long half-lives (rules out Sr-90): C-14, Tc-99, I-129, and Np-237. However, as can be noted from Appendix N summary tables of dose rates from Case 50, Tc-99 comprises virtually all of the dose rate totals prior to Np breakthrough. At later times, approaching 10^6 y, almost all of the total is from Np-237.

Case 53 investigates the effect of substantial decreases in the K_d values. For this case, all K_d values are reduced by a factor of 20; K_d for radium is thereby reduced from 70 to 3.5. The effect is to diminish the retardation of the previously noted nuclides plus introducing additional nuclides previously retarded to beyond 10^6 y. The corresponding increase in local total body dose rate in Zone 2 is shown in Fig. 7-7, and the nonspecific dose rate in Fig. 7-8. Tc-99 again dominates early

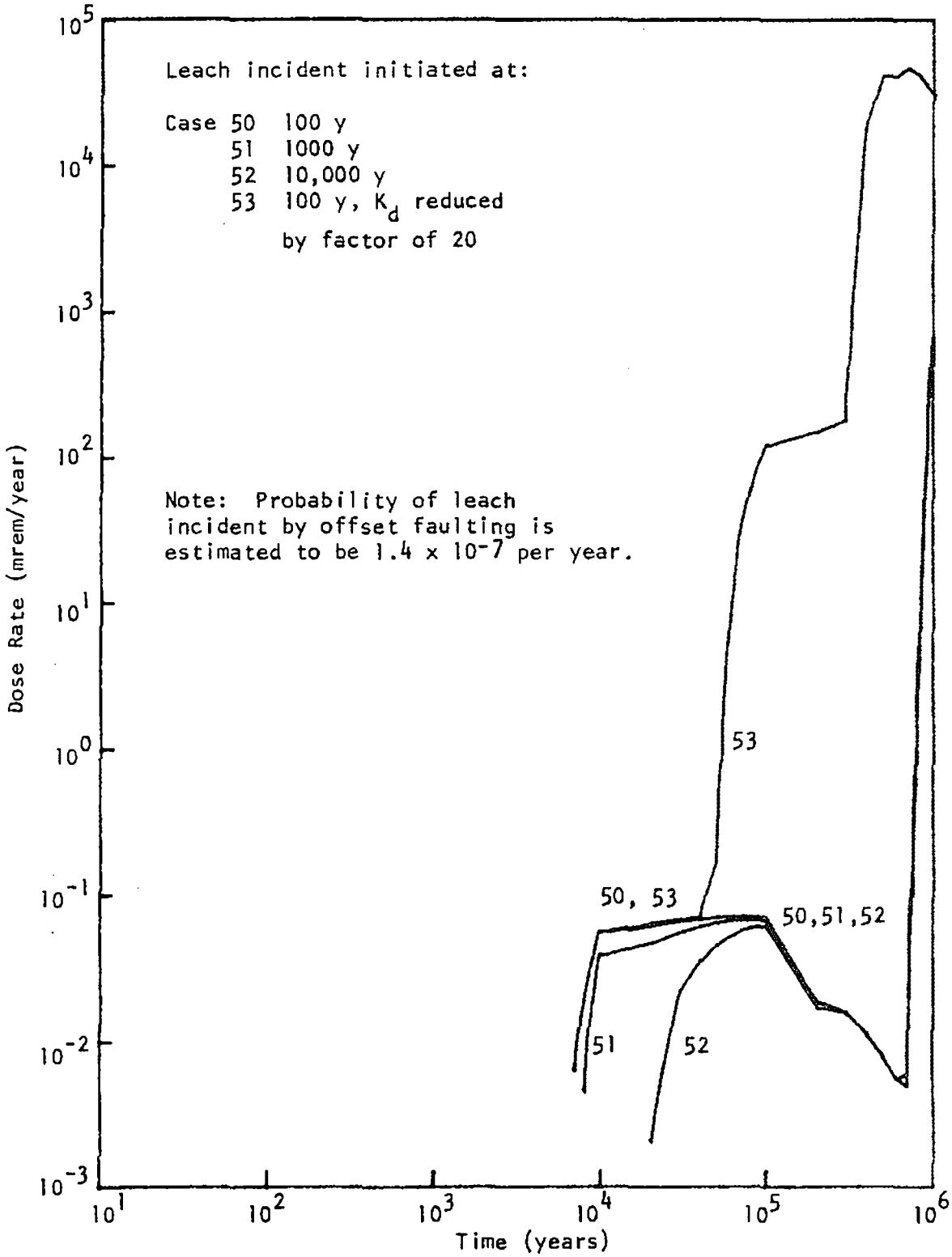

Figure 7-7. Average annual total body dose to individual in Zone 2 from all nuclides following discrete leach incident initiated at various times.

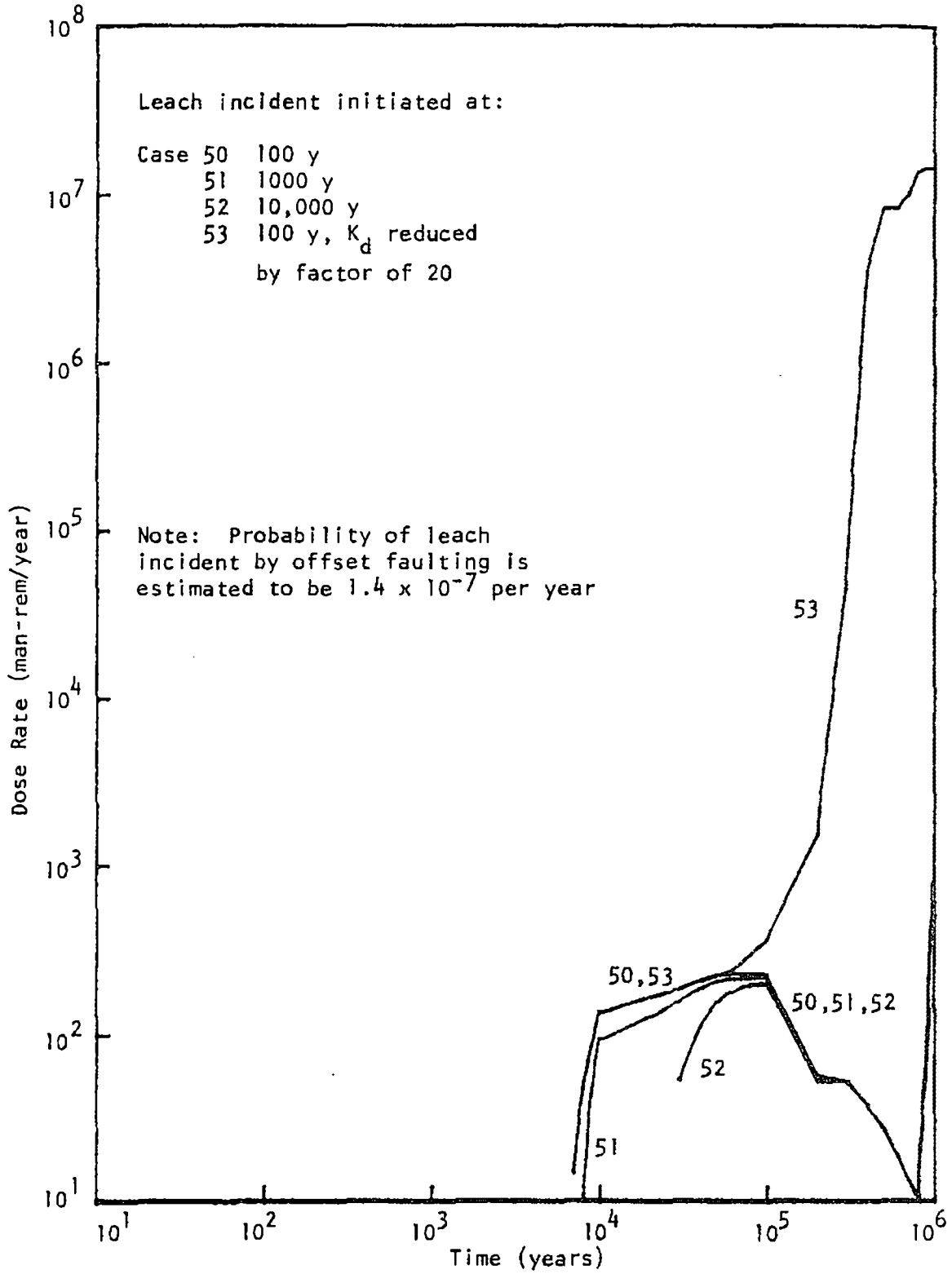

Figure 7-8. Average annual nonspecific total body dose from all nuclides following discrete leach incident initiated at various times.

time periods but Ra and then Np become the major contributors at later times approaching 10^6 y. This is discussed further in Section 8.C.

Table 7-8 lists integrated dose rates for the 10^6 y study period for the discrete leach incident cases. It may be noted that integrated results are not greatly sensitive to the time of initiation, though some reduction occurs as the time of initiation is delayed. Reduction of K_d by a factor of 20 increases 10^6 y integrated local dose by a factor of over 300 and nonspecific dose by a factor of close to 60,000. This illustrates the high sensitivity to K_d.

Table 7-8. Summary of Integrated Total Body Dose for Discrete Leach Incident Events

Case No.	Initiation Time, y	7×10^5 y Integrated Dose[a]		10^6 y Integrated Dose	
		Local, Zone 2 (mrem)	Nonspecific (man-rem)	Local, Zone 2 (mrem)	Nonspecific (man-rem)
50	100	1.30×10^4	3.97×10^7	7.18×10^7	1.27×10^8
51	1,000	1.23×10^4	3.80×10^7	7.04×10^7	1.23×10^8
52	10,000	1.02×10^4	3.27×10^7	5.75×10^7	1.03×10^8
53	100 (K_d reduced)[b]	1.47×10^{10}	3.01×10^{12}	2.57×10^{10}	7.29×10^{12}

[a] 7×10^5 y is prior to breakthrough of Np in ground water discharged in Zone 2.

[b] K_d reduced, ÷ 20.

CHAPTER 8

EVALUATION OF RESULTS

The previous two chapters present and discuss implementation and results obtained for a base case (Chapter 6), and for a series of other cases for sensitivity and consequence analyses (Chapter 7). This chapter provides additional discussion to extend and interpret those results for terminal storage in a bedded salt reference repository.

A. DISCUSSION OF BASE CASE

The base case described in Chapter 6 is a computer run in the probabilistic mode in which several geologic disturbance events are simultaneously considered. The probabilistic distribution represents operation of AMRAW in a risk mode; recall that risk is defined as the product of probability of occurrence of an event and the consequence of an event if it occurs. The results from the base case do not represent predictions of environmental concentrations and population dose equivalent rates. The geologic events have very low probabilities for occurrence and are therefore unlikely to occur during the time period studied: one million years. Allowing the events to partially "occur" via the probabilistic method provides a basis for risk comparisions between alternative repository sites, types of geologic formations, fuel cycles and waste forms. Also the method allows ranking the various release scenarios according to relative contributions to long term risk and helps to identify areas of study requiring additional attention for minimizing risk. The present status of available geologic data results in large uncertainties in estimates of probabilities which affects the calculated risk, but doesn't preclude relative evaluation of various management options. A preliminary demonstration of AMRAW for another geologic setting is described in Chapter 11.

The calculations performed in the base case run (Case 48) in effect weights the consequences of each event by the year to year probability of occurrence and sums for all events considered. On this basis, calculated dose rates are very low, as illustrated by the summary map in Fig. 6-16. The highest calculated dose rates are obtained for Zone 1 which is the immediate area around the site. Integrating the local total body dose rates over the 10^6 y period (from Appendix K: average annual local dose to individual, total for all nuclides, total body, Zone 1) obtains 6.2×10^3 millirems or an average annual rate of only 0.006 millrems/y. The corresponding integrated nonspecific dose from agricultural products in the entire study region (from Appendix K: average annual nonspecific dose to population, total for all nuclides, total body) is 6.9×10^5 man-rems or an average rate of 0.7 man-rems/y.

The total food production in the region, summed from Table 6-19, is: 2.96×10^{11} g/y above surface food, 1.17×10^{11} g/y meat, and 1.36×10^{11} g/y milk. If the average daily intake per person is 250 g above surface food, 300 g meat, and 1000 g milk [Bh71, Kl76], the total production rates correspond to the intake rates of 3.2×10^{6}, 1.1×10^{6}, and 3.7×10^{5} persons, respectively. Thus, while the quantities of each type of food are not in balance, the total represents the food for close to one million persons. This means that any of the results presented for nonspecific dose or dose rate multiplied by 10^{-6} approximately represent the maximum individual dose or dose rate from the nonspecific category. For example, the average rate of 0.7 man-rems/y mentioned in the previous paragraph represents a maximum individual rate of $0.7 \times 10^{-6} = 7 \times 10^{-7}$ rems/y $= 7 \times 10^{-4}$ mrem/y. Actual average dose rates to individuals in the population would be much less than indicated by this procedure; exported food becomes greatly diluted by noncontaminated sources prior to being consumed by the population.

1. Environmental Receptor Significance. The release scenarios evaluated for the base case result in approximately three times as much material dispersed directly to land surface and surface water as by finely divided expulsion into the air (see Table 6-4, and in a later section, Table 8-6). Releases calculated to ground water depend upon non-linear leaching behavior but are generally greater than the releases to the other receptors (see sample results in Appendix K). However, as observed in Section 6.D. (see Figs. 6-32 and 6-34), the contributions to dose rates at time up to 700,000 y from releases to ground water are smaller than from the other receptors due to sorption and low ground water velocity. An exception is ground surface contribution to nonspecific dose rate, which drops below ground water near 10,000 y (Fig. 6-34). The only radionuclides showing up at discharge points (10 km distance in Zone 2 or 20 km distance in Zone 8) are: C-14, Tc-99, I-129, and Np-237. The Np isotope begins to appear in Zone 2 after 700,000 y, but the peak concentrations would not arrive in this zone until well after 10^6 y. Ra-226 with K_d = 70 assumed (and precursors not less than this value), does not emerge within 10^6 y.

It is assumed here that the fracture from offset faulting sufficient to interconnect aquifers above and below the disposal horizon intersects an average of one row (250) of canisters. It is further assumed that the containers have disappeared through corrosion and that each cylindrical monolith of waste incorporated in glass has fractured into ten pieces. It is, of course, possible that a fracture from faulting may not intersect any canisters, in which case there would be a time lag for salt dissolution prior to the onset of waste leaching. If further study indicates that, on the average, more than the equivalent of one row may be exposed by this process or that additional groups of canisters become exposed with time due to salt dissolution, modified input data can reflect these conditions.

It was noted in Section 6.D. (see Figs. 6-32 and 6-33) that in zones where surface water is a major source of drinking water, surface water becomes the most significant receptor for local dose rates over most of the time range. In the absence of drinking water dominance, air becomes the most important receptor.

The integrated concentration in air is primarily from resuspension from accumulated land surface contamination. An incremental release to air leads to an average integrated concentration, $(\mu Ci\text{-}y)/cm^3$, in a given zone as the plume moves over the zone. Deposition onto the land surface plus other direct releases to the land surface produce a calculated continuous accumulation subject to reduction by radiodecay and environmental decay. During each time increment a small fraction of the accumulation is, on the average, continuously resuspended in air near the land surface. In these calculations, a resuspension factor for the desert terrain is taken to be 100 times the U. S. average (see Section 6.C.1.b.). Table 8-1 illustrates the method for determining the percentage of air concentration which is due to resuspension from AMRAW output, and Fig. 8-1 is a plot for this example. The fraction from resuspension for the first release increment (30 - 40 y) for the various zones and for the other cases reported in this volume range from 30 - 75%, but the approach to 100% is similar to the example illustrated. Increased environmental decay constant (EDC) tends to delay the reaching of 100% because of slower net accumulation of land contamination.

2. Most Significant Radionuclides. The 25 radionuclides used in this study were screened from the several hundred initially present in the waste. The screening method [Lo74b], described in Vol. I, Section 4.B., selected the most significant nuclides over the full 10^6 y time range on the basis of a hazard measure defined as the Curies of a given radionuclide in a quantity of waste (such as from one metric ton of fuel) divided by the corresponding Radiation Concentration Guide (RCG) value [CFR20]. The screening does not consider behavior in movements through the geosphere and biosphere. It is therefore of interest to rank the nuclides in order of importance as the calculations progress through the model from the source term to population dose.

The 10 nuclides comprising the greatest mass in the model repository at a reference time of 100 y are summarized from Appendix J in Table 8-2. However, the most significant nuclides shift as one progresses through the model. The 5 most significant nuclides are listed at each stage and for several times in Table 8-3, with base case data taken from AMRAW output (sample in Appendix K and Appendix L). The same top 5 appear for source

Table 8-1. Determination of Resuspension Contribution to Integrated Air Concentration[a]

Time Increment		Air Conc.[b]	Land Surface	Resuspension Conc.[c]	Integrated Resuspension[d]	% of Air Conc.
End Time y	Length, Δt y	$\frac{\mu Ci\text{-}y}{cm^3}$	$\frac{\mu Ci}{cm^2}$			
40	10	1.13×10^{-19}	4.73×10^{-12}	4.73×10^{-21}	4.73×10^{-20}	41.9
100	10	3.96×10^{-19}	3.31×10^{-11}	3.31×10^{-20}	3.31×10^{-19}	83.6
1,000	100	4.58×10^{-17}	4.51×10^{-10}	4.51×10^{-19}	4.51×10^{-17}	98.5
10,000	1,000	4.13×10^{-15}	4.12×10^{-9}	4.12×10^{-18}	4.12×10^{-15}	99.8
100,000	10,000	1.51×10^{-13}	1.51×10^{-8}	1.51×10^{-17}	1.51×10^{-13}	100.
1,000,000	100,000	2.34×10^{-13}	2.34×10^{-9}	2.34×10^{-18}	2.34×10^{-13}	100

[a]Example for Tc-99, Case 48, Zone 1.

[b]Data from Appendix K.

[c]Resuspension concentration is product of land surface concentration, fraction of zone which is land (1.00 in Zone 1), and resuspension factor (1×10^{-9} cm^{-1}).

[d]Integrated resuspension is resuspension concentration multiplied by length of time increment.

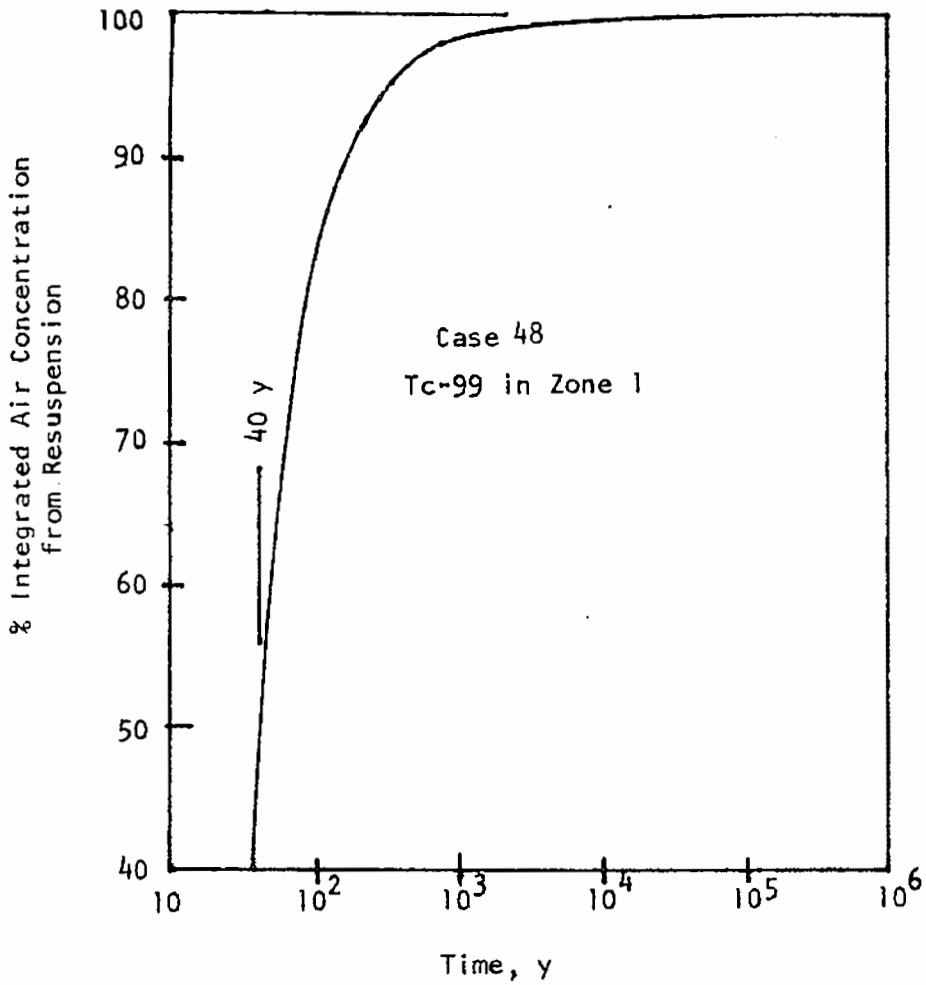

Figure 8-1 . Percentage of integrated air concentration from resuspension.

Table 8-2. Radionuclides Comprising Greatest Mass at 100 Years

Nuclide	Mass, g	Accumulated % of 25 Nuclide Total
Tc-99	1.54E+8[a]	25
Zr-93	1.33E+8	46
Np-237	8.56E+7	59
Am-243	7.20E+7	71
Cs-135	6.80E+7	82
Pu-240	4.16E+7	88
Cs-137	3.11E+7	93
Am-241	1.81E+7	96
Sr-90	1.15E+7	98
Pu-239	7.58E+6	99
25 Nuclide Total	6.28E+8	100

[a]1.54E+8 denotes 1.54×10^8.

term activity and for the environmental input concentration (land surface activity per unit area) in both Zones 1 and 8 at each time, although there is some shifting in order. The two zones used in this sample cover the extremes of a desert area with no surface water nor agricultural crops (Zone 1) and an area with surface water and extensive irrigated farming (Zone 8).

Going from environmental input concentration to dose rates in Table 8-3, several changes appear. Comparing the local dose rates for the two zones, the top 4 for Zone 1 are among the top 5 for Zone 8 over the full time range except that Th-230 becomes prominent in Zone 1 and Tc-99 in Zone 8 after 100,000 y. The nonspecific dose (associated with largely exported agricultural products) is dominated during early time by Cs-137 and Sr-90, at later times by Tc-99 and Ra-226 and at 10^6 y by Np-237. This was illustrated earlier in Fig. 6-30.

Also listed in Table 8-3 are the total body dose rates, total for all nuclides evaluated and for the top 5 as listed, for both the base case and for a corresponding case with the environmental decay rate increased

Table 8-3. Most Significant Radionuclides at Several Calculation Stages Versus Time for the Base Case and Increased Environmental Decay Constant[a]

Time, y	Order[b]	10^2	10^3	10^4	10^5	10^6
SOURCE TERM (ACTIVITY)	1	Cs-137	Am-241	Np-239	Tc-99	Zr-93
	2	Sr-90	Np-239	Am-243	Pu-239	Nb-93m
	3	Y-90	Am-243	Pu-240	Zr-93	Tc-99
	4	Cm-244	Pu-240	Pu-239	Nb-93m	Ra-225
	5	Am-241	Tc-99	Tc-99	Np-237	Th-229
ENVIRONMENTAL INPUT CONCENTRATION (LAND SURFACE ACTIVITY PER UNIT AREA)						
ZONE 1	1	Cs-137	Am-241	Am-243	Tc-99	Zr-93
	2	Sr-90	Np-239	Np-239	Pu-239	Nb-93m
	3	Y-90	Am-243	Pu-240	Zr-93	Tc-99
	4	Cm-244	Pu-240	Tc-99	Nb-93m	Ra-225
	5	Am-241	Tc-99	Pu-239	Np-237	Th-229
ZONE 8	1	Cs-137	Am-241	Am-243	Tc-99	Tc-99
	2	Y-90	Np-239	Np-239	Pu-239	Nb-93m
	3	Sr-90	Am-243	Pu-240	Nb-93m	Zr-93
	4	Cm-244	Pu-240	Tc-99	Zr-93	Ra-225
	5	Am-241	Tc-99	Pu-239	Np-237	Th-229

Table 8-3. (Continued)

Time, y		Order	10^2	10^3	10^4	10^5	10^6
DOSE RATE, TOTAL BODY							
ZONE 1		1	Cm-244	Am-241	Am-243	Pu-239	Th-229
		2	Am-241	Am-243	Pu-240	Th-229	Np-237
		3	Pu-238	Pu-240	Pu-239	Np-237	Th-230
		4	Sr-90	Np-239	Np-239	Th-230	Ra-226
		5	Am-243	Pu-239	Am-241	Ra-226	Pb-210
Local Dose Rate (mrem/yr)							
Base Case Case 48	Total all nuclides		2.55E-3[c]	5.04E-3	1.48E-2	3.91E-3	5.12E-3
	Top 5		2.38E-3	4.94E-3	1.47E-2	3.88E-3	5.12E-3
	% of total		93.3	97.9	99.5	99.4	100
EDC x 100 Case 49	Total all nuclides		2.41E-3	2.32E-3	1.85E-3	8.94E-4	4.61E-3
	Top 5		2.25E-3	2.30E-3	1.83E-3	8.88E-4	4.61E-3
	% of total		93.3	99.1	99.2	99.3	100
% change for EDC x 100[d]			-5.5	-54.	-88.	-77.	-10.

DOSE RATE, TOTAL BODY							
ZONE 8		1	Sr-90	Am-241	Am-243	Tc-99	Th-229
		2	Cm-244	Am-243	Pu-240	Pu-239	Ra-226
		3	Am-241	Pu-240	Pu-239	Ra-226	Np-237
		4	Pu-238	Np-239	Np-239	Th-229	Ra-225
		5	Cs-137	Pu-239	Am-241	Np-237	Tc-99
Local Dose Rate (mrem/yr)							
Base Case Case 48	Total all nuclides		4.09E-5	6.29E-5	1.81E-4	1.05E-4	1.15E-4
	Top 5		3.75E-5	6.23E-5	1.79E-4	1.00E-4	1.13E-4
	% of total		91.7	99.0	99.0	95.4	98.0
EDC x 100 Case 49	Total all nuclides		3.90E-5	3.06E-5	2.70E-5	3.99E-5	1.06E-4
	Top 5		3.58E-5	3.04E-5	2.66E-5	3.85E-5	1.04E-4
	% of total		91.8	99.5	98.6	96.4	97.9
% change for EDC x 100			-4.6	-51.	-85.	-62.	-8.

Table 8-3. (Continued)

Time, y		Order	10^2	10^3	10^4	10^5	10^6
DOSE RATE, TOTAL BODY							
NONSPECIFIC		1	Cs-137	Am-241	Tc-99	Tc-99	Np-237
		2	Sr-90	Am-243	Ra-226	Ra-226	Ra-226
		3	Cm-244	Pu-240	Am-243	Ra-225	Tc-99
		4	Am-241	Ra-226	Ra-225	Pb-210	Ra-225
		5	Am-243	Tc-99	Am-241	Cs-135	Cs-135
Dose Rate (man-rem/yr)							
Base Case Case 48	Total all nuclides		7.09E-2	1.47E-3	1.81E-2	4.57E-1	1.19
	Top 5		7.07E-2	1.46E-3	1.80E-2	4.57E-1	1.19
	% of total		99.7	99.3	99.2	100	100
EDC x 100 Case 49	Total all nuclides		6.85E-2	1.25E-3	8.75E-3	1.26E-1	1.16E+0
	Top 5		6.83E-2	1.24E-3	8.74E-3	1.26E-1	1.16E+0
	% of total		99.7	99.3	99.9	100	100
% change for EDC x 100			-3.	-15.	-52.	-72.	-2.

[a]The base case (no. 48) has environmental half-time of 30,000 y. Case 49 has increased environmental decay constant (EDC) by factor of 100 (environmental half-time of 300 y).

[b]The order lists the sequence of contribution of the 5 most significant nuclides, with most significant listed first.

[c]2.55 E-3 denotes 2.55×10^{-3}.

[d]Percent change for EDC x 100 is the percent change from Case 48 to Case 49 due to increased rate of environmental decay.

by a factor of 100. In most instances, the top 5 nuclides comprise close to 100% of the total. Increasing the rate of environmental decay reduces the calculated dose rate, particularly in the middle portion of the time range, but does not effect the lists of most significant nuclides nor their order. This is discussed further in Section 8.B.1.

Table 8-4 indicates which of the 25 radionuclides studied are included among the top 5 in Table 8-3 at one or more of the times listed, for each stage through the model. It is seen that 20 of the 25 nuclides studied each appear among the top 5 in at least one instance. In the population dose category, only Sr-90 and Cs-137 from the fission product group are among the most significant contributors to local dose, but Tc-99 and Cs-135 join in for nonspecific dose. In the actinides and daughters group, all 16 studied except Pu-241, Am-242m and Cm-242 are among the most significant for local dose but 5 of them drop out from the list for nonspecific dose. If the most significant nuclides are selected only on the basis of population dose rates, the nuclides added to the list based upon environmental concentrations are: Cs-135, Pb-210, Ra-226, Th-230, and Pu-238 while those which are omitted are Y-90, Zr-93 and Nb-93m.

3. Completeness. Not all of the release event combinations shown on the fault tree diagrams (Figs. 6-1 through 6-7) have been implemented in the base case. Several are properly omitted because they represent products of two or more very low probabilities (such as volcanogenic transport to shallower depth coupled with impact by a smaller meteorite than required for the original depth, as in Fig. 6-2). Two scenarios included in Fig. 6-4 which have not been evaluated because of lack of sufficient data are releases to ground water via mine shaft leaks and as a result of deliberate or accidental penetration by drilling. Reviewers of this work have inquired about these and some discussion may be helpful.

Leakage to the upper aquifer or more particularly to the surface in Zone 1 via the mine shaft requires a fracture to furnish a conduit from a lower aquifer to the disposal horizon, sufficient hydrostatic pressure to rise to the surface, and failure of the shaft seal (see conditional gate in Fig. 6-4). In the absence of the lower fracture, an alternate undefined mechanism for creation of a convective cell from above would

Table 8-4. Summary of Radionuclides Among the Five Most Significant at Some Time

No.	Nuclide	Source Term Activity	Environmental Input Concentration	Dose Rates Local		Dose Rates Nonspecific
Fission and activation products						
1	C-14					
2	Sr-90	x	x	x		x
3	Y-90	x	x			
4	Zr-93	x	x			
5	Nb-93m	x	x			
6	Tc-99	x	x			x
7	I-129					
8	Cs-135					x
9	Cs-137	x	x	x		x
Actinides and daughters						
10	Pb-210			x		x
11	Ra-225	x	x	x		x
12	Ra-226			x		x
13	Th-229	x	x	x		
14	Th-230			x		
15	Np-237	x	x	x		x
16	Np-239	x	x	x		
17	Pu-238			x		
18	Pu-239	x	x	x		
19	Pu-240	x	x	x		x
20	Pu-241					
21	Am-241	x	x	x		x
22	Am-242m					
23	Am-243	x	x	x		x
24	Cm-242					
25	Cm-244	x	x	x		x
Number checked		15	15	15	17	12

be required. Under present hydrologic conditions [Mr77], the hydrostatic pressure is not adequate to rise to the surface, though data for changing these conditions may evolve (see Fig. 6-7). It should be recognized that a lag time and limited release rates for leaching apply.

Penetration by drilling leads to two categories of consequences: 1) transport to surface via drill cuttings and 2) exposure of disposal horizon to action of ground water. First, consider the probability for contacting waste by drilling. The reference repository used here has 62,500 canisters, each 0.3 m in diameter, oriented vertically in an area of 10 km^2 (10^7 m^2). If a 0.3 m diameter hole is drilled at random within the repository boundary, a 0.9 m diameter canister effect zone (analogous to volcanism effect zone in Fig. 6-8) is associated with each canister. The probability of any one hole entering a canister effect zone is

$$62{,}500\ (\pi 0.9^2/4)/10^7 = 0.004. \qquad (8\text{-}1)$$

The expected value of intersection for a hole entering the zone is $(0.3/0.9)^2 = 0.11$, representing the average fraction of a canister inventory encountered if contacted by drilling. Thus it would require 250 randomly drilled holes to bring up an average of 0.1 the contents of one canister. Political control prevents the drilling attempt during early time decades, but a probability function for later years is required to more completely evaluate this scenario. Action by ground water initially affects no more than one canister but if salt dissolution takes place, additional canisters become effected after time lags. If appropriate data becomes available, the above release paths can be input to AMRAW.

Other conditions having some potential for causing migration from the repository are slow processes such as fracturing overlying strata from thermal effects. This can be accommodated by AMRAW (see Section 4.C.1.d in Vol. I) if the data becomes available.

While the present implementation in the base case is not represented as being complete, the low calculated dose rates obtained indicate a substantial buffer for accommodating other postulated releases.

4. Alternatives in Source Term. The source term (inventory at risk) used for this model repository application of AMRAW is detailed in Section 6.A. In summary, the accumulated inventory at the beginning of the terminal storage phase is the high-level waste from reprocessing of 187,000 metric tons of fuel from a projected mix of reactor types (primarily light water reactors), with gradual phase in of plutonium recycle. The waste age at the time of emplacement is 10 y, 0.5% of U and Pu are retained in the waste, no H, Kr and Xe remain and only 0.1% of I and Br remain in the waste. Adjustment of results for some variations in source term conditions can be made without reruns of AMRAW, while other variations are best accommodated by reruns with revised input. The calculated results vary linearly with the total number of accumulated metric tons if the repository area and reactor mix remain the same. If the repository area also varies with the accumulation (as with constant emplacement density), a small effect is introduced from changed probabilities of geologic disruption (see alternate demonstration, Chapter 11).

The 10 y waste age used in radioactive waste projections [Bk74] is generally assumed to provide for decay of thermal output by a factor of more than 10 from that at the time of reprocessing (180 d after irradiation). Increasing the age of waste prior to emplacement would reduce the calculated results for times soon after the end of repository operations, but there is virtually no effect at later times. For example, a 10 or 20 y shift in the time scale due to emplacement delay is negligible at subsequent times after 1000 y.

Volatile elements driven off from high-level waste during solidification (such as by calcination and incorporation into glass) are assumed to be trapped in another waste form. It is expected that regulations will require all iodine to be retained. When defined, this may be handled by AMRAW with separate runs if analysis of these elements is needed. The contributions by iodine to local dose rates, for the cases reported here, is found to be negligible for total body dose and also for the iodine-sensitive thyroid. That is, other radionuclides dominate. Table 8-5 summarizes sample output data from Appendix L, for Zone 1 local dose rates and nonspecific dose rates. Domination by other nuclides is also true for total body nonspecific dose, but thyroid non-

Table 8-5. Effect of Increasing Iodine Retained in Waste from 0.1% to 100%

Time, y	0.1% I (Case 48)				100% I					
	Total Body		Thyroid		Total Body			Thyroid		
	I-129	Total	I-129	Total	I-129	Total	% Incr.	I-129	Total	% Incr.
Local Dose Rates (Zone 1), mrem/y										
10^2	2.76E-12	2.55E-3	8.75E-12	5.99E-5	2.76E-9	2.55E-3	0	8.75E-9	5.99E-5	0
10^3	3.79E-11	5.04E-3	1.08E-10	3.74E-4	3.79E-8	5.04E-3	0	1.08E-7	3.74E-4	0
10^4	3.56E-10	1.48E-2	1.00E-9	1.27E-3	3.56E-7	1.48E-2	0	1.00E-6	1.27E-3	0
10^5	1.72E-9	3.91E-3	4.85E-9	4.04E-5	1.72E-6	3.91E-3	0	4.85E-6	4.53E-5	12
10^6	4.22E-9	5.12E-3	1.19E-8	6.85E-5	4.22E-6	5.12E-3	0	1.19E-5	8.04E-5	17
Nonspecific Dose Rates, man-rem/y										Incr. Factor
10^2	1.93E-11	7.09E-2	1.38E-8	5.77E-8[a]	1.93E-8	7.09E-2	0	1.38E-5	1.39E-5[a]	240
10^3	1.36E-10	1.47E-3	9.76E-8	6.33E-7	1.36E-7	1.47E-3	0	9.76E-5	9.82E-5	154
10^4	4.16E-8	1.81E-2	2.98E-5	3.15E-5	4.16E-5	1.81E-2	0	2.98E-2	2.98E-2	945
10^5	8.51E-6	4.57E-1	6.09E-3	6.09E-3	8.51E-3	4.66E-1	0	6.09E-0	6.09E-0	1000
10^6	4.08E-5	1.19E-0	2.92E-2	2.92E-2	4.08E-2	1.23E-0	3.3	2.92E+1	2.92E+1	1000

[a]Thyroid nonspecific dose due to C-14 and I-129.

specific dose is due only to C-14 and I-129; iodine comprises 26% of the total at 100 y rising to 100% by about 50,000 y. If all of the iodine in the spent fuel is assumed to remain in the high-level waste instead of 0.1%, iodine increases by a factor of 1000. From Table 8-5, it may be seen that this increase in iodine has no effect on the three-significant-figure total for all nuclides for total body dose rates, either local or nonspecific. Local thyroid dose does show an increase after 10,000 y, ranging to an increase of up to 17% at 10^6 y. As nonspecific thyroid dose is due only to C-14 and I-129, this category increases directly with I-129 increase. At 10^6 y, for example, the nonspecific total thyroid dose rate with iodine increased by the factor of 1000 becomes 29.2 man-rem/y (Table 8-5).

Adjustments of results for variation in the inventory of any other simply decaying nuclide may be made similarly to the above adjustment for iodine. Adjustment for large changes in the initial inventory (at the end of repository operations) of members of decay chains becomes complex and is best handled by rerunning AMRAW with the changes. In discussion of AMRAW-B, the Economic Model (see Table 8-12 in Vol. III), it is shown that attribution of total damages over the 10^6 y study period to the initial inventory attributes 5.2% of the total to plutonium initially present. That is, damages from plutonium daughters are attributed back to parents in proportion to the initial mass distribution. Therefore, as an approximation it may be noted that an increase of Pu by a factor of 200 leads to an increase in the 10^6 y damages (such as an integrated dose rate) by a factor of $(1 - .052) + 200 \times .052 = 11$. Disposal of spent fuel (with 100% of the Pu) as waste instead of fuel reprocessing waste (with 0.5% of the Pu) increases the Pu content of the waste by a factor of 200, assuming enriched U fuel in both cases. A factor somewhat lower than 200 applies to a comparison with the source term used here, as the latter involves some increased Pu use through recycling. Disposal of spent fuel as waste increases the potential environmental damage due to: 1) a large increase in Pu inventory, 2) a possible increase in leachability if not processed into a leach resistant waste form and 3) an increase in repository area required for the large increase in waste quantity. Further, total damages over the 10^6 y study period also attribute 45.2% to neptunium, 11.3% to americium, and 38.3% to technetium.

With reprocessing, the option of partitioning and transmutation is available to reduce environmental damage by elimination of a portion of these few elements.

B. SENSITIVITY ANALYSIS DISCUSSION

Sensitivity analysis, described in Section 7.A. consists of a series of runs with AMRAW-A plus operation of a portion of AMRAW-A as an auxiliary program for leaching and ground water transport studies. In this chapter, extension of the AMRAW run results is discussed, followed by discussion of chain decay and reconcentration effects.

1. Extension of AMRAW Sensitivity Results. The series of computer runs for the sensitivity analysis (Table 8-6) handles one release scenario or combination at a time to determine relative contributions by each to the total. Three categories of volcanism (volcanic explosion, volcanogenic transport, and diatreme) and meteorite impact are examined. While AMRAW provides for occurrence parameters which are time dependent, the available data during this study is limited to probability estimates which are constant with time. Therefore, the results for any of these sensitivity runs may be scaled up or down linearly with changes in either the occurrence probability, the expected value of the release fraction, or their product (probabilistic release fraction). For example, Case 22 is expulsion to air by volcanic explosion. Table 8-6 includes this event, listing the probability of occurrence as $2.4 \times 10^{-12}\ y^{-1}$ and the release fraction as 0.075. If a probability increase by a factor of 10 is to be considered, it is not necessary to rerun AMRAW. Any result of interest, including an environmental concentration or dose rate, increases by the factor of 10. The relative effect on the total of all events can be evaluated by adding the change increment to the corresponding base case (Case 48) and comparing the base case before and after incrementing with the component change. Similarly, values of the release parameters for other events are listed in Table 8-6 (summarized from Table 6-4). Thus, Cases 23 and 24 (Table 7-2) relate directly to "Volcanogenic Transport" in Table 8-6; Case 25 is a combination of "Volcanic Explosion," "Volcanogenic Transport," and "Diatreme." Linear extension of results for a combination such as this require each component to be changed by

Table 8-6. Summary of Release Parameters for Volcanism and Meteorite Impact

Release Receptor	Parameter	Volcanic Explosion	Diatreme	Meteorite
Air	Probability of occurrence (PROB)[a]	2.4×10^{-12}	2.4×10^{-12}	1.0×10^{-13}
	Release fraction (A1)[b]	0.075	0.006	0.05
	Probabilistic release fraction[c]	1.8×10^{-13}	1.4×10^{-14}	5.0×10^{-15}
		Volcanic Transport		
Land Surface & Surface Water	Probability of occurrence (PROB)	8.1×10^{-12}		1.0×10^{-13}
	Release fraction (A1)	0.075		0.05
	Probabilistic release fraction	6.1×10^{-13}		5.0×10^{-15}

[a]Probability of occurrence is annual probability of volcano or diatreme occurring within the "volcanism effect zone," or a direct strike on repository area by a meteorite.

[b]Release fraction includes effected area of intersection (of repository) and fraction of intersected inventory which is transported.

[c]Probabilistic release fraction is (PROB) x (A1).

the same factor; otherwise, rerun of AMRAW is preferred. The meteorite category relates to Case 26. If discrete events are being considered instead of a probabilistic distribution, the probability becomes equal to unity at the appropriate time.

Comparisons between different events also allow scaling one event to simulate a different event. For example, from Table 8-6, comparing the probabilistic release fractions, meteorite impact results scale as $5.0 \times 10^{-15}/1.8 \times 10^{-13} = 2.78 \times 10^{-2}$ times volcanic explosion to air, or $5.0 \times 10^{-15}/6.1 \times 10^{-13} = 8.20 \times 10^{-3}$ times volcanic transport to land surface or surface water. For the non-probabilistic mode, comparing listed release fractions, meteorite results become two-thirds of volcanic results. As improved data becomes available and the model capabilities are more fully utilized, particularly with regard to time dependent functions, simple relations for linear extension of AMRAW results may not apply.

2. Chain Decay and Reconcentration in Ground Water. Chain decay refers to the behavior of decay series. A member of a decay series may display a net growth for some time due to decay of one or more precursors, reach a maximum value, and then display a net decay as the precursors become depleted. AMRAW avoids using complex chain calculations by use of the nuclide inventories which are input data for each of the times to be calculated. The ratio of the quantity of a nuclide of interest at two times is a factor (DECFAC) which expresses the decay or buildup between the two times (see Section 4.D.1.e. in Vol. I for details). This works well when the various nuclides are transported together but some discussion of the behavior in ground water is necessary.

A reconcentration phenomena can occur when different members of a chain move at different velocities because of different sorption properties. The effect occurs when the daughter migrates faster than the parents. During a band release from continued leaching into ground water, the slower moving parent becomes distributed over a distance in the medi with daughter production by decay all along this path. An increment of daughter leaving the source and moving faster than the parent encounters additions along the way from the parent. Each addition moves with the daughter, augmenting the concentration. This reconcentration continues

until the daughter outruns the leaching edge of the parent, is offset by decay of the accumulating daughter, or discharges. A detailed analysis of this phenomena is given by Burkholder and Cloninger [Bu77a].

However, for reasonable values of the distribution coefficient, K_d, and low ground water velocities, the peak reconcentration effect occurs close to the source. For example, a base case calculation [Bu77a] was made for the last two members of the $^{234}U \rightarrow {}^{230}Th \rightarrow {}^{226}Ra$ decay chain, assuming water velocity of 0.3 m/d, retardation factors for Th and Ra of 50,000 and 500 respectively, and a period of 10,000 y for complete leaching. The resulting maximum reconcentration occurred at a distance of only 50 m (0.03 mile) and the effect disappeared by 1000 m (0.6 mile). At more rapid leach rates, the effect diminishes and moves to shorter distances; at longer leach times to 10^6 y, the peak approaches 160 m (0.1 mile) and disappears by 1600 m (1.0 mile). These distances vary linearly with water velocity. Therefore, considering the velocity of 4×10^{-3} m/d used for Los Medaños, the corresponding distance from the source to a peak reconcentration effect would be only $(4 \times 10^{-3}/0.3) \times 50 = 0.7$ m! While this very interesting phenomena should be kept in mind during repository site studies and separate test calculations made as insurance, it does not appear to warrant adding provisions to AMRAW.

Next, consider other effects of chain decay on calculated migration. In AMRAW, a band release is simulated by a series of pulse releases. Downstream concentrations are superimposed and averaged during each time increment calculated. Briefly the process is as follows:

1) The quantity leached during a time increment is accumulated and released to transport at the end of the time increment with an initial concentration based upon ground water flow past the discharge plane during the time increment.

2) The ratio of concentration at the usage or discharge location to the initial concentration (in the ground water at point of release to ground water) is calculated, considering sorption and dispersion, but not including radiodecay.

3) The result is then corrected for decay (or buildup) by multiplying by the factor (DECFAC) previously defined.

In AMRAW, one nuclide at a time is handled. In effect, the way DECFAC

is used assumes that all precursors migrate with the nuclide being considered. If the radionuclide of interest has no radioactive parent or if a radioactive parent has the same K_d as the daughter, the simplified method used in the AMRAW subprogram (CRATIO) correctly accounts for chain decay. A short-lived daughter of a long-lived parent (e.g., Np-239 daughter of Am-243 in Table 8-7) may be approximated by setting the K_d value for the daughter equal to K_d for the parent; the daughter inventory in this case is dependent upon the parent and in effect moves with the parent. If both parent and daughter are long-lived, the method in AMRAW overstates daughter concentrations if the daughter moves faster than the parent and understates daughter concentrations if the daughter moves slower than the parent. In this case, an intermediate value of K_d assigned to the daughter may provide an approximate corrected representation. A complete interpretation of the validity of these simplified calculations depends upon inspection of the K_d values determined for the specific site for the nuclides in decay groups to be considered. For nuclides where the travel time to a usage or discharge point exceeds the time range to be calculated (i.e., K_d exceeds a "border value"; see Section 7.A.2.a), the calculation method becomes moot.

Table 8-7 lists the decay chains involved with the 25 nuclides included in this study. Several nuclides shown have very short half-lives and do not influence the ground water transport, but they are included in the table for completeness. The only nuclides in Table 8-7 (nuclides in decay series) which show up within 10^6 y at a distance of 10 km are those having $K_d < 15$: isotopes of Np (Sr decays away early in its migration). Other nuclides with low K_d such as C-14, Tc-99, and I-129 are in simple decay and are not affected by chain decay considerations. As mentioned in the previous paragraph, Np-239 can appropriately be assigned the K_d value of its parent, Am-243. This was not done here but is suggested for follow-on work. Substantial reductions in K_d and/or substantial increases in ground water velocity can be encountered before other decay chain members contribute to consequences of a leach incident. In Case 53, reduction of K_d by a factor of 20 reduces K_d for radium from 70 to 3.5, and results in appearance in Zone 2 (at 10 km) within 10^6 y, peaking at about 700,000 y. The parent of Ra-226, Th-230 (see part (c) of Table 8-7), correspondingly has $K_d = 10500/20 = 525$, giving a

Table 8-7. Decay Series Relationships for Radionuclides Studied

(a) Thorium Series

Nuclide	Half-life	K_d [a]
Cm-244	18 y	420
Pu-240	6600 y	1400

(b) Neptunium Series

Nuclide	Half-life	K_d
Pu-241	14 y	1400
Am-241	433 y	1400
Np-237	2.1×10^6 y	10.5
[b] (Pa-233)	27 d	2800
(U-232)	1.6×10^5 y	2100
Th-229	7340 y	10,500
Ra-225	15 d	70

(c) Uranium Series

Nuclide	Half-life	K_d
Am-242m	152 y	1400
(Am-242)	16 h	1400
Cm-242	163 d	420
Pu-238	87 y	4200
U-238	4.5×10^9 y	2100
Th-234	24 d	10,500
Pa-234m	1.2 m	2800
(U-234)	2.5×10^5 y	2100
Th-230	7.8×10^4 y	10,500
Ra-226	1602 y	70
(Ra daughter sequence)		
Pb-210	21 y	2800

(d) Actinium Series

Nuclide	Half-life	K_d
Am-243	7370 y	1400
Np-239	2.4 d	10.5
Pu-239	2.4×10^3 y	4200

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(e)

Nuclide	Half-life	K_d
Sr-90	27.7 y	14
Y-90	64 h	1400

(f)

Zr-93	1.5×10^6 y	1400
Nb-93 m	13.6 y	1400

[a] K_d values are from ref. De73, reduced by 30%.

[b] Nuclides in parentheses are not included in the 25 studied but are listed here for series completeness.

retardation factor (from Eq. 6-7b) of $R_d = 1 + 2.3 \times 525/0.15 = 8049$. The approximate travel distance for the Th-230 during 700,000 y is only slightly over 100 m, but its contribution by decay to Ra-226 buildup is conservatively included by the use of DECFAC. Similarly, Ra-225 (part (b) of Table 8-7) has the parent: Th-229. Burkholder [Bu77a] indicates that K_d for Th is expected to be greater than for Ra for all geologic media. The Ra isotopes may be more appropriately represented by the K_d values for their Th parents, or an intermediate value.

The large uncertainties in available K_d data preclude benefits from further model refinement at this time. Meanwhile, the provisions in AMRAW handle chain decay in an approximate indirect manner without requiring complex calculations.

C. CONSEQUENCE ANALYSIS DISCUSSION

The cases run for consequence analysis, described in Section 7.B., are divided into two series (see Table 7-6): 1) volcanic explosion release to air, and 2) leach incident release to ground water. Extension of the earlier discussion is given in the following paragraphs.

1. Volcanic Explosion Release to Air. A list of the most significant radionuclides as indicated by the base case (Case 48) appears in Table 8-3 and is summarized in Table 8-4. In the base case, the various radionuclides are released a bit at a time according to the probabilistic distributions of several release scenarios. Now it is of interest to compare the earlier list with a list of the most significant nuclides for a one time acute release. Table 8-8 is for a volcanic explosion release to air at 1000 y. There is some change in the nuclides listed compared to Table 8-3. In Zone 8, Tc-99 is dropped and Th-230 is added at 10^5 y; Tc-99 and Ra-225 are dropped and Th-230 and Pb-210 are added at 10^6 y. For the nonspecific category, Tc-99 and Ra-226 are dropped and Am-242m and Np-237 are added at 10^3 y; Tc-99 is dropped and Pb-210 is added at 10^6 y. Addition of Am-242m to the summary from Table 8-4 means that 18 of the 25 nuclides studied are among the most significant contributors to dose at some time following an acute release.

Limited data is available for environmental concentrations to compare with this severe acute event. Table 8-9 compares the calculated

Table 8-8. Most Significant Radionuclides Based Upon Total Body Dose Rates, Versus Time for Volcanic Explosion Release to Air[a]

	Order[b]	10^3	10^4	10^5	10^6
Local Dose Rate Total Body					
Zone 1	1	Am-241	Am-243	Pu-239	Th-229
	2	Am-243	Pu-240	Th-229	Np-237
	3	Pu-240	Pu-239	Np-237	Th-230
	4	Np-239	Np-239	Th-230	Ra-226
	5	Pu-239	Am-241	Ra-226	Pb-210
Local Dose Rate Total Body					
Zone 8	1	Am-241	Am-243	Pu-239	Th-229
	2	Am-243	Pu-240	Th-229	Np-237
	3	Pu-240	Pu-239	Np-237	Th-230
	4	Np-239	Np-239	Th-230	Ra-226
	5	Pu-239	Am-241	Ra-226	Pb-210
Nonspecific Dose Rate Total Body	1	Am-241	Ra-226	Ra-226	Ra-226
	2	Am-243	Am-243	Ra-225	Ra-225
	3	Pu-240	Ra-225	Tc-99	Cs-135
	4	Am-242m	Tc-99	Pb-210	Np-237
	5	Np-237	Am-241	Cs-135	Pb-210

[a]Case 32, volcanic explosion release to air at 1000 y.

[b]The order lists the sequence of contribution of the 5 most significant nuclides, with most significant listed first.

Table 8-9. Comparison of Deposition from Volcanic Explosion Through Repository and 1972 Accumulation from Fallout from Nuclear Weapons Testing

Zone	Nuclide	Land Surface $\mu Ci/cm^2$	1972 Fallout Accumulation $\mu Ci/cm^2$
1	Sr-90	[a] 8.43×10^{-8}	[b] 2.37×10^{-6}
2	" "	4.03×10^{-10}	
4	" "	2.19×10^{-11}	
1	Pu-239	2.33×10^{-2}	[c] 2.65×10^{-7}
2	" "	1.11×10^{-4}	
4	" "	6.06×10^{-6}	

[a] Case 32, volcanic explosion release to air at reference time of 1000 y.

[b] 1972 worldwide accumulation of Sr-90 deposition from "Radiological Quality of the Environment," [EPA76], 12.1 MCi, divided by world surface area, 5.1×10^{18} cm^2 [Hm65].

[c] 1972 cumulative deposit of Pu-239 in New York State [EPA76].

Table 8-10. Total Body Dose Rates Following Volcanic Explosion Through Repository[a]

Zone	1000 y mrem/y	2000 y mrem/y
1	1.12E6[b]	6.74E5
2	1.75E4	1.20E4
3	1.13E3	7.65E2
4	2.68E2	1.75E2
5	4.62E2	2.99E2
6	3.12E3	1.95E3
7	1.34E3	9.32E2
8	4.97E3	2.78E3
	man-rem/y	man-rem/y
Nonspecific	6.51E5	1.32E4

[a] Case 32, volcanic explosion release to air at reference time of 1000 y.

[b] Total body dose rate, total all nuclides; 1.12E6 denotes 1.12×10^6.

deposition from a volcanic explosion (estimated occurrence probability is $2.4 \times 10^{-12}\ y^{-1}$) with published Sr-90 and Pu-239 accumulations from nuclear weapons testing fallout [EPA76]. Sr-90 would decay within the 1000 y prior to the calculated release such that the land surface concentration from volcanic dispersion is everywhere less than the 1972 accumulated fallout. Pu-239 on the other hand, exceeds the measured environmental value by almost 5 orders of magnitude in Zone 1 (the repository and volcanism zone) ranging down to a factor of 23 in Zone 4 (the furthest zone from the repository in the study region).

Total body dose rates, summarized from Appendix M, are listed for each zone in Table 8-10. The indicated dose rate within Zone 1 is too high for continuous residence; a one month exposure would be 100 rem. To place this into perspective, it should be noted that this zone would certainly be inhospitable for some period of time following formation of a volcano. In Zone 2, the dose rate is far above regulatory limits but is not at a lethal level. These results indicate, that while the volcanic event is very unlikely, an occurrence does appear to provide time for protection of the population from excessive radiological consequences.

2. Leach Incident Release to Ground Water. The ground water velocity used in this study, 4.0×10^{-3} m/d, is a factor of 6 greater than the estimated velocity in the principle aquifer above the model repository, to provide for uncertainty. Published values of distribution coefficients, K_d, estimated for U. S. western soil and applicable to a non-salt geologic medium are used. Appropriate values for K_d for various degrees of salinity in Los Medaños area aquifers are not available. The non-salt values are reduced by 30% as an approximate assumed compensation for salinity. In addition, one case (Case 53) has all K_d values further multiplied by 0.05 to provide a more conservative comparison.

A discrete leach incident commencing at a reference time of 100 y is represented by Case 50. Only 4 nuclides appear in Zone 2 (distance of 10 km) within 10^6 y: C-14, Tc-99, I-129, and Np-237. Concentrations versus time are shown in Fig. 8-2. The calculations is AMRAW include calculation of leached quantities, ground water transport, and radiodecay (or buildup and decay in the case of Np-237). The peak concentrations

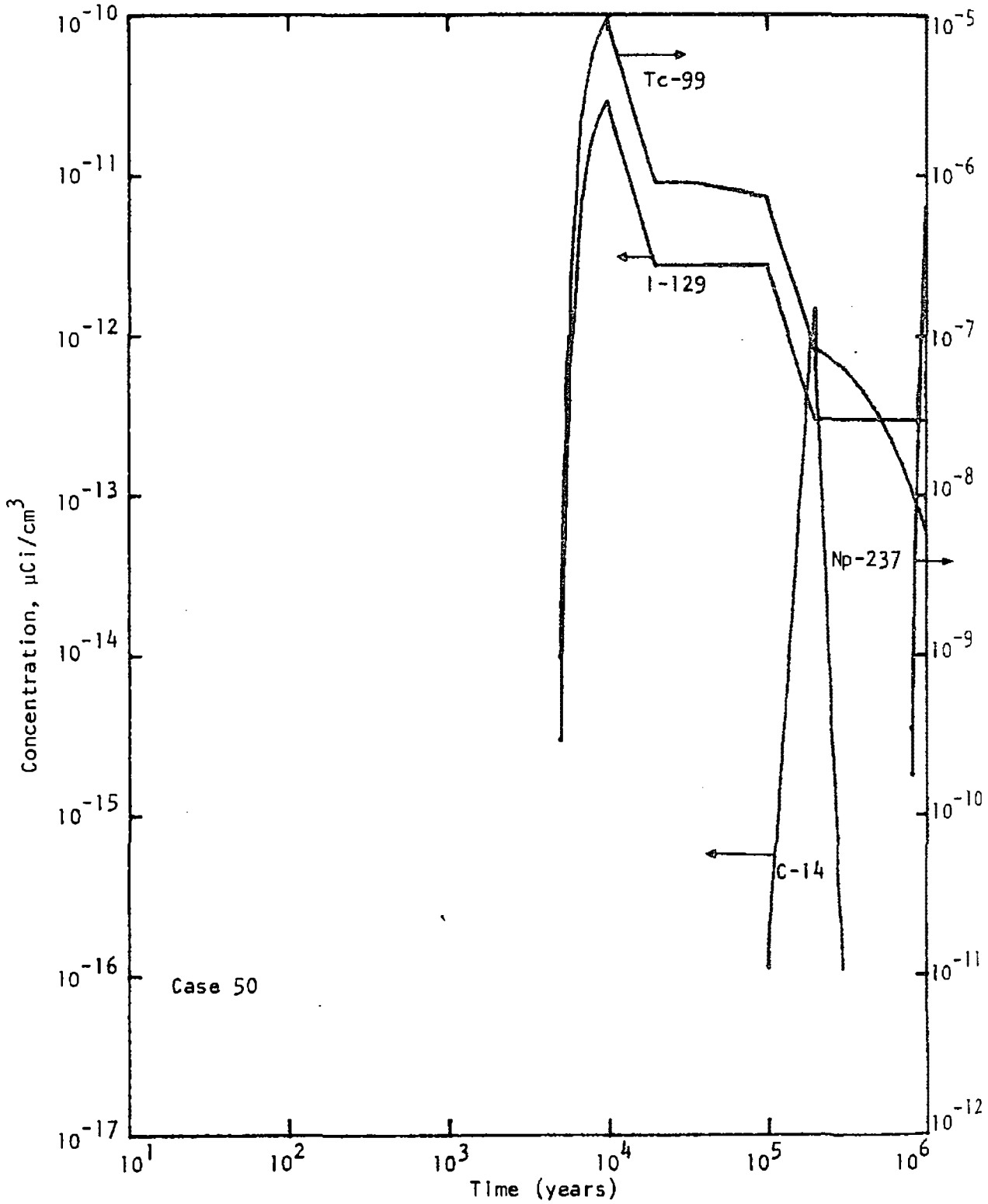

Figure 8-2. Concentration versus time at a distance of 10 km following a leach incident commencing at 100 y.

for Np (K_d = 10.5) do not occur until after 10^6 y; only the early rises toward the peaks appear. The indicated concentrations are low and the corresponding dose rates (Appendix N) are negligible. The orders of importance for the transported nuclides at several times are listed in Table 8-11.

Also listed in Table 8-11 are the orders of importance for the nuclides which appear when K_d is reduced by a factor of 20 (Case 53). The lower K_d values add 3 nuclides discharging within 10^6 y: Cs-135 (K_d now 7.0), Ra-225 and Ra-226 (K_d now 3.5). The maximum concentration of Ra-226 is reached at about 700,000 y in Zone 2. With this large reduction in assumed sorption effectiveness, the maximum total body local dose rate, totaled for all nuclides, is calculated to be 4.72×10^4 mrem/y in Zone 2 (reached after 700,000 y) and 1.79×10^4 mrem/y in Zone 8 (reached after 10^6 y). The nonspecific dose rate reaches 1.46×10^7 man-rem/y after 10^6 y. Note that these are results assuming that the leach incident does occur at 100 y, though the estimated probability of occurrences is 1.4×10^{-7} y^{-1} and also that K_d is reduced by a factor of 20 from the nominal values for all nuclides. Again, this demonstrates the sensitivity of ground water contributions to K_d values.

Table 8-11. Most Significant Radionuclides Based Upon Total Body Dose Rates, Versus Time for Leach Incident Release to Ground Water[a]

	Order	Reference Time, y		
		10^4	10^5	10^6
Case 50				
Zone 2 and nonspecific	1	Tc-99	Tc-99	Np-237
	2	I-129	I-129	Tc-99
	3		C-14	I-129
Zone 8	1	Tc-99	Tc-99	Tc-99
	2	I-129	I-129	I-129
Case 53[b]				
Zone 2	1	Tc-99	Np-237	Ra-226
	2	I-129	Tc-99	Ra-225
	3	C-14	I-129	Cs-135
	4		C-14	Np-237
	5			Tc-99
	6			I-129
Zone 8	1	Tc-99	Tc-99	Ra-226
	2	I-129	Np-237	Ra-225
	3		I-129	Np-237
	4		C-14	Tc-99
	5			I-129
	6			Cs-135
Nonspecific	1	Tc-99	Tc-99	Ra-226
	2	I-129	Np-237	Ra-225
	3	C-14	I-129	Cs-135
	4		C-14	Np-237
	5			Tc-99
	6			I-129

[a]Cases 50 and 53, leach incident initiated by offset faulting at 100 y.

[b]Case 53, distribution coefficient, K_d, decreased by factor of 20 for all nuclides.

APPENDIX A

SUPPLEMENTARY HYDROLOGIC DESCRIPTIONS
(T. E. KELLY)

1. Ogallala Formation. The Ogallala Formation is rather widespread throughout Lea County, and consequently it is locally present along the east side of the Los Medaños area. However, the thickness increases from west to east, and in the project study area the Ogallala is relatively thin and non-water bearing. This deposit consists chiefly of calcareous clay and silt, unconsolidated sand and gravel, and local deposits of lucastrine limestone. All of these lithologic types are intricately interbedded, which makes it extremely difficult to correlate different units for a significant distance. This gives rise to many perched water tables.

Although the Ogallala is not widespread in the Los Medaños area, the porosity and permeability probably are sufficiently high to act as a recharge area for precipitation. Theis [Ts37] estimated that a typical value for the rate of recharge to water-table aquifers in the southern High Plains is about one-quarter to one-half inch of water per year. Nicholson and Clebsch [Ni61] estimated that the porosity of the Ogallala Formation on the High Plains is about 20 percent. In the Los Medaños area the regional water table generally is present near the base of the Ogallala or in the underlying deposits. Consequently, most of the precipitation that falls on the Ogallala deposits will migrate downward to the water table, then laterally--south and west--to the point of discharge.

2. Alluvium. Unconsolidated alluvium comprise the youngest aquifer deposits in the Los Medaños area. The alluvium consists of clay, silt, sand, gravel, caliche, and conglomerate. These are irregularly distributed; greatest thicknesses have been reported in the Pecos Valley where test wells have penetrated 200 feet of alluvium; in other areas these deposits are either thin or absent. Most of the alluvium is present in the drainage channels, including Nash Draw and its tributaries, as well as those channels which empty into the

Pecos River. Along the Eddy-Lea County border, an area known as the James Dune area is characterized by aeolian deposits of silt to fine sand.

In general, the water table underlies the alluvium in the Los Medaños area except along the Pecos River itself. Consequently few wells have been developed in the alluvial deposits; most of these tap perched water tables within the alluvium. As a result, few hydrologic data are available for the alluvium. In general, these deposits are similar to the Ogallala Formation by acting as recharge areas for the underlying rocks, but they could not be considered as major aquifers themselves.

APPENDIX B

REPOSITORY INVENTORY SOURCE DATA

Table B-1. Input Data for Cubic Spline Curve Fitting Program

** INPUT DATA

* PROPERTIES OF ACCUMULATED 10-YEAR OLD WASTE AS A FUNCTION OF AGE.

[a] CONCENTRATION, GRAMS

TIME(YRS)	C-14	SR-90	Y-90	ZR-93	NB-93M	TC-99	I-129	CS-135	CS-137	PB-210
0.	[b]0.0	5.30D+05	1.38D+02	8.44D+05	2.69D+00	9.64D+05	3.46D+02	3.71D+05	1.21D+06	2.12D-07
5.	4.14D+01	3.89D+06	1.01D+03	6.38D+06	2.24D+01	7.32D+06	2.66D+03	2.85D+06	8.95D+06	2.12D-06
10.	1.20D+03	1.06D+07	2.75D+03	1.82D+07	7.03D+01	2.13D+07	7.96D+03	8.96D+06	2.54D+07	9.10D-06
15.	4.07D+03	2.24D+07	5.82D+03	4.00D+07	1.66D+02	4.70D+07	1.77D+04	2.02D+07	5.44D+07	3.90D-05
20.	9.99D+03	4.72D+07	1.10D+04	7.72D+07	3.38D+02	9.01D+07	3.40D+04	3.91D+07	1.02D+08	1.32D-04
25.	2.17D+04	7.11D+07	1.85D+04	1.33D+08	6.11D+02	1.54D+08	5.84D+04	6.80D+07	1.71D+08	3.25D-04
30.	4.04D+04	6.28D+07	1.63D+04	1.33D+08	7.45D+02	1.54D+08	5.84D+04	6.80D+07	1.52D+08	4.51D-04
40.	4.04D+04	4.91D+07	1.28D+04	1.33D+08	9.29D+02	1.54D+08	5.84D+04	6.80D+07	1.21D+08	7.00D-04
130.	3.99D+04	5.33D+06	1.38D+03	1.33D+08	1.20D+03	1.54D+08	5.84D+04	6.80D+07	1.51D+07	4.68D-03
330.	3.90D+04	3.84D+04	9.97D+00	1.33D+08	1.21D+03	1.54D+08	5.84D+04	6.80D+07	1.48D+05	4.74D-02
1030.	3.58D+04	1.22D-03	3.17D-07	1.33D+08	1.21D+03	1.53D+08	5.84D+04	6.80D+07	1.40D-02	7.78D-01
3030.	2.81D+04	4.57D-25	1.19D-28	1.33D+08	1.20D+03	1.52D+08	5.84D+04	6.80D+07	1.20D-22	6.16D+00
10030.	1.21D+04	0.0	0.0	1.32D+08	1.20D+03	1.49D+08	5.84D+04	6.79D+07	0.0	3.64D+01
30030.	1.07D+03	0.0	0.0	1.31D+08	1.19D+03	1.39D+08	5.83D+04	6.75D+07	0.0	1.27D+02
100030.	2.25D-01	0.0	0.0	1.27D+08	1.15D+03	1.11D+08	5.82D+04	6.65D+07	0.0	2.88D+02
300030.	7.00D-12	0.0	0.0	1.16D+08	1.05D+03	5.77D+07	5.77D+04	6.35D+07	0.0	3.08D+02
1000030.	1.18D-48	0.0	0.0	8.38D+07	7.59D+02	5.85D+06	5.61D+04	5.40D+07	0.0	5.47D+01

TIME(YRS)	RA-225	RA-226	TH-229	TH-230	NP-237	NP-239	PU-238	PU-239	PU-240	PU-241
0.	4.00D-08	1.13D-04	7.09D-03	1.23D+00	5.53D+05	8.96D-02	7.70D+03	3.04D+04	1.99D+04	4.34D+03
5.	3.00D-07	9.82D-04	7.20D-02	9.31D+00	4.15D+06	9.76D-01	6.95D+04	2.36D+05	2.06D+05	3.40D+04
10.	2.27D-06	3.63D-03	4.11D-01	2.58D+01	1.13D+07	7.83D+00	3.92D+05	7.81D+05	1.69D+06	1.37D+05
15.	1.45D-05	1.35D-02	2.63D+00	5.70D+01	2.45D+07	2.11D+01	1.26D+06	1.84D+06	5.11D+06	3.32D+05
20.	5.73D-05	4.07D-02	1.04D+01	1.14D+02	4.76D+07	4.13D+01	3.18D+06	3.74D+06	1.12D+07	6.56D+05
25.	1.48D-04	9.05D-02	2.71D+01	2.04D+02	8.34D+07	6.00D+01	6.10D+06	7.10D+06	1.90D+07	1.07D+06
30.	1.96D-04	9.94D-02	3.60D+01	2.21D+02	8.35D+07	6.00D+01	5.88D+06	7.13D+06	2.33D+07	8.47D+05
40.	2.93D-04	1.19D-01	5.38D+01	2.63D+02	8.38D+07	5.99D+01	5.46D+06	7.20D+06	2.96D+07	5.30D+05
130.	1.17D-03	5.77D-01	2.14D+02	1.08D+03	8.64D+07	5.94D+01	2.82D+06	7.77D+06	4.25D+07	1.51D+04
330.	3.10D-03	4.81D+00	5.68D+02	4.33D+03	9.11D+07	5.84D+01	6.80D+05	8.99D+06	4.21D+07	7.73D+03
1030.	9.77D-03	6.38D+01	1.78D+03	1.85D+04	9.95D+07	5.49D+01	9.57D+03	1.30D+07	3.92D+07	7.28D+03
3030.	2.83D-02	5.05D+02	5.19D+03	5.95D+04	1.04D+08	4.57D+01	8.14D-01	2.28D+07	3.19D+07	6.16D+03
10030.	8.89D-02	2.99D+03	1.63D+04	1.96D+05	1.05D+08	2.42D+01	1.11D-14	4.16D+07	1.56D+07	3.42D+03
30030.	2.42D-01	1.04D+04	4.44D+04	5.28D+05	1.06D+08	3.96D+00	0.0	4.05D+07	2.00D+06	6.40D+02
100030.	6.71D-01	2.36D+04	1.23D+05	1.20D+06	1.04D+08	7.07D-03	0.0	6.47D+06	1.53D+03	1.82D+00
300030.	1.36D+00	2.52D+04	2.50D+05	1.28D+06	9.77D+07	3.10D-06	0.0	2.22D+04	2.17D-02	9.43D-08
1000030.	1.49D+00	4.48D+03	2.73D+05	2.28D+05	7.79D+07	3.10D-06	0.0	1.14D+01	4.18D-02	0.0

TIME(YRS)	AM-241	AM-242M	AM-243	CM-242	CM-244
0.	5.39D+04	1.04D+03	1.08D+05	3.05D+00	2.66D+04
5.	4.68D+05	1.09D+04	1.17D+06	3.09D+01	3.76D+05
10.	2.35D+06	8.22D+04	9.45D+06	2.16D+02	3.92D+06
15.	5.94D+06	2.19D+05	2.55D+07	5.61D+02	1.03D+07
20.	1.16D+07	4.26D+05	4.98D+07	1.07D+03	1.91D+07
25.	1.92D+07	6.37D+05	7.25D+07	1.50D+03	2.47D+07
30.	1.93D+07	6.23D+05	7.25D+07	1.50D+03	2.04D+07
40.	1.93D+07	5.95D+05	7.24D+07	1.43D+03	1.39D+07
130.	1.72D+07	3.95D+05	7.18D+07	9.51D+02	4.45D+05
330.	1.25D+07	1.59D+05	7.05D+07	3.82D+02	2.09D+02
1030.	4.23D+06	6.51D+03	6.62D+07	1.57D+01	4.77D-10
3030.	3.54D+05	7.12D-01	5.52D+07	1.72D-03	2.60D-43
10030.	1.02D+05	9.73D-15	2.93D+07	2.35D-17	0.0
30030.	1.90D+04	0.0	4.78D+06	0.0	0.0
100030.	5.39D+01	0.0	8.54D+03	0.0	0.0
300030.	2.95D-06	0.0	3.75D+00	0.0	0.0
1000030.	0.0	0.0	3.64D+00	0.0	0.0

Notes:

[a]"Concentration" represents the net accumulated mass in the waste mixture.

[b]Zero value for C-14 at zero reference time is due to a source table starting at a reference time of 5 y.

APPENDIX C

VOLCANISM

The probability of a volcanic disturbance affecting a waste repository in the Los Medaños area is estimated by a two-step process: 1) determination of the maximum rate of occurrence in the Delaware Basin, and 2) modification by the fraction of the basin associated with the repository.

There have been no volcanos in the Delaware Basin since formation during Permian time, though there have been some dike emplacements about 30 million years ago. Assuming the "rate" in the future is no greater than in the past, and using a nominal age of 200 million years for the basin, the volcanism probability is estimated by Kudo [Ku76] to be

$$P \not> 1/200 \times 10^{6} = 5.0 \times 10^{-9},\ y^{-1}. \qquad \text{(C-1)}$$

A 10-km^2 repository has a 4-km radius "volcanism effect zone" (Fig. C-1) with area of 50.3 km^2. This assumes that the average diameter of area affected by a volcano is 2.2 km (see later paragraph) and that the envelope of tangency to the repository represents the effect zone. The total area of the Delaware Basin is 3.10×10^{4} km^2. The probability of volcanism affecting the repository becomes

$$P = (5.0 \times 10^{-9})\ (50.3/3.10 \times 10^{4}) = 8.1 \times 10^{-12},\ y^{-1} \qquad \text{(C-2)}$$

1. <u>Repository Fraction Intercepted</u>. In addition to estimating the probability of occurrence, the average fraction of the repository inventory affected by such an occurrence also must be estimated. Let r_1 = repository radius centered at C_1 (Fig. C-1), r_2 = volcano effect radius with center at C_2 and r = distance between C_1 and C_2.

Assuming $r_2 < r_1$, the area of intersection, a(r), the shaded portion of Fig. C-1, as a function of r is:

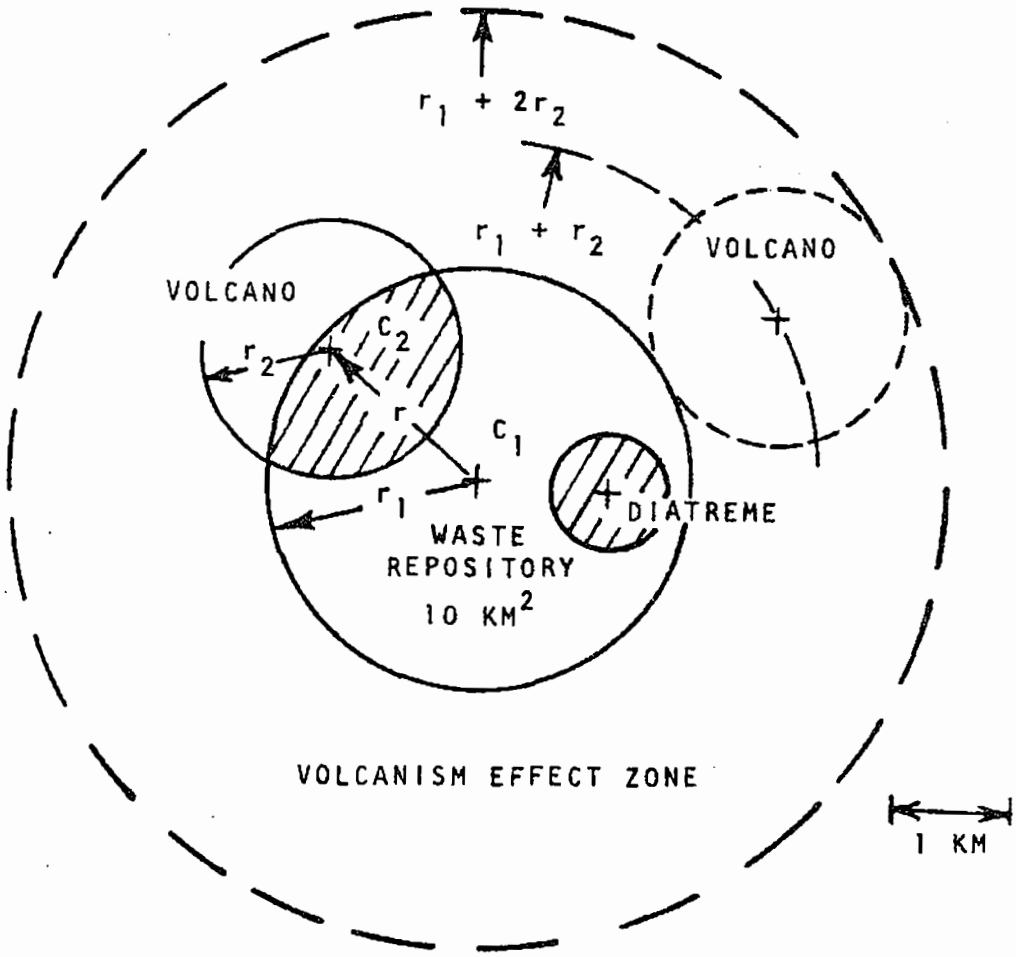

Figure C-1. Volcanic interception of waste repository.

$$a(r) = \begin{cases} 0 \text{ if } r \geq (r_1 + r_2) \\ \text{a complicated function if } (r_1 - r_2) < r < (r_1 + r_2) \\ \pi r_2^{\,2} \text{ if } r \leq (r_1 - r_2) \end{cases} \qquad \text{(C-3)}$$

The average area of intersection of the repository and volcano, occurring with $r < (r_1 + r_2)$ is

$$\frac{1}{(r_1 + r_2)^2} \int_0^{r_1+r_2} a(r)\,r\,dr. \qquad \text{(C-4)}$$

This integral has been approximated by Riemann Sums, for $r_1 = 1.8$ km, and $r_2 = 1.1$ km, to a value of 1.5 km^2. This expected value of the area of intersection represents 1.5/10 = 0.15 fraction of the repository.

A diatreme is a smaller diameter violent volcanic disturbance. Assuming for this case, $r_2 = 0.5$ km, and the same volcanism effect zone as before (4-km radius) (Fig. C-1), the approximation of Eq. C-4 by Riemann Sums gives an expected value of intersection of 0.210 km^2, or a repository fractional area of 0.210/10 = 0.021. Note that this value is much lower than for the volcano because: 1) the diatreme area is smaller, and 2) there is an annular region in the volcanism effect zone where the diatreme does not contact any part of the repository. The diatreme repository fractional area used in the base case for this study is 0.012, which corresponds to $r_2 = 0.4$ km.

2. <u>Alternate Probability Estimate</u>. An estimate of new volcano occurrence by Smith at Battelle Pacific Northwest Laboratories [BNWL74] is based upon an observation that an average of one new volcano every 20 years has occurred during the last 225 years and obtaining a random probability from the affected repository area relative to the total area of the earth. If the average core height, h, of land-sited new volcanos is 430 m and the outer diameter of the affected area is 5h = 2150 m, the probability of a new volcano affecting

a part of a circular 10-km^2 repository can be shown to be

$$P = \frac{\pi(1.8 + 2.15/2)^2}{20 \times 5.1 \times 10^8} = 2.5 \times 10^{-9},\ y^{-1} \qquad \text{(C-5)}$$

where 5.1×10^8 km^2 is the surface area of the earth, and 1.8 km is the repository radius. Smith shows that the historical rate of occurrence of volcanos in mid-continent areas is only 1/28 that of the earth's surface as a whole. On this basis, the probability for volcanism affecting the Los Medaños repository, located in a mid-continent area, becomes

$$P = 2.5 \times 10^{-9}/28 = 8.9 \times 10^{-11},\ y^{-1}. \qquad \text{(C-6)}$$

This is about an order of magnitude greater than the value obtained in Eq. C-2.

3. Global Plate Tectonic Considerations. Press and Siever [Ps74], Dewey [Dy72], and other investigators have demonstrated that approximately 98 percent of the volcanoes on earth are situated in close proximity to global plate boundaries; the remaining two percent are along emerging global plate boundaries such as the rift system in Africa.

Dott and Batten [Do76, page 152], postulate that the basic lithospheric plate mechanism has been operating 2.5 billion years with plate boundaries and patterns of motion changing drastically several times during this time. Thus, the average duration of a particular plate boundary is roughly between 300 and 500 million years and the present configuration has lasted already about 200 million years. Assuming this to be the case, the present boundary between the North American plate and the Pacific plate is not apt to change for the next 100 to 300 million years and the expectations of volcanism in the Los Medaños area during this time can be expected to approach zero probability.

The world geography based upon motion of present day lithospheric plate movement at 1 to 4 cm/y, in accordance with the predictions of Dietz and Holden for the next 50 million years [Di70], suggests that volcanic activity will not occur in the Los Medaños area during the next one

million years.

When further work on the global plate tectonic concept is completed by geologists, consideration of time and spatial requirements should enable more realistic assessment of risk due to volcanism. It may be possible to reduce the probabilities from those used in this study, including definition of a time-dependent probability which takes on finite or increased values only after some period of time.

4. Other Volcanism Processes. Interaction of volcanism with ground water can lead to a phreatomagmatic explosion and resulting marr tuff ring and diatreme. There have been no such incidents in the repository area but there have been many in the Rio Grande rift [Au]. Kudo places the probability of such ground water interaction at 0.3 times the basic volcanism probability.

APPENDIX D

OFFSET FAULTING

(A. SANFORD)

Factors causing offsets by faulting include the mechanisms of 1) basin extension if it were to occur, 2 epeirogenic uplift, 3) subsidence, and 4) volcanism. These can lead to reactivation of old faults or generation of new ones, with a much higher probability expected for reactivation of old faults. The relation between old and new faults is unknown, but the following analysis is based upon the aggregate observed seismic activity. Another mechanism for producing offsets is to reactivate old faults by injection of water for secondary recovery of oil.

1. Number of Earthquakes in The Region Surrounding The Repository. To assign a probability to offset faulting, begin with the earthquake activity observed in the area surrounding the proposed repository:

Geographic limits - 31.4° to 33.4°N
102.4° to 105°W

Geographic area - 50,000 km^2

Time period - 1962 through 1974 (13 years)

Number of shocks detected - 10

Magnitudes (local) from 2.5 to 3.3. Ref: Sanford and Toppozada, 1974 [Sa74] and Sanford, et al., 1976a [Sa].

2. Relation Between Number of Earthquakes and Magnitude. The cumulative number of shocks, ΣN, is related to magnitude by the relation (Richter, 1958 [Rc58])

$$\log_{10}\Sigma N = a - bM_L. \qquad \text{(D-1)}$$

For New Mexico, the value of b is very nearly 1.0 [Sa76]. For the 13-year time period and area of 5×10^4 km^2, we obtain

$$\log_{10}\Sigma N = 3.6 - M_L. \qquad \text{(D-2)}$$

Equation D-2 is illustrated by Fig. D-1. For the same 13-year time period but considering a smaller 1×10^4 km^2 area around the repository, the relation becomes

$$\log_{10}\Sigma N = 2.9 - M_L. \qquad \text{(D-3)}$$

This can be extrapolated to 1.637×10^6 years by adding $\log_{10}(1.637 \times 10^6/13) = 5.10$ to the value of "a", obtaining 8.0, and the expression becomes

$$\log_{10}\Sigma N = 8.0 - M_L. \qquad \text{(D-4)}$$

Note that this equation indicates that the largest earthquake in 1.637×10^6 years will be of magnitude 8. A magnitude 8 earthquake is a conservative estimate of the largest earthquake likely to occur in that region. A more realistic upper limit might be 7.5. This is also the magnitude estimated by Sanford to be required to create a fracture adequate to interconnect aquifers above and below a repository in the Los Medaños area.

3. Faulting. King and Knopoff (1968) [KiC68] established a relation between magnitude and the fault parameters L (length of faulting) and D (maximum displacement)

$$\log_{10}LD^2 = 2.24\ M_L - 4.99 \qquad \text{(D-5)}$$

The ratio D/L is generally around 10^{-4}. By substituting this ratio into Eq. D-5, L and L^2 can be calculated for all earthquakes occurring in 1.637×10^6 years. The summation of L^2 is 20,000 km^2 and is the total fault surface that has some movement during the 1.637×10^6-year period. The long-term average of fault surface over which some movement occurs becomes

$$\frac{20{,}000\ \text{km}^2}{1.637 \times 10^6} = 0.012\ \text{km}^2/\text{y}. \qquad \text{(D-6)}$$

4. Permian-Pennsylvanian Faults. Subsurface data from drill holes reveal a fair number of faults of Late-Pennsylvanian-Early

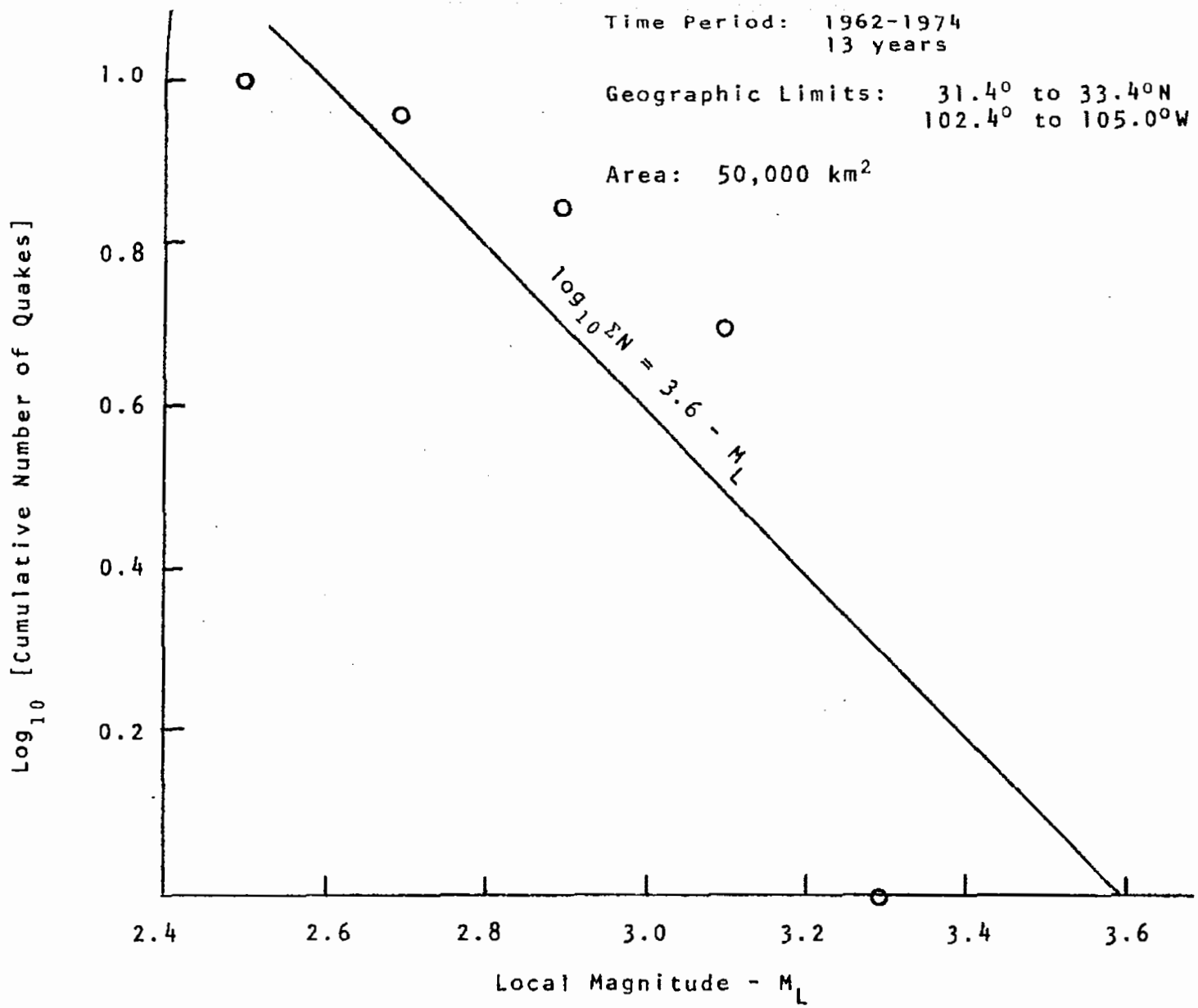

Figure D-1. Number of earthquakes versus local magnitude.

Permian age (Foster, 1974) [Fs74] beneath the salt beds. Well-sampling of the subsurface is widely spaced or missing over much of the 10^4 km^2 area surrounding the site. However, judging from the fault density in areas that have been adequately sampled, the probability of an old fracture beneath this area is a density of one per 5 km. Only movements on fractures close to the salt have a chance of penetrating the repository.

5. Probabilities. Assuming the 10 km^2 repository may be represented with linear dimensions of 3.16 km, the probability of a fracture beneath the repository is 3.16/5 = 0.6. The probability that movement on a fault beneath the repository will penetrate the repository is estimated by Sanford at 0.2.

6. Probability of Offset Faulting (yearly basis). Combining the previous parameters, the annual probability of a fault penetrating the repository becomes

$$\frac{\text{Average Fault Surface with Movement/Yr.}}{\text{Total Surface of Permian-Penn. Faults}} \times \begin{pmatrix}\text{Prob. of fracture}\\ \text{beneath repository}\end{pmatrix} \times \begin{pmatrix}\text{Prob. of}\\ \text{movement}\\ \text{on fault}\end{pmatrix}$$

$$= \frac{0.012\ km^2/y}{10^4\ km^2} \times 0.60 \times 0.20 = 1.4 \times 10^{-7},\ y^{-1}. \qquad \text{(D-7)}$$

A reasonable range for this estimate is 2.9×10^{-8} — 7.2×10^{-7}. These are the probabilities for use when considering exposure of salt to circulating water by faulting in this region.

The probability of having rupture through the repository extending to the surface is estimated by Sanford to be at least an order of magnitude less than the numbers stated above. The fault trees used here conservatively use one order of magnitude less for this extension to the surface.

Assignment of probabilities to the individual mechanisms that can cause faulting may not be necessary because, regardless of cause, the result is the same. The only exception would be if the faulting were induced by water flooding for secondary recovery of oil. In this case,

the probabilities might be initially fairly high (if the flooding was near the repository) and then become very low or non-existent within a 100-year period. It is still not known whether most if not all of the observed activity near the repository is caused by water injection or mining activities.

APPENDIX E

METEORITE IMPACT AND SURFACE EROSION

1. Meteorite Impact. The total depth (surrounding plane to bottom of crushing zone) of a meteorite impact crater is approximately 1/3 of the diameter. Claiborne and Gera [Cℓ74] report from the literature the following predicted impact probabilities:

$$300 \text{ m deep } (\sim 1 \text{ km dia.}) = 1 \times 10^{-13}/\text{km}^2 \cdot \text{y}$$

$$600 \text{ m deep } (\sim 2 \text{ km dia.}) = 2 \times 10^{-14}/\text{km}^2 \cdot \text{y}$$

To exhume material from burial at a depth of 800 m, using a relationship by Hartman [Cℓ74]

$$N = k\, D^{-2.4} \qquad \text{(E-1)}$$

where N is number of craters with diameter greater than D, and k is an empirical constant,

$$\frac{N_{800}}{N_{600}} = \left(\frac{D_{800}}{D_{600}}\right)^{-2.4} = \left(\frac{3 \times 800}{3 \times 600}\right)^{-2.4} \qquad \text{(E-2)}$$

$$= (1.333)^{-2.4} = 0.501$$

or

$$N_{800} = 0.50 \times 2\text{x}10^{-14} = 1\text{x}10^{-14},\ (\text{km}^2\text{-y})^{-1}. \qquad \text{(E-3)}$$

For a 10 km^2 repository, the probability of a direct strike by a meteorite of enough energy to exhume material from a depth of 800 m is

$$P = 10 \times 1 \times 10^{-14} = 1 \times 10^{-13},\ y^{-1}. \qquad \text{(E-4)}$$

The greatest part of the ejected material would fall back inside the crater and in the immediate vicinity to form the crater rim. It is

assumed here that 5 percent of the repository inventory would be ejected into the air and 5 percent initially dispersed over land surface (and surface water). The sum, 10 percent, is considered by Claiborne and Gera to be about 10 times as large as a "reasonable assumption" for ejected material and it is therefore considered to be conservative.

2. Surface Erosion. Examples of surface erosion rates [Ge72] are

Drainage	cm/1000 y
Colorado Plateau*	17
Pacific slopes, California	9
Total U.S.	6

According to Claiborne and Gera [Cl74], Nash Draw, west of the Los Medaños area, has lowered at 10 cm/1000 y, mostly due to dissolution and subsidence. A drastic change in the rate of erosion could be caused by a significant uplift in the area.

Considering a conservative erosion rate assumption of 10 cm/1000 y, denuding a repository at a depth of 800 m requires

$$\frac{800}{0.10/1000} = 8 \times 10^6 \text{ y.}$$

Thus, at this erosion rate, there is a probability of 1.0 that the waste disposal horizon becomes exposed after 8 million years. It appears that an erosion rate 5 times higher (50 cm/1000 y) would be an absolute maximum and that there is therefore a zero probability for denuding in less than

$$\frac{8 \times 10^6}{5} = 1.6 \times 10^6 \text{ y.}$$

* The Colorado Plateau is an uplifted region having a high erosion rate.

Accordingly, the probability for exposing the waste by erosion may be represented by a ramp function as indicated in Fig. E-1.

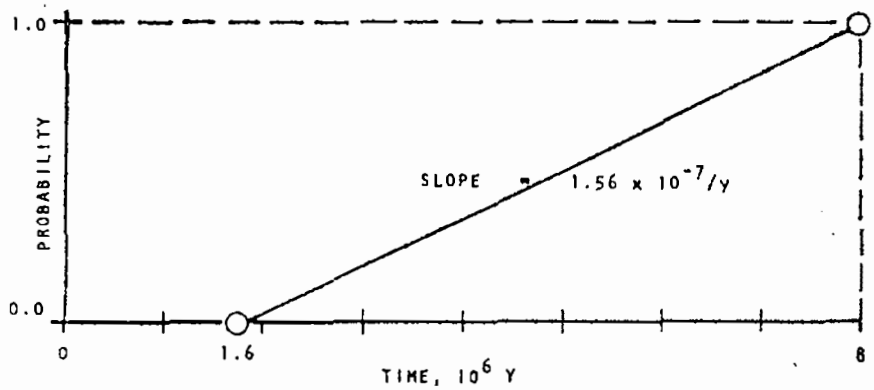

Figure E-1. Probability function for exposure by surface erosion.

APPENDIX F

ALLOCATION OF RADIOISOTOPES TO ZONES

The first step in obtaining environmental concentrations is to allocate the initial releases to the environmental receptors in each zone. This is done using zone dispersion allocation factors (ZONALO). Values of ZONALO are not calculated within AMRAW but are determined by application of existing dispersion models or codes, considering the effective surface areas of land and water in each zone, and are furnished to AMRAW as input data. As discussed in Section 6.C.1, dispersion factors for releases to air are obtained by use of data from an air dispersion code. Direct transfer to land surface (and associated surface water) and dispersion by ballistic flight, lava flows, and other processes not covered by air dispersion codes, is not well modeled at this time. For this purpose, in the absence of a more complete land dispersion model, a simplified $1/r^2$ basis is used.

The density of radioisotope distribution on the ground surface surrounding the repository as a result of a direct release to land surface event is assumed to be proportional to

$$\frac{1}{r^2} \quad \text{if} \quad r \geq r_o$$

$$\frac{1}{r_o^2} \quad \text{if} \quad r < r_o,$$

where r is the radial distance to the center of Zone 1 and r_o is the radius of Zone 1.

Let Z_i = fraction of total amount released which is deposited in Zone i. Then, if all the release is assumed to be deposited only in the zones comprising the study region,

$$Z_i = \frac{\iint_{\text{Zone } i} \left(\frac{1}{r^2}\right) dA}{\sum_{\text{All zones}} \iint \left(\frac{1}{r^2}\right) dA}$$

where

$$\iint_{\text{Zone } 1} \left(\frac{1}{r^2}\right) dA = \iint_{\text{Zone } 1} \left(\frac{1}{r_o^2}\right) dA.$$

Values for these expressions have been approximated, and the results are the $1/r^2$ dispersion allocation factors. When multiplied by the appropriate receptor area fractions in the zones, the zone allocation factors, ZONALO(JF,IZ), are obtained for input to AMRAW, where JF designates the environmental receptor and IZ designates the zone.

The $1/r^2$ dispersion for land surface is considered here to be conservative as it results in distribution to the entire study region, while the visualized mechanisms more likely restrict the transport to a relatively small area surrounding the repository. It should be emphasized that the dispersion basis is not fixed within AMRAW and results of any other appropriate basis may be used for the input data. Other bases include: 1) a different distance functional relationship than $1/r^2$, 2) a land dispersion model and code, or 3) assumed sensitivity analysis dispersions such as weighting in favor of denser population areas.

APPENDIX G

BIOACCUMULATION FACTORS IN EDIBLE AQUATIC ORGANISMS

Table G-1. Fresh Water Habitat

Isotope	Fish[a]	Invertebrates[a]	Aquatic Plants[a]	Waterfowl[b]
C-14	4.55E+03	9.09E+03	4.55E+03	
Sr-90	5.00E+00	1.00E+02	5.00E+02	
Y-90	2.50E+01	1.00E+03	5.00E+03	
Zr-93	3.33E+00	6.67E+00	1.00E+03	
Nb-93m	3.00E+04	1.00E+02	8.00E+02	
Tc-99	1.50E+01	5.00E+00	4.00E+01	
I-129	1.50E+01	5.00E+00	4.00E+01	
Cs-135	3.00E+03	1.00E+02	5.00E+02	3.00E+03
Cs-137				
Pb-210	3.00E+02	1.00E+02	2.00E+02	
Ra-225	5.00E+01	2.50E+02	2.50E+03	
Ra-226				
Th-229	3.00E+01	5.00E+02	1.50E+03	
Th-230				
Np-237	1.00E+01	4.00E+02	1.00E+03	
Np-239				
Pu-238	3.50E+00	1.00E+02	3.50E+02	
Pu-239				
Pu-240				
Pu-241				
Am-241	2.50E+01	1.00E+03	5.00E+03	
Am-242m				
Am-243				
Cm-242	2.50E+01	1.00E+03	5.00E+03	
Cm-244				

Notes: [a]Ref.: Tp72

[b]Ref.: ORNL75

Table G-2. Salt Water Habitat

Isotope	Fish[a]	Invertebrates[a]	Aquatic Plants[a]	Waterfowl[b]
C-14	1.79E+03	1.43E+03	1.79E+03	
Sr-90	5.00E-01	6.25E+00	1.25E+01	
Y-90	2.50E+01	1.00E+03	5.00E+03	
Zr-93	2.00E+02	2.00E+01	2.00E+03	
Nb-93m	3.00E+04	1.00E+02	1.00E+03	
Tc-99	1.00E+01	5.00E+01	4.00E+03	
I-129	1.00E+01	5.00E+01	4.00E+03	
Cs-135	3.00E+01	2.00E+01	5.00E+01	3.00E+03
Cs-137				
Pb-210	3.00E+02	1.00E+03	5.00E+03	
Ra-225	5.00E+01	1.00E+02	1.00E+02	
Ra-226				
Th-229	1.00E+04	2.00E+03	3.00E+03	
Th-230				
Np-237	1.00E+01	1.00E+01	6.00E+00	
Np-239				
Pu-238	3.50E+00	2.00E+02	1.00E+03	
Pu-239				
Pu-240				
Pu-241				
Am-241	2.50E+01	1.00E+03	5.00E+03	
Am-242m				
Am-243				
Cm-242	2.50E+01	1.00E+03	5.00E+03	
Cm-244				

Notes: [a]Ref.: Tp72
[b]Ref.: ORNL75

APPENDIX H

MEAT AND MILK PRODUCTION RATES

(S. E. LOGAN)

Meat production per head of beef cattle:

Calving rate = 0.85 (per year). 0.20 held back for herd replacement and 0.20 held back for yearling program. Net calves exported = 0.45, at 193 kg (425 lb) average.

0.45 x 193 = 86.9 kg/y

Yearling program grazes calves for another year and adds 136 kg (300 lb) to a 329 kg (725 lb) total.

0.2 x 329 = 65.8 kg/y

Cull cows, 5-8% at 454 kg (1000 lb)

.06 x 454 = 27.2 kg/y

(the balance from replenishment represents death loss)

Total: 180 kg/y (397 lb/y)

Meat production per head of hogs:

At 7-8 pigs/litter and 2 litters/y, yield is 15 pigs/y per sow. What is the sow fraction in a hog population? If we assume 1 year for each pig to become a 95 kg (210 lb average for 200-220 lb range) fat hog, the average population will be 15 hogs per sow, and if we assume 1 breeding boar per 10 sows,

sow fraction = 1/1 +15 + 0.1 = 0.062

fat hog fraction = 15/1 + 15 + 0.1 = 0.932

Production of meat per head becomes

0.932 x 95 = 88.5 kg/y (use 90.)

Meat production per head of sheep:

100% annual lamb crop. Graze to 31.8 kg (70 lb) and lamb feed lots (local) to 45.4 kg (100 lb) fat lambs for export.

1.00 x 45.4 = 45.4 kg/y (use 45.)

Meat production per chicken:

If chicken population represents imported chicks being raised for export as broilers at 1.59 kg (3.5 lb), and if 3 months are assumed as residence time for growth, the annual production rate per head of chicken is

1.59 x 12/3 = 6.36 kg/y

If chicken population represents laying hens used for egg production, and assuming 200 eggs/y per laying hen and an average of 0.050 kg/egg, the production rate of eggs per head of chicken is

200 x 0.05 = 10.0 kg/y

If it is assumed that two-thirds of the chickens are being raised as broilers and one-third are used for egg production, the weighted average production rate per head of chicken is

$$6.36 \times 2/3 + 10.0 \times 1/3 = 7.6 \text{ kg/y}$$

Meat production equivalent of hay and grain:

Exported calves at 193 kg (425 lb) are conditioned on roughage (hay) for about 250 days to a weight of 318 kg (700 lb). Average day weight of hay consumption is 10 kg/day. This represents

$$(318-193)/(250 \times 10) = 0.050 \text{ kg beef/kg hay}$$
$$\text{or } 0.050 \text{ kg/d (beef)/kg/d(hay)}$$

After conditioning, they are fattened on a feed lot for 120 days to a fat cattle weight of 450 kg (1000 lb), on a diet of 9 kg/day grain and 2 kg/d hay. Assuming the weight gain from hay is at the same rate as during conditioning, the hay "component" is

$$0.050 \times 2 \times 120 = 12 \text{ kg}$$

The balance of the weight gain, from grain, is

$$(450-318-12)/(120 \times 9) = 0.111 \text{ kg beef/kg grain.}$$

The equivalence factors from above are

hay: 0.050 kg/y (beef)/kg/y (hay)
grain: 0.111 kg/y (beef)/kg/y (grain)

Milk production equivalent of hay:

10 kg/d consumption of hay; 11 ℓ/day milk production

1.1 ℓ milk / kg hay.

Milk production equivalent of drinking water:

64 ℓ/day (17 gal/day) drinking water per producing cow.

11/64 = 0.17 ℓ milk / ℓ water

Meat production equivalent of drinking water:

40 ℓ/day (approximately 10 gal/day) drinking water per head; 180 kg/y meat production per head

180/(40 x 365) = 0.012 kg meat/ℓ water

The resulting meat production and milk production rates for each zone in the region are compiled in Table H-1 and Table H-2 respectively.

Table H-1. Meat Production

Zone	1	2	3	4	5	6	7	8
Range land:								
Cattle (1000's)	0.3	54.7	100.	39.	53.	71.	140.	0
kg/y (180/head)	5.4 E4	9.85 E6	1.80 E7	7.02 E6	9.54 E6	1.28 E7	2.52 E7	0
Sheep (1000's)	0.2	43.6	1.3	12.9	15.6	21.3	165.7	0
kg/y (45/head)	9.00 E3	1.96 E6	5.85 E4	5.81 E5	7.02 E5	9.59 E5	7.46 E6	0
Total kg/y	6.30 E4	1.18 E7	1.81 E7	7.60 E6	1.02 E7	1.38 E7	3.27 E7	0
Cultivated land:								
Beef from exported hay								
75% of hay (10^6 kg/y)	0	0	3.6	4.7	39.	22.5	145.	86.
kg meat/y (.05/kg)	0	0	1.80 E5	2.35 E5	1.95 E6	1.13 E6	7.25 E6	4.30 E6
Hogs (1000's)	0	0	1.8	1.6	14.8	6.4	5.2	4.5
kg/y (90/head)	0	0	1.62 E5	1.44 E5	1.33 E6	5.76 E5	4.68 E5	4.05 E5
Chickens (1000's)	0	0	16.5	59.6	282.9	28.2	21.7	200.
kg/y (7.6/head)	0	0	1.25 E5	4.53 E5	2.15 E6	2.14 E5	1.65 E5	1.52 E6
Total kg/y	0	0	4.67 E5	8.32 E5	5.43 E6	1.92 E6	7.88 E6	6.23 E6

Note: Zone 1 is the repository site; Zone 2 is the portion of Eddy County not in Zone 1 or 8; Zone 8 is irrigated land in Eddy County.

Table H-2. Milk Production.

Zone	1	2	3	4	5	6	7	8
Milk cows	0	0	679	360.	384.	1680.	2490.	721.
ℓ/y	0	0	2.73 E6	1.45 E6	1.54 E6	6.75 E6	1.00 E7	2.89 E6
25% of hay, 10^6 kg/y	0	0	1.2	1.6	13.	7.5	48.3	28.8
milk equiv., ℓ/y	0	0	1.32 E6	1.76 E6	1.43 E7	8.25 E6	5.31 E7	3.17 E7
Total milk, ℓ/y	0	0	4.05 E6	3.21 E6	1.58 E7	1.50 E7	6.31 E7	3.46 E7

Note: Zone 1 is the repository site; Zone 2 is the portion of Eddy County not in Zone 1 or 8; Zone 8 is irrigated land in Eddy County.

APPENDIX I

SUPPLEMENTARY BIOLOGY DISCUSSION
(J. R. GOSZ)

The study area near Carlsbad is an area which is not suited to dry-land farming because the soils are sandy and rainfall is low and undependable. The area is suitable for native pasture and wildlife habitat; therefore, the major link between contamination in the study area and the effect on humans is expected to be through consumption of sheep, cattle or game species. The plant production in the area can be expected to range between 70 and 440 kg per hectare (400 to 2400 pounds per acre) of air dry forage depending on whether the site is in poor or excellent condition.

The study area is subject to severe wind erosion if the plant cover is seriously depleted. This condition may be an important factor in the transfer of contamination in the study area to human habitation to the east (Hobbs, New Mexico) and northeast (Lovington, New Mexico).

A preliminary list of species of the Los Medaños area has been compiled. The species of the area which are expected to interact with the human populations by one of several means are listed in Table I-1. The plant species are involved primarily as the dominant forage species for animals which may be in the human food chain. The animals listed may be human food items or may be species which are attracted to human dwellings (e.g., house mouse).

Nine species on the Federal endangered or threatened species list are reported to use the area (Burrowing Owl, Lesser Prairie Chicken, Peregrine Falcon, Prairie Falcon, Bald Eagle, Ferruginous Hawk, Long-billed Curlew, Mountain Plover, Snowy Plover). All the species are terrestrial species, except the Snowy Plover which is listed as an aquatic species. All species are at least a secondary step in the food-chain after primary producers, but many are carnivores and are therefore the third step or higher in the food-chain. The State of New Mexico considers two species in the area as endangered (McCown's Longspur, Pupfish species). The pupfish are found in many ponds and

sink-holes throughout the area and thus would be in immediate contact with any contaminated surface water. Considering full-time residence of many species in the area of concern, or the level in the food-chain, these species would be subject to at least the levels of radiation that man would receive. Various environmental relationships potentially could be altered by a release of radionuclides in the area of the disposal sites.

Predator species, including many endangered species, would be subject to the highest levels of radiation accumulation. If radiation levels cause a decrease in predator numbers, prey species including rodents, rabbits, etc., may increase. These species are herbivore consumers and would therefore decrease the amount of vegetation.

The area is an ecotone between Chihuahuan and desert grassland-shrub communities. An increase in vegetation removal, as already caused by grazing impact, would increase woody-shrub perennials. These shrubs would accumulate more airborne dust contamination of radionuclides. Also, this would decrease grazing capacity for cattle and change the values used in the terrestrial model. Any cattle grazing in this area would then be forced to shift diet to perennial species and thus ingest higher levels of radiation.

Table I-1. Species in Los Medaños Area Interacting with The Human Population

Mammals	
House mouse	Mus musculus
Blacktail jackrabbit	Lepus californicus
Desert cottontail	Sylvilagus auduboni
Mule deer	Odocoileus hemionus
White-tailed deer	Odocoileus virginianus
Pronghorn	Antilocapra americana
Birds	
Mallard	Anas platyrhynchos
Pintail	Anas acuta
Shoveler	Spatula clypeata
Green-winged teal	Anas carolininsis
Canvasback	Aythya valisineria
Redhead	Aythya americana
Lesser prairie chicken	Tympanuchus pallidicinctus
Scaled quail	Callipepla squamata
Mourning dove	Zeniadura macroura
House sparrow	Passer domesticus
House finch	Carpodacus mexicanus
Brown towhee	Pipiko fuscus
Vascular Plants	
Shrubs and Trees:	
Estafiata	Artemisia frigida
Mesquite	Prosopis juliflora
Shinnery oak	Quercus havardii

Grasses:

Sand bluestem	Andropogon hallii
Silver bluestem	Andropogon saccharoides
Little bluestem	Andropogon scoparius
Side-oats grama	Bouteloua curtipendula
Black grama	Bouteloua eriopoda
Blue grama	Bouteloua gracilis
Hairy grama	Bouteloua hirsuta
Lovegrasses	Eragrostis spp.
Giant dropseed	Sporobolus giganteus
Needle-and-thread	Stipa comata

Forbs:

Milkvetches	Astragalus spp.
Fremont goosefoot	Chenopodium fremontii
Croton	Croton neomexicana
James hiddenflower	Cryptantha jamesii
Spectacle pod	Dithyrea wislizenii
Buckwheat	Eriogonum spp.
Stemless hymenoxys	Hymenoxys acaulis
Bladderpod	Lesquerella gordonii
Plains blackfoot	Melampodium leucanthus
Evening primrose	Oenothera mexicana
Beard tongue	Penstemon buckleyi
Caterpillar-weed	Phacelia crenulata
Indianwheat	Plantago sp.
Scurfpea	Psoralea esculenta
Threadleaf groundsel	Senecio longilobus
Fendler globemallow	Sphaeralcea fendleri
Wrights verbena	Verbena wrightii

APPENDIX J

OUTPUT LISTING OF AMRAW INPUT FOR BASE CASE

1. Directory of AMRAW-A Output Tables. Table J-1 lists the titles of tables in full output from AMRAW-A. The output tables are divided into six sections.

2. Output Listing of Base Case AMRAW Input. Table J-2 is computer output from Section 1 of output, which provides tabulations of Base Case[a] input data for the following variables (defined in the main text):

Definitions of environmental inputs and probability inputs.

Release Model probabilities and related data.

Grams of elements in waste at start of terminal storage.

Grams of radionuclides in waste versus time.

DC1, DRC, RKD and other ground water parameters.

EDC

DISPN

ZONALO

ZONDEP

AREAW

ADJ1 and ADJ2

VOLINT

BIOFAC

DOSFAC

[a]Full run base case for terminal storage phase, Case No. 48, all probabilistic releases.

Table J-1. Directory of AMRAW-A Output Tables

Description	[a]Number of Table Combinations				Total
	Nuclides	Zones	Organs	Environ. Receptors	
SECTION 1. Data Input					
1. Output listing of AMRAW input.	(20	pages)			
SECTION 2. Release to Environment					
1. Release Fractions by Each Cutset, RELOUT	25				25
2. Release Increments to Preliminary Environmental Input Receptors, R1J, from All Release Events, Ci	25			(4 in each table)	25
3. Concentrations at Environment Input Receptor, R2TOT. Units: JF = 1 μCi-y/cm^3, JF = 2 μCi/cm^2, JF = 3 and 4 μCi/cm^3.	25	8			200
SECTION 3. Local Dose to Individual					
1. Average Annual Local Dose to Individual, MAN1L, mrem/y.	25	8	(8 in each table)		200
SECTION 4. Nonspecific Dose to Population					
1. Average Annual Nonspecific Dose to Population, MAN1N, manrem/y.	25		(8 in each table)		25

Table J-1. Directory of AMRAW Output Tables (continued)

	Nuclides	Zones	Organs	Environ. Receptors	Total
SECTION 5. Total Dose by Receptors					
1. Average Annual Local Dose to Individual, MAN2LF for JF = 1 to 4, MAN2L for Total, mrem/y, Total for All Nuclides.		8	8	(4 in each table)	64
2. Average Annual Nonspecific Dose to Population, MAN2NF for JF = 1 to 4, MAN2N for Total, manrem/y, Total for All Nuclides.			8	(4 in each table)	8
SECTION 6. Dose Summary Tables					
1. Average Annual Local Dose to Individual, MAN1L, in Zone , mrem/y.	(25 in each table)	[b] up to 8	(8 in each table)	[c] 5	40
2. Average Annual Nonspecific Dose to Population, MAN1N, manrem/y.	(25 in each table)	[b] up to 8	(8 in each table)	[c] 5	40
Total Number of Tables					627

Note:

a. All output tables, except Section 6 are for 50 time steps, 0 to 10^6 years.

b. Individual zones may be specified.

c. Section 6 may call for a table for each of all times beginning with 100 y or skip some times; 5 tables result if call for every ninth time.

Table J-2. Output Listing of Base Case AMRAW Input

** DEFINITION OF ENVIRONMENTAL INPUTS

JF	DEFINITION
1	AIR
2	GROUND SURFACE
3	SURFACE WATER
4	GROUND WATER

** DEFINITION OF PROBABILITY INPUTS

IFLAG	DEFINITION
0	PROBABILITY (PROB) CONSTANT
1	STEP FUNCTION AT TIME TP CHANGES PROB BY AMOUNT CP
2	RAMP FUNCTION AT TP CHANGES PROB BY SLOPE CP
3	EXPONENTIAL FUNCTION AT TP CHANGES PROB BY TIME CONSTANT CP
4	DELTA FUNCTION, AT TIME TP RELEASE TO ENVIRONMENT IS AAI

** PROBABILITY AND RELATED DATA

JF	NJF	J	NJJ	AA1	PROB	IFLAG	TP	CP
1	3	1	1	5.00E-02	1.00E-13	0	0.0	0.0
1	3	2	1	7.50E-02	2.40E-12	0	0.0	0.0
1	3	3	1	6.00E-03	2.40E-12	0	0.0	0.0
2	3	1	2	3.30E-05	1.00E 00	0	0.0	0.0
					0.0	2	1.60000E 06	1.56000E-07
2	3	2	1	5.00E-02	1.00E-13	0	0.0	0.0
2	3	3	1	7.50E-02	8.10E-12	0	0.0	0.0
3	3	1	3	3.30E-05	1.00E 00	0	0.0	0.0
					1.00E 00	0	0.0	0.0
					0.0	2	1.60000E 06	1.56000E-07
3	3	2	2	5.00E-02	1.00E 00	0	0.0	0.0
					1.00E-13	0	0.0	0.0
3	3	3	2	7.50E-02	1.00E 00	0	0.0	0.0
					8.10E-12	0	0.0	0.0
4	1	1	4	0.0	1.00E 00	0	0.0	0.0
					1.00E 00	0	0.0	0.0
					1.00E 00	0	0.0	0.0
					1.40E-07	0	0.0	0.0

** SELECTED RESIDUAL ELEMENTS IN WASTE
GRAMS AT START OF TERMINAL STORAGE
FOR TOTAL FUEL = 187000. METRIC TONS

C	4.04E 04
SR	1.26E 08
Y	8.34E 07
ZR	6.95E 08
NB	1.21E 03
TC	1.54E 08
I	1.84E 05
CS	4.05E 08
PB	9.08E 02
RA	2.96E-01
TH	1.52E 07
NP	8.35E 07
PU	3.83E 07
AM	9.24E 07
CM	2.55E 07

Table J-2. (continued)

** SELECTED RADIONUCLIDES IN WASTE
GRAMS IN WASTE VERSUS TIME IN YEARS

TIME	C-14	SR-90	Y-90	ZR-93	NB-93M	TC-99	I-129	CS-135	CS-137	PB-210
0.	0.0	5.30E 05	1.38E 02	8.44E 05	2.69E 00	9.64E 05	3.48E 02	3.71E 05	1.21E 06	2.12E-07
5.	6.14E 01	3.89E 06	1.01E 03	6.38E 06	2.24E 01	7.32E 06	2.66E 03	2.85E 06	8.95E 06	2.12E-06
10.	1.28E 03	1.06E 07	2.75E 03	1.82E 07	7.03E 01	2.13E 07	7.96E 03	8.96E 06	2.54E 07	9.10E-06
15.	4.07E 03	2.24E 07	5.82E 03	4.00E 07	1.66E 02	4.70E 07	1.77E 04	2.02E 07	5.44E 07	3.90E-05
20.	9.99E 03	4.22E 07	1.10E 04	7.72E 07	3.38E 02	9.01E 07	3.40E 04	3.91E 07	1.02E 08	1.32E-04
25.	2.17E 04	7.11E 07	1.85E 04	1.33E 08	6.11E 02	1.54E 08	5.84E 04	6.80E 07	1.71E 08	3.25E-04
30.	4.04E 04	6.28E 07	1.63E 04	1.33E 08	7.45E 02	1.54E 08	5.84E 04	6.80E 07	1.52E 08	4.51E-04
40.	4.04E 04	4.91E 07	1.28E 04	1.33E 08	9.29E 02	1.54E 08	5.84E 04	6.80E 07	1.21E 08	7.00E-04
50.	4.04E 04	3.90E 07	1.02E 04	1.33E 08	1.04E 03	1.54E 08	5.84E 04	6.80E 07	9.76E 07	9.60E-04
60.	4.03E 04	3.09E 07	8.06E 03	1.33E 08	1.10E 03	1.54E 08	5.84E 04	6.80E 07	7.85E 07	1.26E-03
70.	4.02E 04	2.43E 07	6.34E 03	1.33E 08	1.14E 03	1.54E 08	5.84E 04	6.80E 07	6.28E 07	1.58E-03
80.	4.02E 04	1.91E 07	4.95E 03	1.33E 08	1.16E 03	1.54E 08	5.84E 04	6.80E 07	4.99E 07	1.94E-03
90.	4.01E 04	1.48E 07	3.06E 03	1.33E 08	1.17E 03	1.54E 08	5.84E 04	6.80E 07	3.65E 07	2.35E-03
100.	4.01E 04	1.15E 07	2.99E 03	1.33E 08	1.18E 03	1.54E 08	5.84E 04	6.80E 07	3.11E 07	2.82E-03
200.	3.96E 04	8.87E 05	2.30E 02	1.33E 08	1.20E 03	1.54E 08	5.84E 04	6.80E 07	2.81E 06	1.28E-02
300.	3.91E 04	7.72E 04	2.00E 01	1.33E 08	1.21E 03	1.54E 08	5.84E 04	6.80E 07	2.05E 05	3.68E-02
400.	3.87E 04	7.82E 03	2.03E 00	1.33E 08	1.21E 03	1.54E 08	5.84E 04	6.80E 07	3.33E 04	7.85E-02
500.	3.82E 04	7.85E 02	2.04E-01	1.33E 08	1.21E 03	1.54E 08	5.84E 04	6.80E 07	3.86E 03	1.39E-01
600.	3.77E 04	7.21E 01	1.87E-02	1.33E 08	1.21E 03	1.54E 08	5.84E 04	6.80E 07	4.13E 02	2.20E-01
700.	3.73E 04	6.10E 00	1.58E-03	1.33E 08	1.21E 03	1.53E 08	5.84E 04	6.80E 07	4.08E 01	3.20E-01
800.	3.68E 04	4.83E-01	1.25E-04	1.33E 08	1.21E 03	1.53E 08	5.84E 04	6.80E 07	3.79E 00	4.39E-01
900.	3.64E 04	3.65E-02	9.48E-06	1.33E 08	1.21E 03	1.53E 08	5.84E 04	6.80E 07	3.38E-01	5.75E-01
1000.	3.59E 04	2.68E-03	6.96E-07	1.33E 08	1.21E 03	1.53E 08	5.84E 04	6.80E 07	2.93E-02	7.29E-01
2000.	3.19E 04	1.62E-14	4.20E-18	1.33E 08	1.21E 03	1.52E 08	5.84E 04	6.80E 07	9.09E-13	2.96E 00
3000.	2.82E 04	8.95E-25	0.0	1.33E 08	1.20E 03	1.52E 08	5.84E 04	6.80E 07	2.25E-22	6.06E 00
4000.	2.50E 04	0.0	0.0	1.33E 08	1.20E 03	1.52E 08	5.84E 04	6.80E 07	0.0	9.69E 00
5000.	2.21E 04	0.0	0.0	1.33E 08	1.20E 03	1.51E 08	5.84E 04	6.80E 07	0.0	1.37E 01
6000.	1.95E 04	0.0	0.0	1.32E 08	1.20E 03	1.51E 08	5.84E 04	6.80E 07	0.0	1.79E 01
7000.	1.73E 04	0.0	0.0	1.32E 08	1.20E 03	1.50E 08	5.84E 04	6.80E 07	0.0	2.23E 01
8000.	1.54E 04	0.0	0.0	1.32E 08	1.20E 03	1.50E 08	5.84E 04	6.79E 07	0.0	2.69E 01
9000.	1.36E 04	0.0	0.0	1.32E 08	1.20E 03	1.49E 08	5.84E 04	6.79E 07	0.0	3.15E 01
10000.	1.21E 04	0.0	0.0	1.32E 08	1.20E 03	1.49E 08	5.84E 04	6.79E 07	0.0	3.63E 01
20000.	3.75E 03	0.0	0.0	1.31E 08	1.20E 03	1.44E 08	5.83E 04	6.77E 07	0.0	8.40E 01
30000.	1.07E 03	0.0	0.0	1.31E 08	1.19E 03	1.39E 08	5.83E 04	6.75E 07	0.0	1.27E 02
40000.	3.03E 02	0.0	0.0	1.30E 08	1.19E 03	1.34E 08	5.83E 04	6.73E 07	0.0	1.63E 02
50000.	8.62E 01	0.0	0.0	1.30E 08	1.18E 03	1.30E 08	5.83E 04	6.72E 07	0.0	1.93E 02
60000.	2.49E 01	0.0	0.0	1.29E 08	1.18E 03	1.26E 08	5.83E 04	6.71E 07	0.0	2.19E 02
70000.	7.38E 00	0.0	0.0	1.29E 08	1.17E 03	1.22E 08	5.82E 04	6.69E 07	0.0	2.40E 02
80000.	2.24E 00	0.0	0.0	1.28E 08	1.16E 03	1.18E 08	5.82E 04	6.68E 07	0.0	2.59E 02
90000.	7.02E-01	0.0	0.0	1.28E 08	1.16E 03	1.14E 08	5.82E 04	6.66E 07	0.0	2.74E 02
100000.	2.26E-01	0.0	0.0	1.27E 08	1.15E 03	1.11E 08	5.82E 04	6.65E 07	0.0	2.88E 02
200000.	2.20E-06	0.0	0.0	1.22E 08	1.10E 03	8.14E 07	5.80E 04	6.51E 07	0.0	3.40E 02
300000.	7.03E-12	0.0	0.0	1.16E 08	1.05E 03	5.77E 07	5.77E 04	6.35E 07	0.0	3.08E 02
400000.	1.50E-17	0.0	0.0	1.10E 08	9.90E 02	4.05E 07	5.74E 04	6.19E 07	0.0	2.53E 02
500000.	3.72E-23	0.0	0.0	1.05E 08	9.30E 02	2.86E 07	5.72E 04	6.04E 07	0.0	1.99E 02
600000.	0.0	0.0	0.0	1.00E 08	8.80E 02	2.04E 07	5.69E 04	5.90E 07	0.0	1.55E 02
700000.	0.0	0.0	0.0	9.55E 07	8.50E 02	1.47E 07	5.67E 04	5.76E 07	0.0	1.19E 02
800000.	0.0	0.0	0.0	9.13E 07	8.10E 02	1.07E 07	5.65E 04	5.63E 07	0.0	9.10E 01
900000.	0.0	0.0	0.0	8.74E 07	7.90E 02	7.86E 06	5.63E 04	5.51E 07	0.0	7.07E 01
1000000.	0.0	0.0	0.0	8.38E 07	7.59E 02	5.85E 06	5.61E 04	5.40E 07	0.0	5.47E 01
SPECIFIC ACTIVITY										
CI/G	4.45E 00	1.42E 02	5.45E 05	2.56E-03	2.83E 02	1.70E-02	1.63E-04	8.84E-04	8.68E 01	8.12E 01

Table J-2. (Continued)

TIME	RA-225	RA-226	TH-229	TH-230	NP-237	NP-239	PU-238	PU-239	PU-240	PU-241
0.	4.00E-08	1.13E-04	7.09E-03	1.23E 00	5.53E 05	8.96E-02	7.70E 03	3.04E 04	1.59E 04	4.34E 03
5.	3.00E-07	9.82E-04	7.20E-02	9.31E 00	4.15E 06	9.76E-01	6.95E 04	2.36E 05	2.06E 05	3.40E 04
10.	2.27E-06	3.63E-03	4.11E-01	2.59E 01	1.13E 07	7.83E 00	3.92E 05	7.81E 05	1.69E 06	1.37E 05
15.	1.45E-05	1.35E-02	2.63E 00	5.70E 01	2.45E 07	2.11E 01	1.26E 06	1.84E 06	5.11E 06	3.32E 05
20.	5.73E-05	4.07E-02	1.04E 01	1.14E 02	4.76E 07	4.13E 01	3.18E 06	3.70E 06	1.12E 07	6.56E 05
25.	1.48E-04	9.05E-02	2.71E 01	2.04E 02	8.34E 07	6.00E 01	6.10E 06	7.10E 06	1.90E 07	1.07E 06
30.	1.96E-04	9.94E-02	3.60E 01	2.21E 02	8.35E 07	6.00E 01	5.88E 06	7.13E 06	2.33E 07	8.47E 05
40.	2.93E-04	1.19E-01	5.38E 01	2.63E 02	8.38E 07	5.99E 01	5.46E 06	7.20E 06	2.96E 07	5.30E 05
50.	3.91E-04	1.44E-01	7.18E 01	3.19E 02	8.41E 07	5.98E 01	5.07E 06	7.27E 06	3.39E 07	2.91E 05
60.	4.90E-04	1.75E-01	8.98E 01	3.86E 02	8.44E 07	5.98E 01	4.71E 06	7.33E 06	3.67E 07	1.63E 05
70.	5.88E-04	2.11E-01	1.08E 02	4.62E 02	8.47E 07	5.97E 01	4.37E 06	7.39E 06	3.87E 07	9.62E 04
80.	6.86E-04	2.54E-01	1.26E 02	5.47E 02	8.50E 07	5.96E 01	4.05E 06	7.46E 06	4.00E 07	6.10E 04
90.	7.83E-04	3.02E-01	1.43E 02	6.40E 02	8.53E 07	5.96E 01	3.76E 06	7.52E 06	4.09E 07	4.13E 04
100.	8.80E-04	3.59E-01	1.61E 02	7.40E 02	8.56E 07	5.95E 01	3.50E 06	7.58E 06	4.16E 07	2.97E 04
200.	1.85E-03	1.46E 00	3.38E 02	2.06E 03	8.82E 07	5.91E 01	1.73E 06	8.20E 06	4.28E 07	8.68E 03
300.	2.81E-03	3.03E 00	5.15E 02	3.77E 03	9.05E 07	5.86E 01	8.46E 05	8.81E 06	4.23E 07	7.76E 03
400.	3.77E-03	7.60E 00	6.91E 02	5.66E 03	9.24E 07	5.80E 01	4.10E 05	9.41E 06	4.17E 07	7.68E 03
500.	4.73E-03	1.28E 01	8.65E 02	7.63E 03	9.41E 07	5.75E 01	2.03E 05	1.00E 07	4.13E 07	7.61E 03
600.	5.69E-03	1.95E 01	1.04E 03	9.65E 03	9.55E 07	5.69E 01	1.05E 05	1.06E 07	4.09E 07	7.55E 03
700.	6.64E-03	2.78E 01	1.21E 03	1.17E 04	9.67E 07	5.64E 01	5.68E 04	1.12E 07	4.05E 07	7.49E 03
800.	7.59E-03	3.70E 01	1.38E 03	1.37E 04	9.77E 07	5.59E 01	3.19E 04	1.17E 07	4.01E 07	7.42E 03
900.	8.54E-03	4.78E 01	1.56E 03	1.58E 04	9.86E 07	5.54E 01	1.85E 04	1.23E 07	3.97E 07	7.36E 03
1000.	9.45E-03	5.99E 01	1.73E 03	1.79E 04	9.93E 07	5.49E 01	1.11E 04	1.28E 07	3.93E 07	7.30E 03
2000.	1.88E-02	2.40E 02	3.45E 03	3.85E 04	1.03E 08	5.05E 01	1.12E 02	1.80E 07	3.55E 07	6.70E 03
3000.	2.80E-02	4.96E 02	5.14E 03	5.89E 04	1.04E 08	4.38E 01	9.42E-01	2.27E 07	3.20E 07	6.17E 03
4000.	3.71E-02	7.98E 02	6.80E 03	7.91E 04	1.04E 08	4.14E 01	7.00E-03	2.68E 07	2.88E 07	5.71E 03
5000.	4.59E-02	1.13E 03	8.43E 03	9.91E 04	1.05E 08	3.75E 01	5.47E-05	3.05E 07	2.60E 07	5.28E 03
6000.	5.47E-02	1.48E 03	1.00E 04	1.19E 05	1.05E 08	3.41E 01	4.82E-07	3.36E 07	2.34E 07	4.88E 03
7000.	6.33E-02	1.84E 03	1.16E 04	1.38E 05	1.05E 08	3.11E 01	4.92E-09	3.62E 07	2.11E 07	4.46E 03
8000.	7.19E-02	2.21E 03	1.32E 04	1.58E 05	1.05E 08	2.85E 01	5.82E-11	3.84E 07	1.91E 07	4.09E 03
9000.	8.03E-02	2.59E 03	1.47E 04	1.77E 05	1.05E 08	2.63E 01	7.97E-13	4.01E 07	1.73E 07	3.75E 03
10000.	8.87E-02	2.98E 03	1.63E 04	1.95E 05	1.05E 08	2.43E 01	1.25E-14	4.16E 07	1.56E 07	3.43E 03
20000.	1.68E-01	6.88E 03	3.08E 04	3.72E 05	1.06E 08	1.07E 01	0.0	4.46E 07	5.81E 06	1.43E 03
30000.	2.42E-01	1.04E 04	4.44E 04	5.28E 05	1.06E 08	3.97E 00	0.0	4.05E 07	2.01E 06	6.41E 02
40000.	3.12E-01	1.34E 04	5.72E 04	6.66E 05	1.06E 08	1.37E 00	0.0	3.50E 07	6.81E 05	3.01E 02
50000.	3.79E-01	1.58E 04	6.94E 04	7.88E 05	1.06E 08	4.91E-01	0.0	2.86E 07	2.33E 05	1.38E 02
60000.	4.42E-01	1.79E 04	8.11E 04	8.95E 05	1.05E 08	1.86E-01	0.0	2.24E 07	8.10E 04	6.08E 01
70000.	5.03E-01	1.97E 04	9.22E 04	9.89E 05	1.05E 08	7.55E-02	0.0	1.70E 07	2.89E 04	2.60E 01
80000.	5.61E-01	2.12E 04	1.03E 05	1.07E 06	1.05E 08	3.25E-02	0.0	1.25E 07	1.06E 04	1.09E 01
90000.	6.17E-01	2.25E 04	1.13E 05	1.14E 06	1.04E 08	1.48E-02	0.0	9.06E 06	3.98E 03	4.47E 00
100000.	6.71E-01	2.36E 04	1.23E 05	1.20E 06	1.04E 08	7.09E-03	0.0	6.48E 06	1.53E 03	1.82E 00
200000.	1.10E 00	2.79E 04	2.02E 05	1.42E 06	1.01E 08	4.02E-05	0.0	2.54E 05	1.00E 00	2.74E-04
300000.	1.36E 00	2.52E 04	2.50E 05	1.28E 06	9.77E 07	3.10E-06	0.0	2.22E 04	2.17E-02	9.45E-08
400000.	1.51E 00	2.07E 04	2.78E 05	1.05E 06	9.44E 07	8.96E-07	0.0	3.57E 03	3.47E-03	7.27E-11
500000.	1.59E 00	1.63E 04	2.91E 05	8.26E 05	9.12E 07	5.37E-07	0.0	8.52E 02	1.71E-03	1.07E-13
600000.	1.61E 00	1.26E 04	2.96E 05	6.41E 05	8.82E 07	5.00E-07	0.0	2.65E 02	1.67E-03	2.67E-16
700000.	1.61E 00	9.74E 03	2.95E 05	4.94E 05	8.54E 07	6.21E-07	0.0	1.00E 02	2.57E-03	1.02E-18
800000.	1.58E 00	7.50E 03	2.90E 05	3.81E 05	8.27E 07	9.37E-07	0.0	4.38E 01	5.35E-03	5.62E-21
900000.	1.54E 00	5.79E 03	2.82E 05	2.94E 05	8.02E 07	1.62E-06	0.0	2.13E 01	1.38E-02	4.20E-23
1000000.	1.49E 00	4.48E 03	2.73E 05	2.28E 05	7.79E 07	3.10E-06	0.0	1.14E 01	4.18E-02	4.10E-25
SPECIFIC ACTIVITY										
CI/G	3.93E 04	9.89E-01	2.14E-01	1.94E-02	7.05E-04	2.32E 05	1.69E 01	6.13E-02	2.20E-01	1.02E 02

Table J-2. (Continued)

TIME	AM-241	AM-242M	AM-243	CM-242	CM-244
0.	7.30E 04	1.24E 03	1.08E 05	3.03E 03	2.00E 04
5.	4.68E 05	3.05E 04	1.17E 06	3.04E 01	2.76E 05
10.	2.35E 06	8.72E 04	9.45E 06	2.14E 02	2.93E 06
15.	5.94E 06	2.19E 05	2.55E 07	5.61E 02	3.03E 07
20.	1.16E 07	4.24E 05	4.96E 07	1.07E 03	1.41E 07
25.	1.92E 07	6.37E 05	7.25E 07	1.52E 03	2.47E 07
30.	1.63E 07	8.23E 05	7.25E 07	1.73E 03	2.04E 07
40.	1.93E 07	5.95E 05	7.24E 07	1.41E 03	1.99E 07
50.	1.92E 07	5.69E 05	7.23E 07	1.37E 03	5.73E 06
60.	1.91E 07	5.43E 05	7.23E 07	1.31E 03	6.75E 06
70.	1.89E 07	5.19E 05	7.23E 07	1.25E 03	4.65E 06
80.	1.88E 07	4.95E 05	7.21E 07	1.19E 03	2.21E 06
90.	1.84E 07	4.73E 05	7.21E 07	1.14E 03	2.13E 06
100.	1.81E 07	4.52E 05	7.20E 07	1.09E 03	1.47E 06
200.	1.52E 07	2.30E 05	7.14E 07	6.59E 02	2.75E 04
300.	1.32E 07	1.03E 05	7.07E 07	4.49E 02	6.19E 02
400.	1.14E 07	1.14E 05	7.00E 07	3.74E 02	1.76E 01
500.	1.00E 07	7.10E 04	6.94E 07	1.71E 02	4.67E-01
600.	6.71E 06	4.44E 04	6.87E 07	1.07E 02	1.22E-02
700.	2.45E 06	2.90E 04	6.81E 07	6.73E 01	2.03E-04
800.	6.25E 05	1.79E 04	6.75E 07	4.21E 01	5.34E-06
900.	5.34E 05	1.18E 04	6.69E 07	3.73E 01	9.33E-08
1000.	4.47E 05	7.40E 03	6.64E 07	1.73E 01	1.62E-06
2000.	6.07E 05	5.60E 01	6.10E 07	2.33E-01	0.0
3000.	3.81E 05	8.24E-01	5.54E 07	1.53E-03	0.0
4000.	2.31E 05	6.08E-03	5.01E 07	1.47E-05	0.0
5000.	1.80E 05	4.71E-05	4.54E 07	1.14E-07	0.0
6000.	1.54E 05	4.34E-07	4.12E 07	1.08E-09	0.0
7000.	1.26E 05	4.22E-09	3.77E 07	1.02E-11	0.0
8000.	1.23E 05	5.02E-11	3.45E 07	1.21E-13	0.0
9000.	1.12E 05	6.92E-13	3.18E 07	1.07E-15	0.0
10000.	1.02E 05	3.10E-14	2.94E 07	2.46E-17	0.0
20000.	4.20E 04	0.0	1.24E 07	1.10E-32	0.0
30000.	1.40E 04	0.0	4.80E 06	0.0	0.0
40000.	6.91E 03	0.0	1.66E 06	0.0	0.0
50000.	4.07E 03	0.0	5.92E 05	0.0	0.0
60000.	3.80E 03	0.0	2.25E 05	0.0	0.0
70000.	2.60E 03	0.0	9.11E 04	0.0	0.0
80000.	3.21E 03	0.0	3.93E 04	0.0	0.0
90000.	1.32E 03	0.0	1.79E 04	0.0	0.0
100000.	2.40E 01	0.0	8.56E 03	0.0	0.0
200000.	6.31E-03	0.0	4.87E 01	0.0	0.0
300000.	2.90E-06	0.0	3.75E 00	0.0	0.0
400000.	2.35E-09	0.0	1.04E 00	0.0	0.0
500000.	2.50E-12	0.0	6.45E-01	0.0	0.0
600000.	6.11E-15	0.0	5.90E-01	0.0	0.0
700000.	3.57E-17	0.0	7.34E-01	0.0	0.0
800000.	2.02E-19	0.0	1.11E 00	0.0	0.0
900000.	1.55E-21	0.0	1.91E 00	0.0	0.0
1000000.	1.95E-23	0.0	3.69E 00	0.0	0.0
SPECIFIC ACTIVITY CI/G	3.43E 00	5.73E 00	1.92E-01	3.21E 03	8.04E 01

RADIONUCLIDE	CCI DATA	DRC DATA	HKD DATA
C-14	5.55E-10	4.96E-03	1.40E 00
SR-90	1.04E-08	2.90E-02	1.40E 01
Y-90	1.04E-08	2.00E-02	1.40E 03
ZR-93	6.24E-10	1.05E-02	1.40E 03
NB-93M	6.61E-10	1.11E-02	1.40E 03
TC-99	1.22E-09	5.11E-03	0.0
I-129	9.51E-10	4.95E-03	0.0
CS-135	1.59E-08	3.14E-02	1.40E 02
CS-137	1.69E-08	3.30E-02	1.40E 02
PB-210	9.35E-10	2.75E-03	2.80E 03
RA-225	7.71E-10	4.46E-03	7.00E 01
RA-226	7.71E-10	4.46E-03	7.00E 01
TH-229	6.14E-10	1.08E-02	1.05E 04
TH-230	6.14E-10	1.08E-02	1.05E 04
NP-237	7.61E-10	4.34E-03	1.05E 01
NP-239	7.53E-10	4.35E-03	1.04E 01
PU-238	3.21E-10	7.19E-03	1.40E 02
PU-239	3.21E-10	7.19E-03	1.40E 03
PU-240	3.21E-10	7.22E-03	1.40E 03
PU-241	3.21E-10	7.25E-03	1.40E 03
AM-241	8.12E-10	2.49E-03	1.40E 03
AM-242M	8.12E-10	2.49E-03	1.40E 03
AM-243	8.12E-10	2.62E-03	1.40E 03
CM-242	8.10E-10	2.49E-03	4.20E 02
CM-244	8.10E-10	2.49E-03	4.20E 02

** GROUND WATER PARAMETERS

GROUND WATER SEEPAGE VELOCITY, VX, IN METERS/DAY = 4.00E-02
POROSITY OF SOLID MEDIUM, PORE = 1.50E-01
BULK SOLID DENSITY, DULKD, IN GRAMS/CUBIC CM = 2.20E 03
DISPERSIVITY COEFFICIENTS, IN METERS: AXIAL, AL = 5.00E 01 TRANSVERSE, AT = 6.00E 00

AQUIFER VALUES, IN METERS: HEIGHT, HT= 5.00E 01
DISTANCE FROM SOURCE TO EMERGENCE, XL(IZ) EFFECTIVE WIDTH, YW(IZ)
CONCENTRATION AT YY = AVERAGE CONCENTRATION IN YW

ZONE	IZ= 1	IZ= 2	IZ= 3	IZ= 4	IZ= 5	IZ= 6	IZ= 7	IZ= 8
XL(IZ)	0.0	1.00E 04	0.0	0.0	0.0	0.0	0.0	2.90E 04
YW(IZ)	0.0	2.59E 03	0.0	0.0	0.0	0.0	0.0	3.64E 03
YY(IZ)	0.0	5.20E 02	0.0	0.0	0.0	0.0	0.0	7.39E 02

EXPOSED AREA OF SOLIDIFIED WASTE SPECIMEN, FS, IN SQUARE CM = 4.38E 03
VOLUME OF SOLIDIFIED WASTE SPECIMEN, VS, IN CUBIC CM = 2.22E 05
TOTAL CANISTER INVENTORY, CINV = 6.25E 04
ASSUMED NUMBER OF CANISTER FAILURES, CFAI = 2.50E 02

Table J-2. (Continued)

** EDC(K,JF,IZ) DATA. (JF=1,2,3,4), DEFAULT VALUES USED, EXCEPTING NONE READ IN

IZ= 1

C-14	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
SR-90	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
Y-90	5.00E 01	2.30E-05	2.30E-06	0.0	5.00E 01	2.30E-05	2.30E-06	0.0
ZR-93	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
NB-93M	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
TC-99	5.00E 01	2.30E 05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
I-129	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CS-135	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CS-137	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PB-210	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
RA-225	5.00E 01	2.30E 05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
RA-226	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
TH-229	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
TH-230	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
NP-237	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
NP-239	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-238	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-239	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-240	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-241	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
AM-241	5.00E 01	2.30E 05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
AM-242M	5.00E 01	2.30E 05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
AM-243	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CM-242	5.00E 01	2.30E 05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CM-244	5.00E 01	2.30E 05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0

IZ= 2

IZ= 3

C-14	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
SR-90	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
Y-90	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
ZR-93	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
NB-93M	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
TC-99	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
I-129	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CS-135	5.00E 01	2.30E 05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CS-137	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PB-210	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
RA-225	5.00E 01	2.30E 05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
RA-226	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
TH-229	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
TH-230	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
NP-237	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
NP-239	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-238	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-239	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-240	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-241	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
AM-241	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
AM-242M	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
AM-243	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CM-242	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CM-244	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0

IZ= 4

Table J-2. (Continued)

IZ= 5					IZ= 6			
C-14	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
SR-90	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
Y-90	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
ZR-93	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
NB-93M	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
TC-99	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
I-129	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CS-135	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CS-137	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PB-210	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
RA-225	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
RA-226	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
TH-229	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
TH-230	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
NP-237	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
NP-239	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-238	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-239	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-240	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-241	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
AM-241	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
AM-242M	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
AM-243	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CM-242	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CM-244	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0

IZ= 7					IZ= 8			
C-14	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
SR-90	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
Y-90	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
ZR-93	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
NB-93M	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
TC-99	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
I-129	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CS-135	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CS-137	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PB-210	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
RA-225	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
RA-226	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
TH-229	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
TH-230	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
NP-237	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
NP-239	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-238	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-239	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-240	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
PU-241	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
AM-241	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
AM-242M	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
AM-243	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CM-242	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0
CM-244	5.00E 01	2.30E-05	2.30E-05	0.0	5.00E 01	2.30E-05	2.30E-05	0.0

Table J-2. (Continued)

** DISPN(JF,IZ) DATA, (JF=1,2,3,4)

```
IZ= 1                                                   IZ= 2
 1.00E 00  7.50E 11  0.0       1.00E 00        1.00E 00  1.01E 14  5.06E 13  1.00E 00

IZ= 3                                                   IZ= 4
 1.00E 00  2.27E 14  1.14E 14  1.00E 00        1.00E 00  4.77E 13  1.12E 13  1.00E 00

IZ= 5                                                   IZ= 6
 1.00E 00  1.22E 14  3.06E 13  1.00E 00        1.00E 00  1.14E 14  2.85E 13  1.00E 00

IZ= 7                                                   IZ= 8
 1.00E 00  1.57E 14  7.88E 13  1.00E 00        1.00E 00  5.46E 12  2.60E 14  1.00E 00
```

** ZONALO(JF,IZ) DATA, (JF=1,2,3,4)

```
IZ= 1                                                   IZ= 2
 1.26E-20  1.29E-01  0.0       0.0             5.31E-23  4.41E-01  2.17E-03  1.00E 00

IZ= 3                                                   IZ= 4
 5.09E-24  9.15E-02  4.60E-04  0.0             2.12E-24  8.68E-03  2.10E-05  0.0

IZ= 5                                                   IZ= 6
 3.83E-24  3.59E-02  9.00E-05  0.0             3.03E-23  2.42E-01  6.08E-04  0.0

IZ= 7                                                   IZ= 8
 3.18E-24  4.18E-02  2.10E-04  0.0             3.13E-23  1.46E-02  1.44E-03  1.00E 00
```

** ZCNDEP(IZ) DATA

```
IZ= 1       IZ= 2       IZ= 3       IZ= 4       IZ= 5       IZ= 6       IZ= 7       IZ= 8
 4.04E-13    1.93E-15    1.94E-16    1.05E-16    1.79E-16    1.17E-15    1.50E-16    1.25E-15
```

** AREAW(IZ) DATA

```
IZ= 1       IZ= 2       IZ= 3       IZ= 4       IZ= 5       IZ= 6       IZ= 7       IZ= 8
 0.0         5.06E 11    1.14E 12    1.12E 11    3.06E 11    2.05E 11    7.88E 11    5.40E 11
```

Table J-2. (Continued)

** ADJ1(JF,JFA,IZ),ADJ2(JF,JFA,IZ) DATA, (JFA=1,2,3,4)

IZ= 1								
JF= 1	0.0	0.0	1.00E-09	2.00E 01	0.0	0.0	0.0	0.0
JF= 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JF= 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JF= 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IZ= 2								
JF= 1	0.0	0.0	1.00E-09	2.00E 01	0.0	0.0	0.0	0.0
JF= 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JF= 3	0.0	0.0	0.0	0.0	0.0	0.0	2.00E-01	2.00E 01
JF= 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IZ= 3								
JF= 1	0.0	0.0	1.00E-09	2.00E 01	0.0	0.0	0.0	0.0
JF= 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JF= 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JF= 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IZ= 4								
JF= 1	0.0	0.0	1.00E-09	2.00E 01	0.0	0.0	0.0	0.0
JF= 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JF= 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JF= 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IZ= 5								
JF= 1	0.0	0.0	1.00E-09	2.00E 01	0.0	0.0	0.0	0.0
JF= 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JF= 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JF= 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IZ= 6								
JF= 1	0.0	0.0	1.00E-09	2.00E 01	0.0	0.0	0.0	0.0
JF= 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JF= 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JF= 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IZ= 7								
JF= 1	0.0	0.0	1.00E-09	2.00E 01	0.0	0.0	0.0	0.0
JF= 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JF= 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
JF= 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IZ= 8								
JF= 1	0.0	0.0	1.00E-09	2.00E 01	0.0	0.0	0.0	0.0
JF= 2	0.0	0.0	0.0	0.0	5.00E-01	2.00E 01	0.0	0.0
JF= 3	0.0	0.0	0.0	0.0	0.0	0.0	8.00E-01	2.00E 01
JF= 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table J-2. (continued)

60 VOLINT(JF,MODE,NSP) DATA

IZ= 1

JF	MODE	NSP=1	THRU	VOLINT			
1	1		1	1.00E 00			
1	2		1	7.30E 09			
2	1		4	4.00E-01	0.0	0.0	0.0
2	2		4	0.0	6.30E 07	0.0	0.0
3	1		4	0.0	0.0	0.0	0.0
3	2		4	0.0	0.0	0.0	0.0
4	1		1	0.0			
4	2		1	0.0			

IZ= 2

JF	MODE	NSP=1	THRU	VOLINT			
1	1		1	1.00E 00			
1	2		1	7.30E 09			
2	1		4	4.00E-01	0.0	0.0	0.0
2	2		4	0.0	1.10E 10	0.0	0.0
3	1		4	1.00E-03	0.0	0.0	0.0
3	2		4	4.00E 05	5.90E 09	0.0	0.0
4	1		1	4.00E 03			
4	2		1	7.00E 07			

IZ= 3

JF	MODE	NSP=1	THRU	VOLINT			
1	1		1	1.00E 00			
1	2		1	7.30E 09			
2	1		4	4.00E-01	0.0	0.0	0.0
2	2		4	1.11E 10	1.61E 10	4.07E 08	4.05E 09
3	1		4	1.00E-03	0.0	0.0	0.0
3	2		4	2.00E 05	4.00E 09	4.05E 06	0.0
4	1		1	0.0			
4	2		1	0.0			

IZ= 4

JF	MODE	NSP=1	THRU	VOLINT			
1	1		1	1.00E 00			
1	2		1	7.30E 09			
2	1		4	4.00E-01	0.0	0.0	0.0
2	2		4	2.05E 09	7.60E 09	6.33E 09	3.21E 09
3	1		4	1.00E-03	0.0	0.0	0.0
3	2		4	0.0	0.0	3.71E 04	0.0
4	1		1	0.0			
4	2		1	0.0			

IZ= 5

JF	MODE	NSP=1	THRU	VOLINT			
1	1		1	1.00E 00			
1	2		1	7.30E 09			
2	1		4	4.00E-01	0.0	0.0	0.0
2	2		4	2.52E 11	1.02E 10	5.43E 08	1.86E 10
3	1		4	1.00E-03	0.0	0.0	0.0
3	2		4	0.0	0.0	1.36E 10	0.0
4	1		1	0.0			
4	2		1	0.0			

IZ= 6

JF	MODE	NSP=1	THRU	VOLINT			
1	1		1	1.00E 00			
1	2		1	7.30E 09			
2	1		4	4.00E-01	0.0	0.0	0.0
2	2		4	1.97E 10	1.36E 10	1.92E 09	1.50E 10
3	1		4	1.00E-03	0.0	0.0	0.0
3	2		4	0.0	0.0	1.50E 10	0.0
4	1		1	0.0			
4	2		1	0.0			

IZ= 7

JF	MODE	NSP=1	THRU	VOLINT			
1	1		1	1.00E 00			
1	2		1	7.30E 09			
2	1		4	4.00E-01	0.0	0.0	0.0
2	2		4	5.02E 09	3.27E 10	7.06E 09	6.31E 10
3	1		4	1.00E-03	0.0	0.0	0.0
3	2		4	4.30E 05	1.67E 10	6.31E 10	0.0
4	1		1	0.0			
4	2		1	0.0			

IZ= 8

JF	MODE	NSP=1	THRU	VOLINT			
1	1		1	1.00E 00			
1	2		1	7.30E 09			
2	1		4	4.00E-01	0.0	0.0	0.0
2	2		4	2.04E 09	0.0	6.23E 09	7.48E 10
3	1		4	1.00E-03	0.0	0.0	0.0
3	2		4	4.00E 05	9.60E 08	3.40E 13	0.0
4	1		1	2.00E 04			
4	2		1	4.00E 07			

Table J-2. (Continued)

** BIOFAC(K,JF,NSP) DATA

RADIONUCLIDE= C-14

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	2.22E-03	5.29E-04	5.33E-04	1.29E-03
3		4	1.00E 00	1.24E 01	7.68E 00	0.0
4		1	1.24E 01			

RADIONUCLIDE= SR-90

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	5.26E-01	5.23E-03	3.56E-03	1.84E-02
3		4	1.00E 00	2.40E-01	5.12E-01	0.0
4		1	2.40E-01			

RADIONUCLIDE= Y-90

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	8.85E-02	3.53E-05	6.41E-05	1.29E-05
3		4	1.00E 00	1.84E 00	6.40E-03	0.0
4		1	1.84E 00			

RADIONUCLIDE= ZR-93

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	5.26E-01	8.17E-01	2.23E-01	4.93E-09
3		4	1.00E 00	1.36E 01	3.20E-03	0.0
4		1	1.36E 01			

RADIONUCLIDE= NB-93M

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	5.26E-01	1.97E 00	1.58E 00	2.22E-02
3		4	1.00E 00	1.12E 02	1.60E 00	0.0
4		1	1.12E 02			

RADIONUCLIDE= TC-99

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	5.26E-01	2.37E-02	6.47E-03	2.49E-01
3		4	1.00E 00	1.60E 02	1.60E 01	0.0
4		1	1.60E 02			

RADIONUCLIDE= I-129

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	5.26E-01	9.48E-01	2.59E-01	9.04E-08
3		4	1.00E 00	1.16E 00	3.84E 00	0.0
4		1	1.16E 00			

RADIONUCLIDE= CS-135

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	5.26E-01	9.48E-02	2.59E-02	1.38E-01
3		4	1.00E 00	1.60E 00	7.68E 00	0.0
4		1	1.60E 00			

RADIONUCLIDE= CS-137

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	5.26E-01	3.56E-02	2.38E-02	1.29E-01
3		4	1.00E 00	1.60E 00	7.68E 00	0.0
4		1	1.60E 00			

RADIONUCLIDE= PB-210

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	5.26E-01	2.32E-03	1.71E-03	5.62E-03
3		4	1.00E 00	1.16E-01	3.97E-01	0.0
4		1	1.16E-01			

RADIONUCLIDE= RA-225

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	2.77E-01	5.26E-03	7.54E-03	6.49E-02
3		4	1.00E 00	1.36E 01	5.12E 00	0.0
4		1	1.36E 01			

RADIONUCLIDE= RA-226

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	5.26E-01	7.73E-01	2.22E-01	1.48E-01
3		4	1.00E 00	1.36E 01	5.12E 00	0.0
4		1	1.36E 01			

RADIONUCLIDE= TH-229

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	5.26E-01	4.69E-03	1.30E-03	4.93E-05
3		4	1.00E 00	8.00E-02	3.20E-03	0.0
4		1	8.00E-02			

RADIONUCLIDE= TH-230

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	5.26E-01	4.74E-03	1.30E-03	4.93E-05
3		4	1.00E 00	8.00E-02	3.20E-03	0.0
4		1	8.00E-02			

RADIONUCLIDE= NP-237

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	5.26E-01	4.74E-03	1.30E-03	4.93E-05
3		4	1.00E 00	8.00E-02	3.20E-03	0.0
4		1	8.00E-02			

RADIONUCLIDE= NP-239

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	7.89E-02	4.63E-09	2.18E-06	3.67E-06
3		4	1.00E 00	8.00E-02	3.20E-03	0.0
4		1	8.00E-02			

RADIONUCLIDE= PU-238

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	5.26E-01	1.57E-03	3.75E-04	1.92E-05
3		4	1.00E 00	5.60E-03	1.28E-03	0.0
4		1	5.60E-03			

RADIONUCLIDE= PU-239

JF	NSP=1	THRU	BIOFAC			
1		1	1.00E 00			
2		4	5.26E-01	2.82E-03	3.89E-04	1.97E-05
3		4	1.00E 00	5.60E-03	1.28E-03	0.0
4		1	5.60E-03			

Table J-2. (Continued)

```
RADIONUCLIDE=  PU-240
    JF      NSP=1 THRU          BIOFAC
     1              1      1.00E 00
     2              4      5.26E-01      2.79E-03      3.89E-04      1.97E-05
     3              4      1.00E 00      5.60E-03      1.28E-03      0.0
     4              1      5.60E-03
RADIONUCLIDE=  PU-241
    JF      NSP=1 THRU          BIOFAC
     1              1      1.00E 00
     2              4      5.26E-01      8.38E-04      3.37E-04      1.77E-05
     3              4      1.00E 00      5.60E-03      1.28E-03      0.0
     4              1      5.60E-03
RADIONUCLIDE=  AM-241
    JF      NSP=1 THRU          BIOFAC
     1              1      1.00E 00
     2              4      5.26E-01      3.97E-03      1.29E-03      4.90E-05
     3              4      1.00E 00      8.00E-02      3.20E-03      0.0
     4              1      8.00E-02
RADIONUCLIDE= AM-242M
    JF      NSP=1 THRU          BIOFAC
     1              1      1.00E 00
     2              4      5.26E-01      3.10E-03      1.27E-03      4.85E-05
     3              4      1.00E 00      8.00E-02      3.20E-03      0.0
     4              1      8.00E-02
RADIONUCLIDE=  AM-243
    JF      NSP=1 THRU          BIOFAC
     1              1      1.00E 00
     2              4      5.26E-01      4.69E-03      1.30E-03      4.93E-05
     3              4      1.00E 00      8.00E-02      3.20E-03      0.0
     4              1      8.00E-02
RADIONUCLIDE=  CM-242
    JF      NSP=1 THRU          BIOFAC
     1              1      1.00E 00
     2              4      4.80E-01      4.60E-04      4.71E-04      3.78E-05
     3              4      1.00E 00      8.00E-02      3.20E-03      0.0
     4              1      8.00E-02
RADIONUCLIDE=  CM-244
    JF      NSP=1 THRU          BIOFAC
     1              1      1.00E 00
     2              4      5.20E-01      1.53E-03      1.15E-03      4.52E-05
     3              4      1.00E 00      8.00E-02      3.20E-03      0.0
     4              1      8.00E-02
```

Table J-2. (continued)

** DOSFAC(K,JF,MODE,1H) DATA

ORGAN = TOT BODY

	JF=1		JF=2		JF=3		JF=4	
	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2
C-14	0.0	4.24E-01	0.0	5.69E-01	0.0	5.69E-01	5.69E-01	5.69E-01
SR-90	0.0	1.78E 03	0.0	1.69E 02	0.0	1.69E 02	1.69E 02	1.69E 02
Y-90	0.0	1.15E 00	1.93E-01	2.48E-04	0.0	2.48E-04	2.48E-04	2.48E-04
ZR-93	0.0	1.37E 00	0.0	1.09E-03	0.0	1.09E-03	1.09E-03	1.09E-03
NB-93M	0.0	2.49E 00	0.0	2.05E-03	0.0	2.05E-03	2.05E-03	2.05E-03
TC-99	0.0	1.25E-02	0.0	5.00E-02	0.0	5.00E-02	5.00E-02	5.00E-02
I-129	5.55E 07	4.19E 00	5.73E 04	7.22E 00	2.01E 03	7.22E 00	7.22E 00	7.22E 00
CS-135	0.0	6.00E 00	0.0	8.00E 00	0.0	8.00E 00	8.00E 00	8.00E 00
CS-137	0.0	2.51E 01	3.68E 02	4.33E 01	0.0	4.33E 01	4.33E 01	4.33E 01
PB-210	1.43E 07	3.40E 03	2.27E 04	5.10E 02	3.00E 02	5.10E 02	5.10E 02	5.10E 02
RA-225	1.82E 08	2.20E 02	7.36E 00	1.30E 03	0.0	1.30E 03	1.30E 03	1.30E 03
RA-226	4.90E 07	4.15E 04	9.46E 03	3.11E 04	1.03E 03	3.11E 04	3.11E 04	3.11E 04
TH-229	1.51E 09	4.70E 05	2.36E 05	3.50E 02	0.0	3.50E 02	3.50E 02	3.50E 02
TH-230	3.59E 06	1.91E 05	6.12E 03	7.66E 01	7.55E 01	7.65E 01	7.65E 01	7.65E 01
NP-237	6.14E 08	8.37E 04	1.33E 05	6.34E 02	1.29E 04	6.34E 02	6.34E 02	6.34E 02
NP-239	5.72E 08	1.77E-01	2.49E 05	7.07E-05	2.04E 04	7.07E-05	7.07E-05	7.07E-05
PU-238	1.66E 06	7.71E 04	3.25E 03	1.75E 01	3.49E 01	1.75E 01	1.75E 01	1.75E 01
PU-239	7.22E 05	9.04E 04	1.37E 03	2.06E 01	1.52E 01	2.06E 01	2.06E 01	2.06E 01
PU-240	1.46E 06	9.03E 04	2.85E 03	2.05E 01	3.07E 01	2.05E 01	2.05E 01	2.05E 01
PU-241	0.0	1.26E 03	4.03E-01	2.87E-01	0.0	2.87E-01	2.87E-01	2.87E-01
AM-241	1.44E 08	9.29E 04	7.50E 04	7.04E 02	3.02E 03	7.04E 02	7.04E 02	7.04E 02
AM-242M	0.0	9.06E 04	2.28E 00	6.86E 02	0.0	6.86E 02	6.86E 02	6.86E 02
AM-243	3.16E 08	9.31E 04	6.64E 04	7.05E 02	6.64E 03	7.05E 02	7.05E 02	7.05E 02
CM-242	1.58E 06	1.52E 03	2.92E 03	1.36E 01	3.33E 01	1.36E 01	1.36E 01	1.36E 01
CM-244	4.50E 07	4.06E 04	1.81E 04	3.08E 02	9.47E 02	3.08E 02	3.08E 02	3.08E 02

ORGAN = GI TRACT

	JF=1		JF=2		JF=3		JF=4	
	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2
C-14	0.0	5.34E 00	0.0	9.70E 00	0.0	9.70E 00	9.70E 00	9.70E 00
SR-90	0.0	3.56E 01	0.0	4.85E 01	0.0	4.85E 01	4.85E 01	4.85E 01
Y-90	0.0	7.12E 01	0.0	9.70E 01	0.0	9.70E 01	9.70E 01	9.70E 01
ZR-93	0.0	2.13E 00	0.0	2.43E 00	0.0	2.43E 00	2.43E 00	2.43E 00
NB-93M	0.0	3.05E 00	0.0	4.85E 00	0.0	4.85E 00	4.85E 00	4.85E 00
TC-99	0.0	7.12E 00	0.0	9.70E 00	0.0	9.70E 00	9.70E 00	9.70E 00
I-129	1.98E 07	5.34E 00	1.19E 04	9.70E 00	4.18E 02	9.70E 00	9.70E 00	9.70E 00
CS-135	0.0	5.34E 00	0.0	9.70E 00	0.0	9.70E 00	9.70E 00	9.70E 00
CS-137	0.0	2.67E 01	0.0	4.85E 01	0.0	4.85E 01	4.85E 01	4.85E 01
PB-210	5.75E 06	7.12E 00	9.15E 03	9.70E 00	1.21E 02	9.70E 00	9.70E 00	9.70E 00
RA-225	0.0	2.71E 02	0.0	3.06E 02	0.0	3.06E 02	3.06E 02	3.06E 02
RA-226	3.34E 07	3.56E 01	6.45E 03	6.47E 01	7.03E 02	6.47E 01	6.47E 01	6.47E 01
TH-229	0.0	3.17E 02	0.0	5.12E 02	0.0	5.12E 02	5.12E 02	5.12E 02
TH-230	1.40E 06	3.56E 01	2.39E 03	6.47E 01	2.95E 01	6.47E 01	6.47E 01	6.47E 01
NP-237	3.94E 08	4.27E 01	8.56E 04	6.47E 01	8.29E 03	6.47E 01	6.47E 01	6.47E 01
NP-239	6.39E 08	1.07E 01	1.64E 05	1.94E 01	1.35E 04	1.94E 01	1.94E 01	1.94E 01
PU-238	1.36E 05	4.27E 01	2.67E 02	6.47E 01	2.87E 00	6.47E 01	6.47E 01	6.47E 01
PU-239	2.01E 04	4.27E 01	1.52E 02	6.47E 01	1.69E 00	6.47E 01	6.47E 01	6.47E 01
PU-240	1.38E 05	4.27E 01	2.69E 02	6.47E 01	2.90E 00	6.47E 01	6.47E 01	6.47E 01
PU-241	0.0	1.07E 00	0.0	1.94E 00	0.0	1.94E 00	1.94E 00	1.94E 00
AM-241	6.49E 07	4.27E 01	3.39E 04	6.47E 01	1.36E 03	6.47E 01	6.47E 01	6.47E 01
AM-242M	0.0	1.07E 01	0.0	2.16E 01	0.0	2.16E 01	2.16E 01	2.16E 01
AM-243	1.47E 08	4.27E 01	3.08E 04	6.47E 01	3.08E 03	6.47E 01	6.47E 01	6.47E 01
CM-242	1.09E 05	5.34E 01	1.99E 02	9.70E 01	2.29E 00	9.70E 01	9.70E 01	9.70E 01
CM-244	2.32E 07	4.27E 01	9.32E 03	6.47E 01	4.89E 02	6.47E 01	6.47E 01	6.47E 01

Table J-2. (Continued)

ORGAN = GONADS

	JF=1		JF=2		JF=3		JF=4	
	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2
C-14	0.0	1.42E-01	0.0	1.89E-01	0.0	1.89E-01	1.89E-01	1.89E-01
SR-90	0.0	1.78E 03	0.0	1.69E 02	0.0	1.69E 02	1.69E 02	1.69E 02
Y-90	0.0	1.15E 00	1.93E-01	2.48E-04	0.0	2.48E-04	2.48E-04	2.48E-04
ZR-93	0.0	1.37E 00	0.0	1.09E-03	0.0	1.09E-03	1.09E-03	1.09E-03
NB-93M	0.0	2.49E 00	0.0	2.05E-03	0.0	2.05E-03	2.05E-03	2.05E-03
TC-99	0.0	1.25E-02	0.0	5.00E-02	0.0	5.00E-02	5.00E-02	5.00E-02
I-129	1.31E 08	4.19E 00	7.80E 04	7.22E 00	2.74E 03	7.22E 00	7.22E 00	7.22E 00
CS-135	0.0	6.00E 00	0.0	8.00E 00	0.0	8.00E 00	8.00E 00	8.00E 00
CS-137	0.0	2.51E 01	3.68E 02	4.33E 01	0.0	4.33E 01	4.33E 01	4.33E 01
PB-210	1.21E 07	3.40E 03	1.92E 04	5.10E 02	2.54E 02	5.10E 02	5.10E 02	5.10E 02
RA-225	1.82E 08	2.20E 02	7.36E 00	1.30E 03	0.0	1.30E 03	1.30E 03	1.30E 03
RA-226	6.27E 07	4.15E 04	1.21E 04	3.11E 04	1.32E 03	3.11E 04	3.11E 04	3.11E 04
TH-229	1.51E 09	4.70E 05	2.37E 05	3.50E 02	0.0	3.50E 02	3.50E 02	3.50E 02
TH-230	3.17E 06	1.91E 05	5.40E 03	7.65E 01	6.66E 01	7.65E 01	7.65E 01	7.65E 01
NP-237	6.51E 08	4.50E 04	1.41E 05	3.40E 02	1.37E 04	3.40E 02	3.40E 02	3.40E 02
NP-239	1.13E 09	1.77E-01	2.90E 05	7.07E-05	2.37E 04	7.07E-05	7.07E-05	7.07E-05
PU-238	1.32E 06	4.67E 04	2.59E 03	1.06E 01	2.76E 01	1.06E 01	1.06E 01	1.06E 01
PU-239	6.11E 05	4.88E 04	1.16E 03	1.11E 01	1.29E 01	1.11E 01	1.11E 01	1.11E 01
PU-240	1.17E 06	4.88E 04	2.28E 03	1.11E 01	2.46E 01	1.11E 01	1.11E 01	1.11E 01
PU-241	0.0	1.20E 03	4.03E-01	2.73E-01	0.0	2.73E-01	2.73E-01	2.73E-01
AM-241	1.28E 08	5.13E 04	6.57E 04	3.90E 02	2.65E 03	3.90E 02	3.90E 02	3.90E 02
AM-242M	0.0	4.91E 04	2.28E 00	3.70E 02	0.0	3.70E 02	3.70E 02	3.70E 02
AM-243	2.75E 08	4.97E 04	5.78E 04	3.80E 02	5.78E 03	3.80E 02	3.80E 02	3.80E 02
CM-242	1.26E 06	1.54E 03	2.30E 03	1.20E 01	2.65E 01	1.20E 01	1.20E 01	1.20E 01
CM-244	4.01E 07	3.24E 04	1.61E 04	2.50E 02	8.43E 02	2.50E 02	2.50E 02	2.50E 02

ORGAN = LIVER

	JF=1		JF=2		JF=3		JF=4	
	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2
C-14	0.0	0.0	0.0	5.69E-01	0.0	5.69E-01	5.69E-01	5.69E-01
SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZR-93	0.0	2.92E 00	0.0	2.34E-03	0.0	2.34E-03	2.34E-03	2.34E-03
NB-93M	0.0	1.01E 01	0.0	8.33E-03	0.0	8.33E-03	8.33E-03	8.33E-03
TC-99	0.0	4.64E-02	0.0	1.86E-01	0.0	1.86E-01	1.86E-01	1.86E-01
I-129	3.60E 07	2.11E 00	2.16E 04	2.81E 00	7.57E 02	2.81E 00	2.81E 00	2.81E 00
CS-135	0.0	1.26E 01	0.0	1.80E 01	0.0	1.80E 01	1.80E 01	1.80E 01
CS-137	0.0	6.40E 01	0.0	1.10E 02	0.0	1.10E 02	1.10E 02	1.10E 02
PB-210	7.27E 06	3.10E 04	1.16E 04	4.70E 03	1.53E 02	4.70E 03	4.70E 03	4.70E 03
RA-225	0.0	1.40E 00	0.0	8.10E 00	0.0	8.10E 00	8.10E 00	8.10E 00
RA-226	3.75E 07	2.39E 00	7.23E 03	5.75E 00	7.80E 02	5.75E 00	5.75E 00	5.75E 00
TH-229	0.0	2.01E 05	0.0	1.50E 02	0.0	1.50E 02	1.50E 02	1.50E 02
TH-230	1.68E 06	3.15E 05	2.86E 03	1.57E 02	3.53E 01	1.57E 02	1.57E 02	1.57E 02
NP-237	4.55E 08	1.21E 06	9.90E 04	9.30E 03	9.58E 03	9.30E 03	9.30E 03	9.30E 03
NP-239	7.27E 08	2.87E-01	1.87E 05	1.11E-04	1.53E 04	1.11E-04	1.11E-04	1.11E-04
PU-238	1.33E 05	1.15E 06	2.60E 02	2.61E 02	2.80E 00	2.61E 02	2.61E 02	2.61E 02
PU-239	5.37E 04	1.32E 06	1.78E 02	3.00E 02	1.97E 00	3.00E 02	3.00E 02	3.00E 02
PU-240	1.40E 05	1.32E 06	2.72E 02	3.00E 02	2.94E 00	3.00E 02	3.00E 02	3.00E 02
PU-241	0.0	8.70E 03	0.0	1.98E 00	0.0	1.98E 00	1.98E 00	1.98E 00
AM-241	8.30E 07	1.36E 06	4.33E 04	1.03E 04	1.75E 03	1.03E 04	1.03E 04	1.03E 04
AM-242M	0.0	1.26E 06	0.0	9.50E 03	0.0	9.50E 03	9.50E 03	9.50E 03
AM-243	1.87E 08	1.34E 06	3.94E 04	1.02E 04	3.94E 03	1.02E 04	1.02E 04	1.02E 04
CM-242	1.01E 05	3.03E 04	1.84E 02	2.00E 02	2.11E 00	2.00E 02	2.00E 02	2.00E 02
CM-244	2.86E 07	6.37E 05	1.15E 04	4.80E 03	6.03E 02	4.80E 03	4.80E 03	4.80E 03

Table J-2. (Continued)

ORGAN = LUNGS

	JF=1		JF=2		JF=3		JF=4	
	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2
C-14	0.0	5.94E 01	0.0	5.69E-01	0.0	5.69E-01	5.69E-01	5.69E-01
SR-90	0.0	9.71E 03	0.0	0.0	0.0	0.0	0.0	0.0
Y-90	0.0	3.51E 01	0.0	0.0	0.0	0.0	0.0	0.0
ZR-93	0.0	2.13E 01	0.0	0.0	0.0	0.0	0.0	0.0
NB-93M	0.0	3.11E 01	0.0	0.0	0.0	0.0	0.0	0.0
TC-99	0.0	1.01E 02	0.0	1.58E-02	0.0	1.58E-02	1.58E-02	1.58E-02
I-129	4.85E 07	4.45E 02	2.91E 04	0.0	1.02E 03	0.0	0.0	0.0
CS-135	0.0	1.57E 00	0.0	2.05E 00	0.0	2.05E 00	2.05E 00	2.05E 00
CS-137	0.0	3.65E 03	0.0	1.23E 01	0.0	1.23E 01	1.23E 01	1.23E 01
PB-210	5.02E 06	6.40E 05	1.44E 04	0.0	1.90E 02	0.0	0.0	0.0
RA-225	0.0	2.94E 04	0.0	0.0	0.0	0.0	0.0	0.0
RA-226	4.33E 07	1.21E 05	8.36E 03	0.0	9.11E 02	0.0	0.0	0.0
TH-229	0.0	4.21E 06	0.0	0.0	0.0	0.0	0.0	0.0
TH-230	2.10E 06	6.42E 05	3.59E 03	0.0	4.43E 01	0.0	0.0	0.0
NP-237	5.20E 08	7.98E 05	1.13E 05	0.0	1.09E 04	0.0	0.0	0.0
NP-239	8.36E 08	3.35E 00	2.15E 05	0.0	1.76E 04	0.0	0.0	0.0
PU-238	3.02E 05	5.12E 05	5.92E 02	0.0	6.36E 00	0.0	0.0	0.0
PU-239	1.71E 05	8.62E 05	3.24E 02	0.0	3.59E 00	0.0	0.0	0.0
PU-240	2.89E 05	8.62E 05	5.64E 02	0.0	6.09E 00	0.0	0.0	0.0
PU-241	0.0	4.45E 02	0.0	0.0	0.0	0.0	0.0	0.0
AM-241	1.01E 00	9.27E 05	5.30E 04	0.0	2.14E 03	0.0	0.0	0.0
AM-242M	0.0	3.66E 05	0.0	0.0	0.0	0.0	0.0	0.0
AM-243	2.28E 08	8.78E 05	4.79E 04	0.0	4.80E 03	0.0	0.0	0.0
CM-242	2.62E 05	2.56E 05	4.79E 02	0.0	5.51E 00	0.0	0.0	0.0
CM-244	3.39E 07	9.06E 05	1.36E 04	0.0	7.14E 02	0.0	0.0	0.0

ORGAN = MARROW

	JF=1		JF=2		JF=3		JF=4	
	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2
C-14	0.0	2.26E 00	0.0	2.84E 00	0.0	2.84E 00	2.84E 00	2.84E 00
SR-90	0.0	2.67E 04	0.0	8.43E 03	0.0	8.43E 03	8.43E 03	8.43E 03
Y-90	0.0	4.26E 01	0.0	9.29E-03	0.0	9.29E-03	9.29E-03	9.29E-03
ZR-93	0.0	5.22E 01	0.0	4.19E-02	0.0	4.19E-02	4.19E-02	4.19E-02
NB-93M	0.0	3.10E 01	0.0	2.55E-02	0.0	2.55E-02	2.55E-02	2.55E-02
TC-99	0.0	1.23E-01	0.0	1.26E-01	0.0	1.26E-01	1.26E-01	1.26E-01
I-129	1.56E 08	2.48E 00	9.38E 04	3.27E 00	3.29E 03	3.27E 00	3.27E 00	3.27E 00
CS-135	0.0	1.46E 01	0.0	1.95E 01	0.0	1.95E 01	1.95E 01	1.95E 01
CS-137	0.0	4.70E 01	0.0	8.10E 01	0.0	8.10E 01	8.10E 01	8.10E 01
PB-210	2.65E 07	3.30E 05	4.23E 04	5.00E 04	5.59E 02	5.00E 04	5.00E 04	5.00E 04
RA-225	0.0	1.50E 03	0.0	9.00E 03	0.0	9.00E 03	9.00E 03	9.00E 03
RA-226	7.52E 07	4.93E 05	1.45E 04	3.70E 05	1.58E 03	3.70E 05	3.70E 05	3.70E 05
TH-229	0.0	3.06E 07	0.0	2.30E 04	0.0	2.30E 04	2.30E 04	2.30E 04
TH-230	5.63E 06	7.11E 06	9.59E 03	2.77E 03	1.18E 02	2.77E 03	2.77E 03	2.77E 03
NP-237	1.04E 09	3.07E 06	2.26E 05	2.32E 04	2.18E 04	2.32E 04	2.32E 04	2.32E 04
NP-239	1.56E 09	2.63E 00	4.02E 05	1.08E-03	3.29E 04	1.08E-03	1.08E-03	1.08E-03
PU-238	1.34E 06	2.69E 06	2.62E 03	6.10E 02	2.81E 01	6.10E 02	6.10E 02	6.10E 02
PU-239	6.83E 05	3.31E 06	1.30E 03	7.50E 02	1.44E 01	7.50E 02	7.50E 02	7.50E 02
PU-240	1.22E 06	3.30E 06	2.38E 03	7.50E 02	2.57E 01	7.50E 02	7.50E 02	7.50E 02
PU-241	0.0	5.13E 04	0.0	1.20E 01	0.0	1.20E 01	1.20E 01	1.20E 01
AM-241	2.94E 08	3.26E 06	1.54E 05	2.47E 04	6.29E 03	2.47E 04	2.47E 04	2.47E 04
AM-242M	0.0	3.22E 06	0.0	2.44E 04	0.0	2.44E 04	2.44E 04	2.44E 04
AM-243	6.60E 08	3.33E 06	1.39E 05	2.50E 04	1.39E 04	2.50E 04	2.50E 04	2.50E 04
CM-242	1.23E 06	5.65E 04	2.25E 03	4.30E 02	2.58E 01	4.30E 02	4.30E 02	4.30E 02
CM-244	8.86E 07	1.38E 06	3.55E 04	1.04E 04	1.86E 03	1.04E 04	1.04E 04	1.04E 04

Table J-2. (Continued)

ORGAN = BONE

	JF=1		JF=2		JF=3		JF=4	
	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2
C-14	0.0	2.26E 00	0.0	2.84E 00	0.0	2.84E 00	2.84E 00	2.84E 00
SR-90	0.0	2.67E 04	0.0	8.43E 03	0.0	8.43E 03	8.43E 03	8.43E 03
Y-90	0.0	4.26E 01	0.0	9.29E-03	0.0	9.29E-03	9.29E-03	9.29E-03
ZR-93	0.0	5.22E 01	0.0	4.19E-02	0.0	4.19E-02	4.19E-02	4.19E-02
NB-93M	0.0	3.10E 01	0.0	2.55E-02	0.0	2.55E-02	2.55E-02	2.55E-02
TC-99	0.0	1.23E-01	0.0	1.26E-01	0.0	1.26E-01	1.26E-01	1.26E-01
I-129	1.45E 08	2.48E 00	8.72E 04	3.27E 00	3.06E 03	3.27E 00	3.27E 00	3.27E 00
CS-135	0.0	1.46E 01	0.0	1.95E 01	0.0	1.95E 01	1.95E 01	1.95E 01
CS-137	0.0	4.70E 01	0.0	8.10E 01	0.0	8.10E 01	8.10E 01	8.10E 01
PB-210	2.45E 07	3.30E 05	3.90E 04	5.00E 04	5.15E 02	5.00E 04	5.00E 04	5.00E 04
RA-225	0.0	1.50E 03	0.0	9.00E 03	0.0	9.00E 03	9.00E 03	9.00E 03
RA-226	7.52E 07	4.93E 05	1.45E 04	3.70E 05	1.58E 03	3.70E 05	3.70E 05	3.70E 05
TH-229	0.0	3.06E 07	0.0	2.30E 04	0.0	2.30E 04	2.30E 04	2.30E 04
TH-230	5.31E 06	7.11E 06	9.02E 03	2.77E 03	1.12E 02	2.77E 03	2.77E 03	2.77E 03
NP-237	1.34E 09	3.07E 06	2.25E 05	2.32E 04	2.10E 04	2.32E 04	2.32E 04	2.32E 04
NP-239	1.56E 09	2.63E 00	4.01E 05	1.08E-03	3.29E 04	1.08E-03	1.08E-03	1.08E-03
PU-238	1.26E 06	2.69E 06	2.47E 03	6.10E 02	2.66E 01	6.10E 02	6.10E 02	6.10E 02
PU-239	6.41E 05	3.31E 06	1.22E 03	7.50E 02	1.35E 01	7.50E 02	7.50E 02	7.50E 02
PU-240	1.1[illegible]E 06	3.30E 06	2.25E 03	7.50E 02	2.43E 01	7.50E 02	7.50E 02	7.50E 02
PU-241	0.0	5.13E 04	0.0	1.20E 01	0.0	1.20E 01	1.20E 01	1.20E 01
AM-241	2.[illegible]E 08	3.26E 06	1.42E 05	2.47E 04	5.71E 03	2.47E 04	2.47E 04	2.47E 04
AM-242M	0.0	3.22E 06	0.0	2.44E 04	0.0	2.44E 04	2.44E 04	2.44E 04
AM-243	6.08E 08	3.33E 06	1.28E 05	2.50E 04	1.20E 04	2.50E 04	2.50E 04	2.50E 04
CM-242	1.16E 06	5.66E 04	2.12E 03	4.30E 02	2.44E 01	4.30E 02	4.30E 02	4.30E 02
CM-244	8.38E 07	1.38E 06	3.36E 04	1.04E 04	1.70E 03	1.04E 04	1.04E 04	1.04E 04

ORGAN = THYROID

	JF=1		JF=2		JF=3		JF=4	
	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2	MODE=1	MODE=2
C-14	0.0	0.0	0.0	5.69E-01	0.0	5.69E-01	5.69E-01	5.69E-01
SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ZR-93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NB-93M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TC-99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
I-129	1.01E 08	5.55E 03	6.04E 04	5.17E 03	2.12E 03	5.17E 03	5.17E 03	5.17E 03
CS-135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PB-210	1.20E 07	0.0	1.91E 04	0.0	2.53E 02	0.0	0.0	0.0
RA-225	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RA-226	4.79E 07	0.0	9.29E 03	0.0	1.01E 03	0.0	0.0	0.0
TH-229	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TH-230	2.61E 06	0.0	4.46E 03	0.0	5.50E 01	0.0	0.0	0.0
NP-237	6.92E 08	0.0	1.50E 05	0.0	1.46E 04	0.0	0.0	0.0
NP-239	1.02E 09	0.0	2.61E 05	0.0	2.14E 04	0.0	0.0	0.0
PU-238	2.45E 05	0.0	4.81E 02	0.0	5.17E 00	0.0	0.0	0.0
PU-239	1.89E 05	0.0	3.59E 02	0.0	3.98E 00	0.0	0.0	0.0
PU-240	2.53E 05	0.0	4.93E 02	0.0	5.32E 00	0.0	0.0	0.0
PU-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AM-241	1.38E 08	0.0	7.21E 04	0.0	2.91E 03	0.0	0.0	0.0
AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AM-243	3.09E 08	0.0	6.50E 04	0.0	6.59E 03	0.0	0.0	0.0
CM-242	1.92E 05	0.0	3.51E 02	0.0	4.03E 00	0.0	0.0	0.0
CM-244	4.73E 07	0.0	1.90E 04	0.0	9.95E 02	0.0	0.0	0.0

APPENDIX K

SAMPLE AMRAW BASE CASE DOSE CALCULATION OUTPUT

Sample output for the full run base case for terminal storage phase, Case No. 48, all probabilistic releases, for output Sections 2 through 5 are presented in the appendix as follows:

1. Tc-99 (Table K-1)

   (a) Section 2. Release to Environment.

      1) Release Fractions by Each Cut Set, RELOUT.

      2) Release Increments to Preliminary Environmental Input Receptors, R1J, from All Release Events, Ci.

      3) Concentrations at Environment Input Receptor, R2TOT, Zones 1 and 8. Units: JF = 1, μCi-y/cm^3; JF = 2, μCi/cm^2; JF = 3 and 4, μCi/cm^3.

   (b) Section 3. Local Dose to Individual.

      1) Average Annual Local Dose to Individual, MAN1L, mrem/y, Zones 1 and 8.

   (c) Section 4. Nonspecific Dose to Population.

      1) Average Annual Nonspecific Dose to Population, MAN1N, man-rem/y.

2. Pb-210 (Table K-2)

   (Same sequence as for Tc-99).

3. Totals for All Nuclides (Table K-3)

   Section 5. Total Dose by Receptors.

   1) Average Annual Local Dose to Individual, MAN2LF for JF = 1 to 4, MAN2L for Total, mrem/y, Total for All Nuclides, for each of 8 zones.

   2) Average Annual Nonspecific Dose to Population, MAN2NF for JF = 1 to 4, MAN2N for Total, man-rem/y, Total for All Nuclides.

Table K-1-a. Tc-99 Release to Environment

RADIONUCLIDE: TC-99 (K = 6)

RELEASE FRACTIONS BY EACH CUTSET, RELOUT

TIME	JF	INITIAL RELEASE FRACTIONS		
40.	1	5.00E-14	1.80E-12	1.44E-13
40.	2	0.0	5.00E-14	6.07E-12
40.	3	0.0	5.00E-14	6.07E-12
40.	4	1.21E-11		
50.	1	5.00E-14	1.80E-12	1.44E-13
50.	2	0.0	5.00E-14	6.07E-12
50.	3	0.0	5.00E-14	6.07E-12
50.	4	1.21E-11		
60.	1	5.00E-14	1.80E-12	1.44E-13
60.	2	0.0	5.00E-14	6.07E-12
60.	3	0.0	5.00E-14	6.07E-12
60.	4	1.21E-11		
70.	1	5.00E-14	1.80E-12	1.44E-13
70.	2	0.0	5.00E-14	6.07E-12
70.	3	0.0	5.00E-14	6.07E-12
70.	4	1.21E-11		
80.	1	5.00E-14	1.80E-12	1.44E-13
80.	2	0.0	5.00E-14	6.07E-12
80.	3	0.0	5.00E-14	6.07E-12
80.	4	1.21E-11		
90.	1	5.00E-14	1.80E-12	1.44E-13
90.	2	0.0	5.00E-14	6.07E-12
90.	3	0.0	5.00E-14	6.07E-12
90.	4	1.21E-11		
100.	1	5.00E-14	1.80E-12	1.44E-13
100.	2	0.0	5.00E-14	6.07E-12
100.	3	0.0	5.00E-14	6.07E-12
100.	4	1.21E-11		
200.	1	5.00E-13	1.80E-11	1.44E-12
200.	2	0.0	5.00E-13	6.07E-11
200.	3	0.0	5.00E-13	6.07E-11
200.	4	1.11E-09		
300.	1	5.00E-13	1.80E-11	1.44E-12
300.	2	0.0	5.00E-13	6.07E-11
300.	3	0.0	5.00E-13	6.07E-11
300.	4	1.11E-09		
400.	1	5.00E-13	1.80E-11	1.44E-12
400.	2	0.0	5.00E-13	6.07E-11
400.	3	0.0	5.00E-13	6.07E-11
400.	4	1.11E-09		
500.	1	5.00E-13	1.80E-11	1.44E-12
500.	2	0.0	5.00E-13	6.07E-11
500.	3	0.0	5.00E-13	6.07E-11
500.	4	1.11E-09		
600.	1	5.00E-13	1.80E-11	1.44E-12
600.	2	0.0	5.00E-13	6.07E-11
600.	3	0.0	5.00E-13	6.07E-11
600.	4	1.11E-09		
700.	1	5.00E-13	1.80E-11	1.44E-12
700.	2	0.0	5.00E-13	6.07E-11
700.	3	0.0	5.00E-13	6.07E-11
700.	4	1.11E-09		
800.	1	5.00E-13	1.80E-11	1.44E-12
800.	2	0.0	5.00E-13	6.07E-11
800.	3	0.0	5.00E-13	6.07E-11
800.	4	1.11E-09		

TIME	JF	INITIAL RELEASE FRACTIONS, CONT'D		
900.	1	5.00E-13	1.80E-11	1.44E-12
900.	2	0.0	5.00E-13	6.07E-11
900.	3	0.0	5.00E-13	6.07E-11
900.	4	1.11E-09		
1000.	1	5.00E-13	1.80E-11	1.44E-12
1000.	2	0.0	5.00E-13	6.07E-11
1000.	3	0.0	5.00E-13	6.07E-11
1000.	4	1.11E-09		
2000.	1	5.00E-12	1.80E-10	1.44E-11
2000.	2	0.0	5.00E-12	6.07E-10
2000.	3	0.0	5.00E-12	6.07E-10
2000.	4	1.09E-07		
3000.	1	5.00E-12	1.80E-10	1.44E-11
3000.	2	0.0	5.00E-12	6.07E-10
3000.	3	0.0	5.00E-12	6.07E-10
3000.	4	1.09E-07		
4000.	1	5.00E-12	1.80E-10	1.44E-11
4000.	2	0.0	5.00E-12	6.07E-10
4000.	3	0.0	5.00E-12	6.07E-10
4000.	4	1.09E-07		
5000.	1	5.00E-12	1.80E-10	1.44E-11
5000.	2	0.0	5.00E-12	6.07E-10
5000.	3	0.0	5.00E-12	6.07E-10
5000.	4	1.09E-07		
6000.	1	5.00E-12	1.80E-10	1.44E-11
6000.	2	0.0	5.00E-12	6.07E-10
6000.	3	0.0	5.00E-12	6.07E-10
6000.	4	1.09E-07		
7000.	1	5.00E-12	1.80E-10	1.44E-11
7000.	2	0.0	5.00E-12	6.07E-10
7000.	3	0.0	5.00E-12	6.07E-10
7000.	4	1.09E-07		
8000.	1	5.00E-12	1.80E-10	1.44E-11
8000.	2	0.0	5.00E-12	6.07E-10
8000.	3	0.0	5.00E-12	6.07E-10
8000.	4	1.09E-07		
9000.	1	5.00E-12	1.80E-10	1.44E-11
9000.	2	0.0	5.00E-12	6.07E-10
9000.	3	0.0	5.00E-12	6.07E-10
9000.	4	1.09E-07		
10000.	1	5.00E-12	1.80E-10	1.44E-11
10000.	2	0.0	5.00E-12	6.07E-10
10000.	3	0.0	5.00E-12	6.07E-10
10000.	4	1.09E-07		
20000.	1	5.00E-11	1.80E-09	1.44E-10
20000.	2	0.0	5.00E-11	6.07E-09
20000.	3	0.0	5.00E-11	6.07E-09
20000.	4	1.08E-05		
30000.	1	5.00E-11	1.80E-09	1.44E-10
30000.	2	0.0	5.00E-11	6.07E-09
30000.	3	0.0	5.00E-11	6.07E-09
30000.	4	1.08E-05		
40000.	1	5.00E-11	1.80E-09	1.44E-10
40000.	2	0.0	5.00E-11	6.07E-09
40000.	3	0.0	5.00E-11	6.07E-09
40000.	4	1.08E-05		
50000.	1	5.00E-11	1.80E-09	1.44E-10
50000.	2	0.0	5.00E-11	6.07E-09
50000.	3	0.0	5.00E-11	6.07E-09
50000.	4	1.08E-05		

TIME	JF	INITIAL RELEASE FRACTIONS, CONT'D		
60000.	1	5.00E-11	1.80E-09	1.44E-10
60000.	2	0.0	5.00E-11	6.07E-09
60000.	3	0.0	5.00E-11	6.07E-09
60000.	4	1.08E-05		
70000.	1	5.00E-11	1.80E-09	1.44E-10
70000.	2	0.0	5.00E-11	6.07E-09
70000.	3	0.0	5.00E-11	6.07E-09
70000.	4	1.08E-05		
80000.	1	5.00E-11	1.80E-09	1.44E-10
80000.	2	0.0	5.00E-11	6.07E-09
80000.	3	0.0	5.00E-11	6.07E-09
80000.	4	1.08E-05		
90000.	1	5.00E-11	1.80E-09	1.44E-10
90000.	2	0.0	5.00E-11	6.07E-09
90000.	3	0.0	5.00E-11	6.07E-09
90000.	4	1.08E-05		
100000.	1	5.00E-11	1.80E-09	1.44E-10
100000.	2	0.0	5.00E-11	6.07E-09
100000.	3	0.0	5.00E-11	6.07E-09
100000.	4	1.08E-05		
200000.	1	5.00E-10	1.80E-08	1.44E-09
200000.	2	0.0	5.00E-10	6.07E-08
200000.	3	0.0	5.00E-10	6.07E-08
200000.	4	1.08E-03		
300000.	1	5.00E-10	1.80E-08	1.44E-09
300000.	2	0.0	5.00E-10	6.07E-08
300000.	3	0.0	5.00E-10	6.07E-08
300000.	4	1.08E-03		
400000.	1	5.00E-10	1.80E-08	1.44E-09
400000.	2	0.0	5.00E-10	6.07E-08
400000.	3	0.0	5.00E-10	6.07E-08
400000.	4	1.08E-03		
500000.	1	5.00E-10	1.80E-08	1.44E-09
500000.	2	0.0	5.00E-10	6.07E-08
500000.	3	0.0	5.00E-10	6.07E-08
500000.	4	1.08E-03		
600000.	1	5.00E-10	1.80E-08	1.44E-09
600000.	2	0.0	5.00E-10	6.07E-08
600000.	3	0.0	5.00E-10	6.07E-08
600000.	4	1.08E-03		
700000.	1	5.00E-10	1.80E-08	1.44E-09
700000.	2	0.0	5.00E-10	6.07E-08
700000.	3	0.0	5.00E-10	6.07E-08
700000.	4	1.08E-03		
800000.	1	5.00E-10	1.80E-08	1.44E-09
800000.	2	0.0	5.00E-10	6.07E-08
800000.	3	0.0	5.00E-10	6.07E-08
800000.	4	1.08E-03		
900000.	1	5.00E-10	1.80E-08	1.44E-09
900000.	2	0.0	5.00E-10	6.07E-08
900000.	3	0.0	5.00E-10	6.07E-08
900000.	4	1.08E-03		
1000000.	1	5.00E-10	1.80E-08	1.44E-09
1000000.	2	0.0	5.00E-10	6.07E-08
1000000.	3	0.0	5.00E-10	6.07E-08
1000000.	4	1.08E-03		

Table K-1-a. (Continued)

RADIONUCLIDE: TC-99 (K= 6)

RELEASE INCREMENTS TO PRELIMINARY ENVIRONMENT INPUT RECEPTORS, RIJ, FROM ALL RELEASE EVENTS, IN CURIES

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER
0.	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0
40.	5.22E-06	1.60E-05	1.60E-05	3.17E-05
50.	5.22E-06	1.60E-05	1.60E-05	3.17E-05
60.	5.22E-06	1.60E-05	1.60E-05	3.17E-05
70.	5.22E-06	1.60E-05	1.60E-05	3.17E-05
80.	5.22E-06	1.60E-05	1.60E-05	3.17E-05
90.	5.22E-06	1.60E-05	1.60E-05	3.17E-05
100.	5.22E-06	1.60E-05	1.60E-05	3.17E-05
200.	5.22E-05	1.60E-04	1.60E-04	2.90E-03
300.	5.22E-05	1.60E-04	1.60E-04	2.90E-03
400.	5.22E-05	1.60E-04	1.60E-04	2.90E-03
500.	5.22E-05	1.60E-04	1.60E-04	2.90E-03
600.	5.22E-05	1.60E-04	1.60E-04	2.90E-03
700.	5.20E-05	1.60E-04	1.60E-04	2.89E-03
800.	5.19E-05	1.59E-04	1.59E-04	2.88E-03
900.	5.19E-05	1.59E-04	1.59E-04	2.88E-03
1000.	5.19E-05	1.59E-04	1.59E-04	2.88E-03
2000.	5.17E-04	1.59E-03	1.59E-03	2.81E-01
3000.	5.15E-04	1.58E-03	1.58E-03	2.80E-01
4000.	5.15E-04	1.58E-03	1.58E-03	2.80E-01
5000.	5.14E-04	1.58E-03	1.58E-03	2.79E-01
6000.	5.12E-04	1.57E-03	1.57E-03	2.79E-01
7000.	5.10E-04	1.57E-03	1.57E-03	2.78E-01
8000.	5.08E-04	1.56E-03	1.56E-03	2.77E-01
9000.	5.07E-04	1.56E-03	1.56E-03	2.76E-01
10000.	5.05E-04	1.55E-03	1.55E-03	2.75E-01
20000.	4.47E-03	1.53E-02	1.53E-02	2.70E 01
30000.	4.80E-03	1.47E-02	1.47E-02	2.61E 01
40000.	4.63E-03	1.42E-02	1.42E-02	2.51E 01
50000.	4.47E-03	1.37E-02	1.37E-02	2.43E 01
60000.	4.34E-03	1.33E-02	1.33E-02	2.36E 01
70000.	4.20E-03	1.29E-02	1.29E-02	2.28E 01
80000.	4.07E-03	1.25E-02	1.25E-02	2.21E 01
90000.	3.93E-03	1.21E-02	1.21E-02	2.14E 01
100000.	3.81E-03	1.17E-02	1.17E-02	2.07E 01
200000.	3.26E-02	1.00E-01	1.00E-01	1.77E 03
300000.	2.73E-02	7.24E-02	7.24E-02	1.28E 03
400000.	1.66E-02	5.11E-02	5.11E-02	9.04E 02
500000.	1.17E-02	3.60E-02	3.60E-02	6.36E 02
600000.	8.30E-03	2.55E-02	2.55E-02	4.51E 02
700000.	5.95E-03	1.83E-02	1.83E-02	3.23E 02
800000.	4.31E-03	1.32E-02	1.32E-02	2.34E 02
900000.	3.15E-03	9.66E-03	9.66E-03	1.71E 02
1000000.	2.32E-03	7.14E-03	7.14E-03	1.26E 02

RADIONUCLIDE: TC-99 (K= 6)

CONCENTRATIONS AT ENVIRONMENT INPUT RECEPTOR, R2IDT UNITS: JF=1 MICROCURIE*YEARS/CUBIC CM
JF=2 MICROCURIES/SQUARE CM, JF=3 AND 4 MICROCURIES/CUBIC CM

ZONE= 1

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER
0.	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0
40.	1.13E-18	4.73E-12	0.0	0.0
50.	1.60E-19	9.45E-12	0.0	0.0
60.	2.08E-19	1.42E-11	0.0	0.0
70.	2.55E-19	1.89E-11	0.0	0.0
80.	3.02E-19	2.36E-11	0.0	0.0
90.	3.49E-19	2.83E-11	0.0	0.0
100.	3.96E-19	3.31E-11	0.0	0.0
200.	8.69E-18	8.03E-11	0.0	0.0
300.	1.34E-17	1.27E-10	0.0	0.0
400.	1.81E-17	1.74E-10	0.0	0.0
500.	2.28E-17	2.21E-10	0.0	0.0
600.	2.75E-17	2.68E-10	0.0	0.0
700.	3.20E-17	3.14E-10	0.0	0.0
800.	3.65E-17	3.59E-10	0.0	0.0
900.	4.12E-17	4.05E-10	0.0	0.0
1000.	4.58E-17	4.51E-10	0.0	0.0
2000.	9.19E-16	9.13E-10	0.0	0.0
3000.	1.38E-15	1.36E-09	0.0	0.0
4000.	1.80E-15	1.79E-09	0.0	0.0
5000.	2.22E-15	2.21E-09	0.0	0.0
6000.	2.62E-15	2.62E-09	0.0	0.0
7000.	3.02E-15	3.01E-09	0.0	0.0
8000.	3.40E-15	3.39E-09	0.0	0.0
9000.	3.77E-15	3.76E-09	0.0	0.0
10000.	4.13E-15	4.12E-09	0.0	0.0
20000.	8.07E-14	8.07E-09	0.0	0.0
30000.	1.03E-12	1.05E-08	0.0	0.0
40000.	1.23E-13	1.23E-08	0.0	0.0
50000.	1.35E-13	1.35E-08	0.0	0.0
60000.	1.43E-13	1.43E-08	0.0	0.0
70000.	1.48E-13	1.48E-08	0.0	0.0
80000.	1.51E-13	1.51E-08	0.0	0.0
90000.	1.54E-13	1.51E-08	0.0	0.0
100000.	1.51E-13	1.51E-08	0.0	0.0
200000.	2.32E-12	3.32E-08	0.0	0.0
300000.	2.38E-12	2.33E-08	0.0	0.0
400000.	1.68E-12	1.68E-08	0.0	0.0
500000.	1.18E-12	1.18E-08	0.0	0.0
600000.	8.36E-13	8.26E-09	0.0	0.0
700000.	5.99E-13	5.99E-09	0.0	0.0
800000.	4.23E-13	4.23E-09	0.0	0.0
900000.	3.17E-13	3.17E-09	0.0	0.0
1000000.	2.34E-13	2.34E-09	0.0	0.0

ZONE= 8

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER
0.	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0
40.	6.57E-22	5.18E-14	1.02E-16	0.0
50.	1.18E-21	1.05E-13	1.34E-16	0.0
60.	1.71E-21	1.59E-13	1.79E-16	0.0
70.	2.24E-21	2.12E-13	1.92E-16	0.0
80.	2.77E-21	2.67E-13	1.93E-16	0.0
90.	3.32E-21	3.21E-13	2.01E-16	0.0
100.	3.86E-21	3.75E-13	2.03E-16	0.0
200.	8.85E-20	8.95E-13	1.13E-15	0.0
300.	1.40E-19	1.42E-12	1.53E-15	0.0
400.	1.97E-19	1.96E-12	1.81E-15	0.0
500.	2.46E-19	2.49E-12	1.93E-15	0.0
600.	3.00E-19	3.03E-12	1.99E-15	0.0
700.	3.52E-19	3.53E-12	2.01E-15	0.0
800.	4.04E-19	4.07E-12	2.03E-15	0.0
900.	4.37E-19	4.50E-12	2.02E-15	0.0
1000.	5.10E-19	5.13E-12	2.03E-15	0.0
2000.	9.98E-18	1.02E-11	1.11E-14	0.0
3000.	1.43E-17	1.52E-11	1.55E-14	0.0
4000.	1.97E-17	2.01E-11	1.77E-14	0.0
5000.	2.45E-17	2.49E-11	1.87E-14	0.0
6000.	2.91E-17	2.96E-11	1.91E-14	0.0
7000.	3.36E-17	3.41E-11	1.93E-14	2.32E-34
8000.	3.80E-17	3.85E-11	1.94E-14	2.12E-26
9000.	4.23E-17	4.27E-11	1.94E-14	7.27E-21
10000.	4.64E-17	4.69E-11	1.93E-14	4.84E-17
20000.	8.76E-16	9.01E-11	5.77E-11	4.69E-13
30000.	1.15E-15	1.17E-09	9.47E-11	4.11E-11
40000.	9.39E-15	2.28E-09	1.50E-09	8.36E-10
50000.	1.78E-14	2.10E-08	1.81E-09	8.12E-10
60000.	1.62E-13	4.19E-08	2.04E-09	7.88E-10
70000.	3.23E-13	3.39E-08	2.30E-09	7.60E-10
80000.	4.60E-13	7.37E-08	2.05E-09	7.30E-10
90000.	5.66E-13	8.37E-08	2.31E-09	7.11E-10
100000.	6.45E-13	9.09E-08	1.96E-09	6.93E-10
200000.	2.17E-12	2.96E-08	4.66E-10	1.10E-11
300000.	2.27E-13	2.75E-09	3.69E-09	4.55E-10
400000.	3.41E-14	9.21E-09	4.37E-09	3.26E-10
500000.	7.22E-14	7.34E-09	3.11E-09	2.31E-10
600000.	5.71E-14	5.31E-09	2.22E-09	1.64E-10
700000.	4.19E-14	3.85E-09	1.59E-09	1.18E-10
800000.	3.06E-14	2.80E-09	1.13E-09	8.53E-11
900000.	2.25E-14	2.05E-09	8.40E-10	6.23E-11
1000000.	1.67E-14	1.53E-09	6.22E-10	4.61E-11

Table K-1-b. Average Annual Local Dose to Individual, MANIL, In Millirems/Year

ZONE= 1... NUCLIDE= TC-99 K= 6

TIME	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
0.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40.	1.03E-12	5.88E-10	1.03E-12	3.83E-12	8.34E-09	1.02E-11	1.02E-11	0.0
50.	1.46E-12	8.33E-10	1.46E-12	5.43E-12	1.18E-08	1.44E-11	1.44E-11	0.0
60.	1.89E-12	1.08E-09	1.89E-12	7.03E-12	1.53E-08	1.86E-11	1.86E-11	0.0
70.	2.33E-12	1.32E-09	2.33E-12	8.63E-12	1.88E-08	2.29E-11	2.29E-11	0.0
80.	2.76E-12	1.57E-09	2.76E-12	1.02E-11	2.23E-08	2.71E-11	2.71E-11	0.0
90.	3.19E-12	1.82E-09	3.19E-12	1.18E-11	2.58E-08	3.14E-11	3.14E-11	0.0
100.	3.62E-12	2.06E-09	3.62E-12	1.34E-11	2.92E-08	3.56E-11	3.56E-11	0.0
200.	7.93E-12	4.52E-09	7.93E-12	2.94E-11	6.41E-08	7.80E-11	7.80E-11	0.0
300.	1.22E-11	6.96E-09	1.22E-11	4.54E-11	9.88E-08	1.20E-10	1.20E-10	0.0
400.	1.65E-11	9.41E-09	1.65E-11	6.13E-11	1.33E-07	1.62E-10	1.62E-10	0.0
500.	2.08E-11	1.18E-08	2.08E-11	7.72E-11	1.68E-07	2.05E-10	2.05E-10	0.0
600.	2.51E-11	1.43E-08	2.51E-11	9.30E-11	2.02E-07	2.47E-10	2.47E-10	0.0
700.	2.92E-11	1.66E-08	2.92E-11	1.08E-10	2.36E-07	2.88E-10	2.88E-10	0.0
800.	3.33E-11	1.90E-08	3.33E-11	1.24E-10	2.69E-07	3.28E-10	3.28E-10	0.0
900.	3.76E-11	2.14E-08	3.76E-11	1.39E-10	3.03E-07	3.70E-10	3.70E-10	0.0
1000.	4.18E-11	2.38E-08	4.18E-11	1.55E-10	3.37E-07	4.11E-10	4.11E-10	0.0
2000.	8.38E-11	4.77E-08	8.38E-11	3.11E-10	6.77E-07	8.25E-10	8.25E-10	0.0
3000.	1.24E-10	7.08E-08	1.24E-10	4.61E-10	1.00E-06	1.22E-09	1.22E-09	0.0
4000.	1.64E-10	9.34E-08	1.64E-10	6.09E-10	1.33E-06	1.61E-09	1.61E-09	0.0
5000.	2.02E-10	1.15E-07	2.02E-10	7.51E-10	1.63E-06	1.99E-09	1.99E-09	0.0
6000.	2.39E-10	1.36E-07	2.39E-10	8.88E-10	1.93E-06	2.35E-09	2.35E-09	0.0
7000.	2.75E-10	1.57E-07	2.75E-10	1.02E-09	2.22E-06	2.71E-09	2.71E-09	0.0
8000.	3.10E-10	1.77E-07	3.10E-10	1.15E-09	2.51E-06	3.05E-09	3.05E-09	0.0
9000.	3.44E-10	1.96E-07	3.44E-10	1.28E-09	2.78E-06	3.38E-09	3.38E-09	0.0
10000.	3.77E-10	2.15E-07	3.77E-10	1.40E-09	3.04E-06	3.71E-09	3.71E-09	0.0
20000.	7.37E-10	4.20E-07	7.37E-10	2.74E-09	5.95E-06	7.25E-09	7.25E-09	0.0
30000.	9.62E-10	5.48E-07	9.62E-10	3.57E-09	7.77E-06	9.47E-09	9.47E-09	0.0
40000.	1.12E-09	6.38E-07	1.12E-09	4.16E-09	9.05E-06	1.10E-08	1.10E-08	0.0
50000.	1.23E-09	7.01E-07	1.23E-09	4.57E-09	9.94E-06	1.21E-08	1.21E-08	0.0
60000.	1.31E-09	7.44E-07	1.31E-09	4.85E-09	1.06E-05	1.29E-08	1.29E-08	0.0
70000.	1.35E-09	7.71E-07	1.35E-09	5.02E-09	1.09E-05	1.33E-08	1.33E-08	0.0
80000.	1.38E-09	7.84E-07	1.38E-09	5.11E-09	1.11E-05	1.35E-08	1.35E-08	0.0
90000.	1.38E-09	7.87E-07	1.38E-09	5.13E-09	1.12E-05	1.36E-08	1.36E-08	0.0
100000.	1.38E-09	7.86E-07	1.38E-09	5.12E-09	1.12E-05	1.36E-08	1.36E-08	0.0
200000.	3.03E-09	1.72E-06	3.03E-09	1.12E-08	2.45E-05	2.98E-08	2.98E-08	0.0
300000.	2.17E-09	1.23E-06	2.17E-09	8.05E-09	1.75E-05	2.13E-08	2.13E-08	0.0
400000.	1.53E-09	8.71E-07	1.53E-09	5.68E-09	1.24E-05	1.50E-08	1.50E-08	0.0
500000.	1.08E-09	6.13E-07	1.08E-09	3.99E-09	8.69E-06	1.06E-08	1.06E-08	0.0
600000.	7.63E-10	4.35E-07	7.63E-10	2.83E-09	6.16E-06	7.51E-09	7.51E-09	0.0
700000.	5.46E-10	3.11E-07	5.46E-10	2.03E-09	4.42E-06	5.38E-09	5.38E-09	0.0
800000.	3.95E-10	2.25E-07	3.95E-10	1.47E-09	3.20E-06	3.89E-09	3.89E-09	0.0
900000.	2.89E-10	1.65E-07	2.89E-10	1.07E-09	2.33E-06	2.84E-09	2.84E-09	0.0
1000000.	2.13E-10	1.22E-07	2.13E-10	7.92E-10	1.72E-06	2.10E-09	2.10E-09	0.0

Table K-1-b. (Continued)

** AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN MILLIREMS/YEAR

ZONE= 8... NUCLIDE= TC-99 K= 6

TIME	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
0.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40.	2.05E-12	4.01E-10	2.05E-12	7.64E-12	4.91E-11	5.22E-12	5.22E-12	0.0
50.	3.08E-12	6.02E-10	3.08E-12	1.15E-11	8.76E-11	7.84E-12	7.84E-12	0.0
60.	3.60E-12	7.04E-10	3.60E-12	1.34E-11	1.27E-10	9.18E-12	9.18E-12	0.0
70.	3.86E-12	7.56E-10	3.86E-12	1.44E-11	1.67E-10	9.87E-12	9.87E-12	0.0
80.	3.99E-12	7.84E-10	3.99E-12	1.48E-11	2.06E-10	1.02E-11	1.02E-11	0.0
90.	4.06E-12	7.99E-10	4.06E-12	1.51E-11	2.46E-10	1.05E-11	1.05E-11	0.0
100.	4.10E-12	8.08E-10	4.10E-12	1.52E-11	2.86E-10	1.06E-11	1.06E-11	0.0
200.	2.26E-11	4.41E-09	2.26E-11	8.40E-11	6.59E-10	5.75E-11	5.75E-11	0.0
300.	3.18E-11	6.22E-09	3.18E-11	1.18E-10	1.04E-09	8.11E-11	8.11E-11	0.0
400.	3.65E-11	7.14E-09	3.65E-11	1.36E-10	1.44E-09	9.32E-11	9.32E-11	0.0
500.	3.88E-11	7.61E-09	3.88E-11	1.44E-10	1.83E-09	9.94E-11	9.94E-11	0.0
600.	4.00E-11	7.86E-09	4.00E-11	1.49E-10	2.22E-09	1.03E-10	1.03E-10	0.0
700.	4.05E-11	7.97E-09	4.05E-11	1.51E-10	2.61E-09	1.04E-10	1.04E-10	0.0
800.	4.07E-11	8.03E-09	4.07E-11	1.51E-10	2.99E-09	1.05E-10	1.05E-10	0.0
900.	4.09E-11	8.08E-09	4.09E-11	1.52E-10	3.38E-09	1.06E-10	1.06E-10	0.0
1000.	4.10E-11	8.13E-09	4.10E-11	1.52E-10	3.77E-09	1.07E-10	1.07E-10	0.0
2000.	2.24E-10	4.37E-08	2.24E-10	8.32E-10	7.41E-09	5.70E-10	5.70E-10	0.0
3000.	3.12E-10	6.10E-08	3.12E-10	1.16E-09	1.10E-08	7.96E-10	7.96E-10	0.0
4000.	3.56E-10	6.97E-08	3.56E-10	1.32E-09	1.47E-08	9.09E-10	9.09E-10	0.0
5000.	3.76E-10	7.38E-08	3.76E-10	1.40E-09	1.82E-08	9.64E-10	9.64E-10	0.0
6000.	3.85E-10	7.58E-08	3.85E-10	1.43E-09	2.16E-08	9.91E-10	9.91E-10	0.0
7000.	3.90E-10	7.67E-08	3.90E-10	1.45E-09	2.49E-08	1.00E-09	1.00E-09	0.0
8000.	3.91E-10	7.72E-08	3.91E-10	1.45E-09	2.82E-08	1.01E-09	1.01E-09	0.0
9000.	3.91E-10	7.74E-08	3.91E-10	1.46E-09	3.13E-08	1.01E-09	1.01E-09	0.0
10000.	3.91E-10	7.75E-08	3.91E-10	1.46E-09	3.43E-08	1.02E-09	1.02E-09	0.0
20000.	1.20E-06	2.33E-04	1.20E-06	4.46E-06	4.44E-07	3.02E-06	3.02E-06	0.0
30000.	1.94E-06	3.76E-04	1.94E-06	7.20E-06	6.96E-07	4.88E-06	4.88E-06	0.0
40000.	2.25E-05	4.36E-03	2.25E-05	8.36E-05	7.79E-06	5.66E-05	5.66E-05	0.0
50000.	3.69E-05	7.16E-03	3.69E-05	1.37E-04	1.30E-05	9.30E-05	9.30E-05	0.0
60000.	4.17E-05	8.09E-03	4.17E-05	1.55E-04	2.52E-05	1.05E-04	1.05E-04	0.0
70000.	4.26E-05	8.26E-03	4.26E-05	1.58E-04	3.73E-05	1.07E-04	1.07E-04	0.0
80000.	4.20E-05	8.15E-03	4.20E-05	1.56E-04	4.72E-05	1.06E-04	1.06E-04	0.0
90000.	4.09E-05	7.94E-03	4.09E-05	1.52E-04	5.47E-05	1.03E-04	1.03E-04	0.0
100000.	3.99E-05	7.74E-03	3.99E-05	1.48E-04	6.02E-05	1.01E-04	1.01E-04	0.0
200000.	9.34E-06	1.81E-03	9.34E-06	3.47E-05	1.89E-05	2.35E-05	2.35E-05	0.0
300000.	1.12E-04	2.18E-02	1.12E-04	4.18E-04	3.72E-05	2.83E-04	2.83E-04	0.0
400000.	8.77E-05	1.70E-02	8.77E-05	3.26E-04	2.80E-05	2.21E-04	2.21E-04	0.0
500000.	6.25E-05	1.21E-02	6.25E-05	2.33E-04	2.03E-05	1.58E-04	1.58E-04	0.0
600000.	4.45E-05	8.63E-03	4.45E-05	1.66E-04	1.45E-05	1.12E-04	1.12E-04	0.0
700000.	3.19E-05	6.19E-03	3.19E-05	1.19E-04	1.04E-05	8.04E-05	8.04E-05	0.0
800000.	2.31E-05	4.48E-03	2.31E-05	8.59E-05	7.52E-06	5.82E-05	5.82E-05	0.0
900000.	1.69E-05	3.27E-03	1.69E-05	6.28E-05	5.50E-06	4.25E-05	4.25E-05	0.0
1000000.	1.25E-05	2.42E-03	1.25E-05	4.65E-05	4.07E-06	3.15E-05	3.15E-05	0.0

Table K-1-c. Average Nonspecific Dose to Population, MAN1N, In Man-rem/Year

** AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MAN1N, IN MANREMS/YEAR

NONSPECIFIC ... NUCLIDE= TC-99 K= 6

TIME	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
0.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40.	6.91E-08	1.34E-05	6.91E-08	2.57E-07	2.19E-08	1.74E-07	1.74E-07	0.0
50.	1.26E-07	2.45E-05	1.26E-07	4.69E-07	3.98E-08	3.18E-07	3.18E-07	0.0
60.	1.82E-07	3.53E-05	1.82E-07	6.78E-07	5.76E-08	4.59E-07	4.59E-07	0.0
70.	2.38E-07	4.61E-05	2.38E-07	8.84E-07	7.51E-08	5.99E-07	5.99E-07	0.0
80.	2.93E-07	5.69E-05	2.93E-07	1.09E-06	9.26E-08	7.39E-07	7.39E-07	0.0
90.	3.48E-07	6.76E-05	3.48E-07	1.30E-06	1.10E-07	8.78E-07	8.78E-07	0.0
100.	4.03E-07	7.83E-05	4.03E-07	1.50E-06	1.27E-07	1.02E-06	1.02E-06	0.0
200.	5.87E-07	1.92E-04	9.87E-07	3.67E-06	3.12E-07	2.49E-06	2.49E-06	0.0
300.	1.55E-06	3.01E-04	1.55E-06	5.78E-06	4.91E-07	3.91E-06	3.91E-06	0.0
400.	2.11E-06	4.09E-04	2.11E-06	7.85E-06	6.67E-07	5.32E-06	5.32E-06	0.0
500.	2.66E-06	5.16E-04	2.66E-06	9.90E-06	8.41E-07	6.70E-06	6.70E-06	0.0
600.	3.21E-06	6.22E-04	3.21E-06	1.19E-05	1.01E-06	8.08E-06	8.08E-06	0.0
700.	3.74E-06	7.26E-04	3.74E-06	1.39E-05	1.18E-06	9.43E-06	9.43E-06	0.0
800.	4.27E-06	8.28E-04	4.27E-06	1.59E-05	1.35E-06	1.08E-05	1.08E-05	0.0
900.	4.81E-06	9.33E-04	4.81E-06	1.79E-05	1.52E-06	1.21E-05	1.21E-05	0.0
1000.	5.35E-06	1.04E-03	5.35E-06	1.99E-05	1.69E-06	1.35E-05	1.35E-05	0.0
2000.	1.10E-05	2.14E-03	1.10E-05	4.11E-05	3.49E-06	2.78E-05	2.78E-05	0.0
3000.	1.64E-05	3.18E-03	1.64E-05	6.09E-05	5.17E-06	4.13E-05	4.13E-05	0.0
4000.	2.15E-05	4.18E-03	2.15E-05	8.01E-05	6.80E-06	5.43E-05	5.43E-05	0.0
5000.	2.65E-05	5.15E-03	2.65E-05	9.87E-05	8.38E-06	6.68E-05	6.68E-05	0.0
6000.	3.06E-05	9.82E-03	3.06E-05	1.88E-04	1.60E-05	1.28E-04	1.28E-04	0.0
7000.	2.54E-04	4.94E-02	2.54E-04	9.47E-04	8.04E-05	6.41E-04	6.41E-04	0.0
8000.	1.57E-03	3.05E-01	1.57E-03	5.84E-03	4.96E-04	3.96E-03	3.96E-03	0.0
9000.	5.92E-03	1.15E 00	5.92E-03	2.20E-02	1.87E-03	1.49E-02	1.49E-02	0.0
10000.	1.27E-02	2.47E 00	1.27E-02	4.74E-02	4.03E-03	3.21E-02	3.21E-02	0.0
20000.	1.79E-02	3.47E 00	1.79E-02	6.65E-02	5.65E-03	4.51E-02	4.51E-02	0.0
30000.	8.06E-02	1.56E 01	8.06E-02	3.00E-01	2.55E-02	2.03E-01	2.03E-01	0.0
40000.	1.60E-01	3.11E 01	1.60E-01	5.96E-01	5.06E-02	4.03E-01	4.03E-01	0.0
50000.	2.18E-01	4.23E 01	2.18E-01	8.11E-01	6.89E-02	5.49E-01	5.49E-01	0.0
60000.	2.49E-01	4.84E 01	2.49E-01	9.28E-01	7.88E-02	6.29E-01	6.29E-01	0.0
70000.	2.67E-01	5.18E 01	2.67E-01	9.93E-01	8.44E-02	6.73E-01	6.73E-01	0.0
80000.	2.76E-01	5.36E 01	2.76E-01	1.03E 00	8.73E-02	6.96E-01	6.96E-01	0.0
90000.	2.80E-01	5.44E 01	2.80E-01	1.04E 00	8.85E-02	7.06E-01	7.06E-01	0.0
100000.	2.82E-01	5.47E 01	2.82E-01	1.05E 00	8.91E-02	7.11E-01	7.11E-01	0.0
200000.	7.34E-02	1.42E 01	7.34E-02	2.73E-01	2.32E-02	1.85E-01	1.85E-01	0.0
300000.	6.65E-01	1.29E 02	6.65E-01	2.48E 00	2.10E-01	1.68E 00	1.68E 00	0.0
400000.	5.22E-01	1.01E 02	5.22E-01	1.94E 00	1.65E-01	1.32E 00	1.32E 00	0.0
500000.	3.72E-01	7.23E 01	3.72E-01	1.39E 00	1.18E-01	9.39E-01	9.39E-01	0.0
600000.	2.63E-01	5.11E 01	2.63E-01	9.80E-01	8.32E-02	6.64E-01	6.64E-01	0.0
700000.	1.88E-01	3.64E 01	1.88E-01	6.99E-01	5.93E-02	4.73E-01	4.73E-01	0.0
800000.	1.35E-01	2.62E 01	1.35E-01	5.02E-01	4.26E-02	3.40E-01	3.40E-01	0.0
900000.	9.79E-02	1.90E 01	9.79E-02	3.64E-01	3.09E-02	2.47E-01	2.47E-01	0.0
1000000.	7.18E-02	1.39E 01	7.18E-02	2.67E-01	2.27E-02	1.81E-01	1.81E-01	0.0

Table K-2-a. Pb-210, Release to Environment

RADIONUCLIDE: PB-210 (K = 10)

RELEASE FRACTIONS BY EACH CUTSET, RELOUT

TIME	JF	INITIAL RELEASE FRACTIONS		
40.	1	5.00E-14	1.80E-12	1.44E-13
40.	2	0.0	5.00E-14	6.07E-12
40.	3	0.0	5.00E-14	6.07E-12
40.	4	8.09E-12		
50.	1	5.00E-14	1.80E-12	1.44E-13
50.	2	0.0	5.00E-14	6.07E-12
50.	3	0.0	5.00E-14	6.07E-12
50.	4	8.09E-12		
60.	1	5.00E-14	1.80E-12	1.44E-13
60.	2	0.0	5.00E-14	6.07E-12
60.	3	0.0	5.00E-14	6.07E-12
60.	4	8.09E-12		
70.	1	5.00E-14	1.80E-12	1.44E-13
70.	2	0.0	5.00E-14	6.07E-12
70.	3	0.0	5.00E-14	6.07E-12
70.	4	8.09E-12		
80.	1	5.00E-14	1.80E-12	1.44E-13
80.	2	0.0	5.00E-14	6.07E-12
80.	3	0.0	5.00E-14	6.07E-12
80.	4	8.09E-12		
90.	1	5.00E-14	1.80E-12	1.44E-13
90.	2	0.0	5.00E-14	6.07E-12
90.	3	0.0	5.00E-14	6.07E-12
90.	4	8.09E-12		
100.	1	5.00E-14	1.80E-12	1.44E-13
100.	2	0.0	5.00E-14	6.07E-12
100.	3	0.0	5.00E-14	6.07E-12
100.	4	8.09E-12		
200.	1	5.00E-13	1.80E-11	1.44E-12
200.	2	0.0	5.00E-13	6.07E-11
200.	3	0.0	5.00E-13	6.07E-11
200.	4	6.80E-10		
300.	1	5.00E-13	1.80E-11	1.44E-12
300.	2	0.0	5.00E-13	6.07E-11
300.	3	0.0	5.00E-13	6.07E-11
300.	4	6.80E-10		
400.	1	5.00E-13	1.80E-11	1.44E-12
400.	2	0.0	5.00E-13	6.07E-11
400.	3	0.0	5.00E-13	6.07E-11
400.	4	6.80E-10		
500.	1	5.00E-13	1.80E-11	1.44E-12
500.	2	0.0	5.00E-13	6.07E-11
500.	3	0.0	5.00E-13	6.07E-11
500.	4	6.80E-10		
600.	1	5.00E-13	1.80E-11	1.44E-12
600.	2	0.0	5.00E-13	6.07E-11
600.	3	0.0	5.00E-13	6.07E-11
600.	4	6.80E-10		
700.	1	5.00E-13	1.80E-11	1.44E-12
700.	2	0.0	5.00E-13	6.07E-11
700.	3	0.0	5.00E-13	6.07E-11
700.	4	6.80E-10		
800.	1	5.00E-13	1.80E-11	1.44E-12
800.	2	0.0	5.00E-13	6.07E-11
800.	3	0.0	5.00E-13	6.07E-11
800.	4	6.80E-10		

TIME	JF	INITIAL RELEASE FRACTIONS, CONT'D		
900.	1	5.00E-13	1.80E-11	1.44E-12
900.	2	0.0	5.00E-13	6.07E-11
900.	3	0.0	5.00E-13	6.07E-11
900.	4	6.80E-10		
1000.	1	5.00E-13	1.80E-11	1.44E-12
1000.	2	0.0	5.00E-13	6.07E-11
1000.	3	0.0	5.00E-13	6.07E-11
1000.	4	6.80E-10		
2000.	1	5.00E-12	1.80E-10	1.44E-11
2000.	2	0.0	5.00E-12	6.07E-10
2000.	3	0.0	5.00E-12	6.07E-10
2000.	4	6.51E-08		
3000.	1	5.00E-12	1.80E-10	1.44E-11
3000.	2	0.0	5.00E-12	6.07E-10
3000.	3	0.0	5.00E-12	6.07E-10
3000.	4	6.51E-08		
4000.	1	5.00E-12	1.80E-10	1.44E-11
4000.	2	0.0	5.00E-12	6.07E-10
4000.	3	0.0	5.00E-12	6.07E-10
4000.	4	6.51E-08		
5000.	1	5.00E-12	1.80E-10	1.44E-11
5000.	2	0.0	5.00E-12	6.07E-10
5000.	3	0.0	5.00E-12	6.07E-10
5000.	4	6.51E-08		
6000.	1	5.00E-12	1.80E-10	1.44E-11
6000.	2	0.0	5.00E-12	6.07E-10
6000.	3	0.0	5.00E-12	6.07E-10
6000.	4	6.51E-08		
7000.	1	5.00E-12	1.80E-10	1.44E-11
7000.	2	0.0	5.00E-12	6.07E-10
7000.	3	0.0	5.00E-12	6.07E-10
7000.	4	6.51E-08		
8000.	1	5.00E-12	1.80E-10	1.44E-11
8000.	2	0.0	5.00E-12	6.07E-10
8000.	3	0.0	5.00E-12	6.07E-10
8000.	4	6.51E-08		
9000.	1	5.00E-12	1.80E-10	1.44E-11
9000.	2	0.0	5.00E-12	6.07E-10
9000.	3	0.0	5.00E-12	6.07E-10
9000.	4	6.51E-08		
10000.	1	5.00E-12	1.80E-10	1.44E-11
10000.	2	0.0	5.00E-12	6.07E-10
10000.	3	0.0	5.00E-12	6.07E-10
10000.	4	6.51E-08		
20000.	1	5.00E-11	1.80E-09	1.44E-10
20000.	2	0.0	5.00E-11	6.07E-09
20000.	3	0.0	5.00E-11	6.07E-09
20000.	4	6.48E-06		
30000.	1	5.00E-11	1.80E-09	1.44E-10
30000.	2	0.0	5.00E-11	6.07E-09
30000.	3	0.0	5.00E-11	6.07E-09
30000.	4	6.48E-06		
40000.	1	5.00E-11	1.80E-09	1.44E-10
40000.	2	0.0	5.00E-11	6.07E-09
40000.	3	0.0	5.00E-11	6.07E-09
40000.	4	6.48E-06		
50000.	1	5.00E-11	1.80E-09	1.44E-10
50000.	2	0.0	5.00E-11	6.07E-09
50000.	3	0.0	5.00E-11	6.07E-09
50000.	4	6.48E-06		

TIME	JF	INITIAL RELEASE FRACTIONS, CONT'D		
60000.	1	5.00E-11	1.80E-09	1.44E-10
60000.	2	0.0	5.00E-11	6.07E-09
60000.	3	0.0	5.00E-11	6.07E-09
60000.	4	6.48E-06		
70000.	1	5.00E-11	1.80E-09	1.44E-10
70000.	2	0.0	5.00E-11	6.07E-09
70000.	3	0.0	5.00E-11	6.07E-09
70000.	4	6.48E-06		
80000.	1	5.00E-11	1.80E-09	1.44E-10
80000.	2	0.0	5.00E-11	6.07E-09
80000.	3	0.0	5.00E-11	6.07E-09
80000.	4	6.48E-06		
90000.	1	5.00E-11	1.80E-09	1.44E-10
90000.	2	0.0	5.00E-11	6.07E-09
90000.	3	0.0	5.00E-11	6.07E-09
90000.	4	6.48E-06		
100000.	1	5.00E-11	1.80E-09	1.44E-10
100000.	2	0.0	5.00E-11	6.07E-09
100000.	3	0.0	5.00E-11	6.07E-09
100000.	4	6.48E-06		
200000.	1	5.00E-10	1.80E-08	1.44E-09
200000.	2	0.0	5.00E-10	6.07E-08
200000.	3	0.0	5.00E-10	6.07E-08
200000.	4	6.48E-04		
300000.	1	5.00E-10	1.80E-08	1.44E-09
300000.	2	0.0	5.00E-10	6.07E-08
300000.	3	0.0	5.00E-10	6.07E-08
300000.	4	6.48E-04		
400000.	1	5.00E-10	1.80E-08	1.44E-09
400000.	2	0.0	5.00E-10	6.07E-08
400000.	3	0.0	5.00E-10	6.07E-08
400000.	4	6.48E-04		
500000.	1	5.00E-10	1.80E-08	1.44E-09
500000.	2	0.0	5.00E-10	6.07E-08
500000.	3	0.0	5.00E-10	6.07E-08
500000.	4	6.48E-04		
600000.	1	5.00E-10	1.80E-08	1.44E-09
600000.	2	0.0	5.00E-10	6.07E-08
600000.	3	0.0	5.00E-10	6.07E-08
600000.	4	6.48E-04		
700000.	1	5.00E-10	1.80E-08	1.44E-09
700000.	2	0.0	5.00E-10	6.07E-08
700000.	3	0.0	5.00E-10	6.07E-08
700000.	4	6.48E-04		
800000.	1	5.00E-10	1.80E-08	1.44E-09
800000.	2	0.0	5.00E-10	6.07E-08
800000.	3	0.0	5.00E-10	6.07E-08
800000.	4	6.48E-04		
900000.	1	5.00E-10	1.80E-08	1.44E-09
900000.	2	0.0	5.00E-10	6.07E-08
900000.	3	0.0	5.00E-10	6.07E-08
900000.	4	6.48E-04		
1000000.	1	5.00E-10	1.80E-08	1.44E-09
1000000.	2	0.0	5.00E-10	6.07E-08
1000000.	3	0.0	5.00E-10	6.07E-08
1000000.	4	6.48E-04		

Table K-2-a. (Continued)

RADIONUCLIDE: PB-210 (K=10)

RELEASE INCREMENTS TO PRELIMINARY ENVIRONMENT INPUT RECEPTORS, RIJ, FROM ALL RELEASE EVENTS, IN CURIES

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER
0.	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0
40.	9.32E-14	2.08E-13	2.08E-13	3.76E-13
50.	1.35E-13	4.14E-13	4.14E-13	5.48E-13
60.	1.80E-13	5.54E-13	5.54E-13	7.32E-13
70.	2.30E-13	7.08E-13	7.08E-13	9.33E-13
80.	2.85E-13	8.75E-13	8.75E-13	1.16E-12
90.	3.47E-13	1.07E-12	1.07E-12	1.41E-12
100.	4.14E-13	1.29E-12	1.29E-12	1.70E-12
200.	1.26E-11	3.88E-11	3.88E-11	4.31E-10
300.	4.02E-11	1.23E-10	1.23E-10	1.37E-09
400.	9.33E-11	2.87E-10	2.87E-10	3.18E-09
500.	1.76E-10	5.41E-10	5.41E-10	6.01E-09
600.	2.91E-10	8.93E-10	8.93E-10	9.92E-09
700.	4.37E-10	1.34E-09	1.34E-09	1.49E-08
800.	6.14E-10	1.89E-09	1.89E-09	2.10E-08
900.	8.21E-10	2.52E-09	2.52E-09	2.80E-08
1000.	1.06E-09	3.24E-09	3.24E-09	3.60E-08
2000.	2.89E-08	9.17E-08	9.17E-08	9.75E-06
3000.	7.30E-08	2.24E-07	2.24E-07	2.39E-05
4000.	1.28E-07	3.92E-07	3.92E-07	4.16E-05
5000.	1.89E-07	5.82E-07	5.82E-07	6.18E-05
6000.	2.56E-07	7.86E-07	7.86E-07	8.36E-05
7000.	3.25E-07	1.00E-06	1.00E-06	1.06E-04
8000.	3.98E-07	1.22E-06	1.22E-06	1.30E-04
9000.	4.73E-07	1.45E-06	1.45E-06	1.54E-04
10000.	5.49E-07	1.69E-06	1.69E-06	1.79E-04
20000.	9.74E-06	2.99E-05	2.99E-05	3.17E-02
30000.	1.71E-05	5.25E-05	5.25E-05	5.55E-02
40000.	2.35E-05	7.21E-05	7.21E-05	7.63E-02
50000.	2.88E-05	8.85E-05	8.85E-05	9.37E-02
60000.	3.34E-05	1.02E-04	1.02E-04	1.08E-01
70000.	3.72E-05	1.14E-04	1.14E-04	1.21E-01
80000.	4.04E-05	1.24E-04	1.24E-04	1.31E-01
90000.	4.31E-05	1.33E-04	1.33E-04	1.40E-01
100000.	4.55E-05	1.40E-04	1.40E-04	1.48E-01
200000.	5.06E-04	1.56E-03	1.56E-03	1.65E 01
300000.	5.25E-04	1.61E-03	1.61E-03	1.70E 01
400000.	4.54E-04	1.40E-03	1.40E-03	1.48E 01
500000.	3.66E-04	1.12E-03	1.12E-03	1.19E 01
600000.	2.87E-04	8.80E-04	8.80E-04	9.31E 00
700000.	2.22E-04	6.81E-04	6.81E-04	7.21E 00
800000.	1.70E-04	5.24E-04	5.24E-04	5.54E 00
900000.	1.31E-04	4.04E-04	4.04E-04	4.27E 00
1000000.	1.02E-04	3.12E-04	3.12E-04	3.30E 00

RADIONUCLIDE: PB-210 (K=10)

CONCENTRATIONS AT ENVIRONMENT INPUT RECEPTOR, R2TOT UNITS: JF=1 MICROCURIE*YEARS/CUBIC CM
JF=2 MICROCURIES/SQUARE CM, JF=3 AND 4 MICROCURIES/CUBIC CM

ZONE= 1

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER
0.	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0
40.	2.02E-27	6.44E-20	0.0	0.0
50.	4.14E-27	2.44E-19	0.0	0.0
60.	7.17E-27	4.89E-19	0.0	0.0
70.	1.12E-26	8.33E-19	0.0	0.0
80.	1.65E-26	1.29E-18	0.0	0.0
90.	2.32E-26	1.89E-18	0.0	0.0
100.	3.18E-26	2.65E-18	0.0	0.0
200.	2.18E-24	1.95E-17	0.0	0.0
300.	1.03E-23	9.80E-17	0.0	0.0
400.	3.24E-23	3.12E-16	0.0	0.0
500.	7.08E-23	7.46E-16	0.0	0.0
600.	1.53E-22	1.48E-15	0.0	0.0
700.	2.69E-22	2.64E-15	0.0	0.0
800.	4.33E-22	4.23E-15	0.0	0.0
900.	6.51E-22	6.41E-15	0.0	0.0
1000.	9.31E-22	9.18E-15	0.0	0.0
2000.	5.31E-20	5.27E-14	0.0	0.0
3000.	1.93E-19	1.92E-13	0.0	0.0
4000.	4.45E-19	4.43E-13	0.0	0.0
5000.	8.17E-19	8.15E-13	0.0	0.0
6000.	1.31E-18	1.31E-12	0.0	0.0
7000.	1.92E-18	1.92E-12	0.0	0.0
8000.	2.66E-18	2.66E-12	0.0	0.0
9000.	3.52E-18	3.51E-12	0.0	0.0
10000.	4.49E-18	4.48E-12	0.0	0.0
20000.	1.58E-16	1.58E-11	0.0	0.0
30000.	3.75E-16	3.75E-11	0.0	0.0
40000.	6.23E-16	6.22E-11	0.0	0.0
50000.	8.68E-16	8.68E-11	0.0	0.0
60000.	1.10E-15	1.10E-10	0.0	0.0
70000.	1.31E-15	1.31E-10	0.0	0.0
80000.	1.50E-15	1.50E-10	0.0	0.0
90000.	1.66E-15	1.66E-10	0.0	0.0
100000.	1.80E-15	1.80E-10	0.0	0.0
200000.	5.17E-14	5.17E-10	0.0	0.0
300000.	5.29E-14	5.29E-10	0.0	0.0
400000.	4.57E-14	4.57E-10	0.0	0.0
500000.	3.68E-14	3.68E-10	0.0	0.0
600000.	2.88E-14	2.88E-10	0.0	0.0
700000.	2.23E-14	2.23E-10	0.0	0.0
800000.	1.72E-14	1.72E-10	0.0	0.0
900000.	1.32E-14	1.32E-10	0.0	0.0
1000000.	1.02E-14	1.02E-10	0.0	0.0

ZONE= 8

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER
0.	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0
40.	8.82E-30	9.25E-22	1.03E-24	0.0
50.	2.62E-29	2.71E-21	3.97E-24	0.0
60.	5.33E-29	5.47E-21	6.10E-24	0.0
70.	9.16E-29	9.36E-21	0.95E-24	0.0
80.	1.43E-28	1.46E-20	1.00E-23	0.0
90.	2.21E-28	2.13E-20	1.34E-23	0.0
100.	3.10E-28	3.01E-20	1.63E-23	0.0
200.	2.14E-26	2.17E-19	2.73E-22	0.0
300.	1.08E-25	1.10E-18	1.22E-21	0.0
400.	3.45E-25	3.50E-18	3.24E-21	0.0
500.	8.31E-25	8.41E-18	6.51E-21	0.0
600.	1.67E-24	1.69E-17	1.11E-20	0.0
700.	2.96E-24	2.99E-17	1.69E-20	0.0
800.	4.79E-24	4.82E-17	2.39E-20	0.0
900.	7.23E-24	7.28E-17	3.20E-20	0.0
1000.	1.04E-23	1.04E-16	4.12E-20	0.0
2000.	5.75E-22	5.95E-16	6.43E-19	0.0
3000.	2.19E-21	2.15E-15	2.20E-18	0.0
4000.	4.80E-21	4.96E-15	4.28E-18	0.0
5000.	8.03E-21	9.19E-15	6.89E-18	0.0
6000.	1.46E-20	1.48E-14	9.56E-18	0.0
7000.	2.15E-20	2.17E-14	1.22E-17	0.0
8000.	2.98E-20	3.01E-14	1.52E-17	0.0
9000.	3.95E-20	3.99E-14	1.81E-17	0.0
10000.	5.09E-20	5.09E-14	2.10E-17	0.0
20000.	1.72E-18	1.77E-13	2.07E-16	0.0
30000.	4.06E-18	4.19E-13	4.79E-16	0.0
40000.	6.80E-18	6.97E-13	7.22E-16	0.0
50000.	9.53E-18	9.75E-13	9.17E-16	0.0
60000.	1.21E-17	1.24E-12	1.08E-15	0.0
70000.	1.45E-17	1.49E-12	1.20E-15	0.0
80000.	1.66E-17	1.69E-12	1.31E-15	0.0
90000.	1.84E-17	1.87E-12	1.40E-15	0.0
100000.	2.00E-17	2.04E-12	1.48E-15	0.0
200000.	5.45E-16	5.70E-12	1.92E-14	0.0
300000.	5.55E-16	5.81E-12	1.88E-14	0.0
400000.	4.88E-16	5.03E-12	9.37E-15	0.0
500000.	3.87E-16	4.05E-12	7.55E-15	0.0
600000.	3.03E-16	3.17E-12	5.92E-15	0.0
700000.	2.35E-16	2.45E-12	4.50E-15	0.0
800000.	1.80E-16	1.89E-12	3.52E-15	0.0
900000.	1.39E-16	1.45E-12	2.71E-15	0.0
1000000.	1.07E-16	1.12E-12	2.10E-15	0.0

Table K-2-b. Average Annual Local Dose to Individual, MAN1L, In Millirems/Year

ZONE= 1... NUCLIDE= PB-210 K= 10

TIME	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
0.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40.	5.77E-15	3.19E-16	5.66E-15	4.61E-14	9.43E-13	4.88E-13	4.87E-13	6.45E-16
50.	1.25E-14	9.15E-16	1.22E-14	9.49E-14	1.94E-12	1.00E-12	1.00E-12	1.87E-15
60.	2.22E-14	1.83E-15	2.15E-14	1.64E-13	3.35E-12	1.73E-12	1.73E-12	3.74E-15
70.	3.54E-14	3.11E-15	3.42E-14	2.58E-13	5.25E-12	2.72E-12	2.72E-12	6.36E-15
80.	5.26E-14	4.81E-15	5.08E-14	3.79E-13	7.71E-12	3.99E-12	3.99E-12	9.85E-15
90.	7.48E-14	7.02E-15	7.22E-14	5.35E-13	1.09E-11	5.63E-12	5.63E-12	1.44E-14
100.	1.03E-13	9.87E-15	9.93E-14	7.32E-13	1.49E-11	7.70E-12	7.70E-12	2.03E-14
200.	6.99E-13	7.23E-14	6.72E-13	4.85E-12	9.84E-11	5.10E-11	5.10E-11	1.49E-13
300.	3.45E-12	3.64E-13	3.31E-12	2.38E-11	4.82E-10	2.50E-10	2.50E-10	7.49E-13
400.	1.09E-11	1.16E-12	1.04E-11	7.47E-11	1.51E-09	7.85E-10	7.84E-10	2.38E-12
500.	2.58E-11	2.77E-12	2.48E-11	1.77E-10	3.59E-09	1.86E-09	1.86E-09	5.70E-12
600.	5.15E-11	5.54E-12	4.94E-11	3.53E-10	7.15E-09	3.71E-09	3.71E-09	1.14E-11
700.	9.07E-11	9.78E-12	8.70E-11	6.21E-10	1.26E-08	6.53E-09	6.52E-09	2.01E-11
800.	1.46E-10	1.58E-11	1.40E-10	9.99E-10	2.03E-08	1.05E-08	1.05E-08	3.25E-11
900.	2.20E-10	2.38E-11	2.11E-10	1.50E-09	3.05E-08	1.58E-08	1.58E-08	4.95E-11
1000.	3.15E-10	3.41E-11	3.02E-10	2.15E-09	4.36E-08	2.26E-08	2.26E-08	7.01E-11
2000.	1.80E-09	1.96E-10	1.72E-09	1.23E-08	2.48E-07	1.29E-07	1.29E-07	4.03E-10
3000.	6.53E-09	7.13E-10	6.26E-09	4.46E-08	9.03E-07	4.68E-07	4.68E-07	1.47E-09
4000.	1.51E-08	1.65E-09	1.44E-08	1.03E-07	2.08E-06	1.08E-06	1.08E-06	3.39E-09
5000.	2.77E-08	3.02E-09	2.65E-08	1.89E-07	3.82E-06	1.98E-06	1.98E-06	6.22E-09
6000.	4.44E-08	4.85E-09	4.26E-08	3.03E-07	6.13E-06	3.18E-06	3.18E-06	9.99E-09
7000.	6.52E-08	7.13E-09	6.25E-08	4.44E-07	9.00E-06	4.67E-06	4.66E-06	1.47E-08
8000.	9.02E-08	9.86E-09	8.65E-08	6.15E-07	1.25E-05	6.46E-06	6.45E-06	2.03E-08
9000.	1.19E-07	1.30E-08	1.14E-07	8.12E-07	1.64E-05	8.53E-06	8.53E-06	2.68E-08
10000.	1.52E-07	1.66E-08	1.46E-07	1.04E-06	2.10E-05	1.09E-05	1.09E-05	3.42E-08
20000.	5.37E-07	5.87E-08	5.15E-07	3.66E-06	7.41E-05	3.84E-05	3.84E-05	1.21E-07
30000.	1.27E-06	1.39E-07	1.22E-06	8.67E-06	1.76E-04	9.11E-05	9.10E-05	2.87E-07
40000.	2.11E-06	2.31E-07	2.02E-06	1.44E-05	2.91E-04	1.51E-04	1.51E-04	4.75E-07
50000.	2.94E-06	3.22E-07	2.82E-06	2.01E-05	4.06E-04	2.11E-04	2.11E-04	6.63E-07
60000.	3.73E-06	4.08E-07	3.58E-06	2.54E-05	5.15E-04	2.67E-04	2.67E-04	8.41E-07
70000.	4.44E-06	4.86E-07	4.26E-06	3.03E-05	6.13E-04	3.18E-04	3.18E-04	1.00E-06
80000.	5.08E-06	5.56E-07	4.87E-06	3.46E-05	7.01E-04	3.63E-04	3.63E-04	1.14E-06
90000.	5.63E-06	6.17E-07	5.40E-06	3.84E-05	7.78E-04	4.03E-04	4.03E-04	1.27E-06
100000.	6.12E-06	6.70E-07	5.87E-06	4.17E-05	8.44E-04	4.38E-04	4.38E-04	1.38E-06
200000.	1.75E-05	1.92E-06	1.68E-05	1.19E-04	2.42E-03	1.26E-03	1.25E-03	3.95E-06
300000.	1.79E-05	1.96E-06	1.72E-05	1.22E-04	2.47E-03	1.28E-03	1.28E-03	4.04E-06
400000.	1.55E-05	1.70E-06	1.49E-05	1.06E-04	2.14E-03	1.11E-03	1.11E-03	3.49E-06
500000.	1.25E-05	1.37E-06	1.20E-05	8.51E-05	1.72E-03	8.94E-04	8.93E-04	2.81E-06
600000.	9.78E-06	1.07E-06	9.38E-06	6.66E-05	1.35E-03	7.00E-04	6.99E-04	2.20E-06
700000.	7.57E-06	8.29E-07	7.26E-06	5.16E-05	1.04E-03	5.42E-04	5.41E-04	1.71E-06
800000.	5.82E-06	6.37E-07	5.58E-06	3.96E-05	8.03E-04	4.16E-04	4.16E-04	1.31E-06
900000.	4.48E-06	4.91E-07	4.30E-06	3.05E-05	6.19E-04	3.21E-04	3.21E-04	1.01E-06
1000000.	3.46E-06	3.79E-07	3.32E-06	2.36E-05	4.78E-04	2.48E-04	2.48E-04	7.81E-07

Table K-2-b. (Continued)

ZONE= 8... NUCLIDE= PB-210 K= 10

TIME	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
0.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40.	4.03E-16	1.05E-17	4.02E-16	3.64E-15	4.13E-15	3.87E-14	3.87E-14	7.07E-18
50.	8.99E-16	2.54E-17	8.95E-16	8.06E-15	1.22E-14	8.57E-14	8.57E-14	2.07E-17
60.	1.44E-15	4.43E-17	1.44E-15	1.29E-14	2.49E-14	1.37E-13	1.37E-13	4.18E-17
70.	2.04E-15	6.75E-17	2.02E-15	1.80E-14	4.28E-14	1.91E-13	1.91E-13	7.15E-17
80.	2.70E-15	9.60E-17	2.67E-15	2.37E-14	6.69E-14	2.51E-13	2.51E-13	1.11E-16
90.	3.48E-15	1.31E-16	3.45E-15	3.03E-14	1.03E-13	3.22E-13	3.22E-13	1.63E-16
100.	4.36E-15	1.75E-16	4.32E-15	3.78E-14	1.45E-13	4.01E-13	4.01E-13	2.30E-16
200.	6.29E-14	1.86E-15	6.26E-14	5.62E-13	1.00E-12	5.97E-12	5.97E-12	1.66E-15
300.	2.85E-13	8.80E-15	2.84E-13	2.54E-12	5.05E-12	2.70E-11	2.70E-11	8.37E-15
400.	7.79E-13	2.56E-14	7.74E-13	6.90E-12	1.62E-11	7.33E-11	7.33E-11	2.68E-14
500.	1.61E-12	5.65E-14	1.60E-12	1.42E-11	3.89E-11	1.50E-10	1.50E-10	6.43E-14
600.	2.82E-12	1.06E-13	2.80E-12	2.46E-11	7.81E-11	2.62E-10	2.62E-10	1.29E-13
700.	4.45E-12	1.76E-13	4.40E-12	3.85E-11	1.38E-10	4.09E-10	4.09E-10	2.28E-13
800.	6.50E-12	2.72E-13	6.43E-12	5.59E-11	2.24E-10	5.94E-10	5.94E-10	3.69E-13
900.	8.99E-12	3.95E-13	8.88E-12	7.69E-11	3.38E-10	8.16E-10	8.16E-10	5.57E-13
1000.	1.19E-11	5.48E-13	1.18E-11	1.01E-10	4.85E-10	1.08E-09	1.08E-09	7.98E-13
2000.	1.51E-10	4.68E-12	1.50E-10	1.34E-09	2.69E-09	1.43E-08	1.43E-08	4.51E-12
3000.	5.21E-10	1.65E-11	5.18E-10	4.62E-09	9.83E-09	4.91E-08	4.91E-08	1.64E-11
4000.	1.06E-09	3.55E-11	1.05E-09	9.36E-09	2.28E-08	9.94E-08	9.94E-08	3.81E-11
5000.	1.71E-09	6.08E-11	1.70E-09	1.50E-08	4.22E-08	1.60E-07	1.60E-07	7.02E-11
6000.	2.45E-09	9.20E-11	2.43E-09	2.13E-08	6.81E-08	2.27E-07	2.27E-07	1.13E-10
7000.	3.24E-09	1.29E-10	3.21E-09	2.81E-08	1.00E-07	2.99E-07	2.99E-07	1.66E-10
8000.	4.11E-09	1.71E-10	4.07E-09	3.54E-08	1.39E-07	3.76E-07	3.76E-07	2.30E-10
9000.	5.03E-09	2.18E-10	4.97E-09	4.31E-08	1.85E-07	4.57E-07	4.57E-07	3.05E-10
10000.	6.00E-09	2.71E-10	5.93E-09	5.12E-08	2.36E-07	5.43E-07	5.43E-07	3.89E-10
20000.	4.82E-08	1.46E-09	4.79E-08	4.30E-07	8.04E-07	4.56E-06	4.56E-06	1.35E-09
30000.	1.12E-07	3.42E-09	1.11E-07	9.96E-07	1.91E-06	1.06E-05	1.06E-05	3.20E-09
40000.	1.71E-07	5.39E-09	1.70E-07	1.51E-06	3.18E-06	1.61E-05	1.61E-05	5.33E-09
50000.	2.20E-07	7.18E-09	2.18E-07	1.94E-06	4.46E-06	2.07E-05	2.07E-05	7.45E-09
60000.	2.61E-07	8.77E-09	2.59E-07	2.30E-06	5.67E-06	2.45E-05	2.45E-05	9.45E-09
70000.	2.95E-07	1.02E-08	2.93E-07	2.60E-06	6.77E-06	2.76E-05	2.76E-05	1.13E-08
80000.	3.24E-07	1.14E-08	3.22E-07	2.85E-06	7.75E-06	3.03E-05	3.03E-05	1.29E-08
90000.	3.49E-07	1.24E-08	3.46E-07	3.06E-06	8.61E-06	3.25E-05	3.25E-05	1.43E-08
100000.	3.70E-07	1.33E-08	3.67E-07	3.24E-06	9.36E-06	3.45E-05	3.44E-05	1.56E-08
200000.	2.27E-06	6.07E-08	2.26E-06	2.04E-05	2.55E-05	2.17E-04	2.17E-04	4.35E-08
300000.	2.40E-06	6.35E-08	2.39E-06	2.16E-05	2.60E-05	2.30E-04	2.30E-04	4.44E-08
400000.	2.08E-06	5.50E-08	2.07E-06	1.87E-05	2.25E-05	1.99E-04	1.99E-04	3.84E-08
500000.	1.67E-06	4.43E-08	1.67E-06	1.51E-05	1.81E-05	1.60E-04	1.60E-04	3.09E-08
600000.	1.31E-06	3.47E-08	1.31E-06	1.18E-05	1.42E-05	1.26E-04	1.26E-04	2.42E-08
700000.	1.01E-06	2.69E-08	1.01E-06	9.15E-06	1.10E-05	9.73E-05	9.73E-05	1.88E-08
800000.	7.80E-07	2.07E-08	7.77E-07	7.03E-06	8.43E-06	7.48E-05	7.48E-05	1.44E-08
900000.	6.01E-07	1.59E-08	5.99E-07	5.42E-06	6.50E-06	5.76E-05	5.76E-05	1.11E-08
1000000.	4.64E-07	1.23E-08	4.63E-07	4.19E-06	5.02E-06	4.45E-05	4.45E-05	8.58E-09

Table K-2-c. Average Annual Nonspecific Dose to Population, MANIN, In Man-rems/Year

** AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MANIN, IN MANREMS/YEAR

NONSPECIFIC *** NUCLIDE= PB-210 K= 10

TIME	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
0.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40.	1.27E-12	2.41E-14	1.27E-12	1.17E-11	0.0	1.24E-10	1.24E-10	0.0
50.	1.91E-12	3.63E-14	1.91E-12	1.76E-11	0.0	1.87E-10	1.87E-10	0.0
60.	2.64E-12	5.03E-14	2.64E-12	2.44E-11	0.0	2.59E-10	2.59E-10	0.0
70.	3.49E-12	6.63E-14	3.49E-12	3.21E-11	0.0	3.42E-10	3.42E-10	0.0
80.	4.46E-12	8.48E-14	4.46E-12	4.11E-11	0.0	4.37E-10	4.37E-10	0.0
90.	5.60E-12	1.07E-13	5.60E-12	5.16E-11	0.0	5.49E-10	5.49E-10	0.0
100.	6.95E-12	1.32E-13	6.95E-12	6.40E-11	0.0	6.81E-10	6.81E-10	0.0
200.	2.86E-11	5.44E-13	2.86E-11	2.63E-10	0.0	2.80E-09	2.80E-09	0.0
300.	1.12E-10	2.14E-12	1.12E-10	1.03E-09	0.0	1.10E-08	1.10E-08	0.0
400.	3.08E-10	5.86E-12	3.08E-10	2.84E-09	0.0	3.02E-08	3.02E-08	0.0
500.	6.67E-10	1.27E-11	6.67E-10	6.14E-09	0.0	6.54E-08	6.54E-08	0.0
600.	1.24E-09	2.36E-11	1.24E-09	1.14E-08	0.0	1.22E-07	1.22E-07	0.0
700.	2.07E-09	3.94E-11	2.07E-09	1.91E-08	0.0	2.03E-07	2.03E-07	0.0
800.	3.20E-09	6.09E-11	3.20E-09	2.95E-08	0.0	3.14E-07	3.14E-07	0.0
900.	4.66E-09	8.86E-11	4.66E-09	4.29E-08	0.0	4.57E-07	4.57E-07	0.0
1000.	6.48E-09	1.23E-10	6.48E-09	5.98E-08	0.0	6.36E-07	6.36E-07	0.0
2000.	3.61E-08	6.86E-10	3.61E-08	3.33E-07	0.0	3.54E-06	3.54E-06	0.0
3000.	1.26E-07	2.39E-09	1.26E-07	1.16E-06	0.0	1.23E-05	1.23E-05	0.0
4000.	2.80E-07	5.33E-09	2.80E-07	2.58E-06	0.0	2.75E-05	2.75E-05	0.0
5000.	5.01E-07	9.53E-09	5.01E-07	4.62E-06	0.0	4.91E-05	4.91E-05	0.0
6000.	7.87E-07	1.50E-08	7.87E-07	7.25E-06	0.0	7.72E-05	7.72E-05	0.0
7000.	1.14E-06	2.16E-08	1.14E-06	1.05E-05	0.0	1.12E-04	1.12E-04	0.0
8000.	1.55E-06	2.96E-08	1.55E-06	1.43E-05	0.0	1.52E-04	1.52E-04	0.0
9000.	2.03E-06	3.86E-08	2.03E-06	1.87E-05	0.0	1.99E-04	1.99E-04	0.0
10000.	2.57E-06	4.89E-08	2.57E-06	2.37E-05	0.0	2.52E-04	2.52E-04	0.0
20000.	9.90E-06	1.88E-07	9.90E-06	9.12E-05	0.0	9.70E-04	9.70E-04	0.0
30000.	2.33E-05	4.43E-07	2.33E-05	2.15E-04	0.0	2.28E-03	2.28E-03	0.0
40000.	3.81E-05	7.24E-07	3.81E-05	3.51E-04	0.0	3.73E-03	3.73E-03	0.0
50000.	5.24E-05	9.97E-07	5.24E-05	4.83E-04	0.0	5.14E-03	5.14E-03	0.0
60000.	6.58E-05	1.25E-06	6.58E-05	6.06E-04	0.0	6.45E-03	6.45E-03	0.0
70000.	7.78E-05	1.48E-06	7.78E-05	7.17E-04	0.0	7.63E-03	7.63E-03	0.0
80000.	8.84E-05	1.68E-06	8.84E-05	8.15E-04	0.0	8.67E-03	8.67E-03	0.0
90000.	9.77E-05	1.86E-06	9.77E-05	9.01E-04	0.0	9.58E-03	9.58E-03	0.0
100000.	1.06E-04	2.01E-06	1.06E-04	9.75E-04	0.0	1.04E-02	1.04E-02	0.0
200000.	3.44E-04	6.55E-06	3.44E-04	3.17E-03	0.0	3.38E-02	3.38E-02	0.0
300000.	3.55E-04	6.74E-06	3.55E-04	3.27E-03	0.0	3.48E-02	3.48E-02	0.0
400000.	3.07E-04	5.84E-06	3.07E-04	2.83E-03	0.0	3.01E-02	3.01E-02	0.0
500000.	2.47E-04	4.70E-06	2.47E-04	2.28E-03	0.0	2.42E-02	2.42E-02	0.0
600000.	1.94E-04	3.68E-06	1.94E-04	1.78E-03	0.0	1.90E-02	1.90E-02	0.0
700000.	1.50E-04	2.85E-06	1.50E-04	1.38E-03	0.0	1.47E-02	1.47E-02	0.0
800000.	1.15E-04	2.19E-06	1.15E-04	1.06E-03	0.0	1.13E-02	1.13E-02	0.0
900000.	8.88E-05	1.69E-06	8.88E-05	8.18E-04	0.0	8.70E-03	8.70E-03	0.0
1000000.	6.86E-05	1.30E-06	6.86E-05	6.32E-04	0.0	6.72E-03	6.72E-03	0.0

Table K-3. Average Annual Local Dose to Individual, Total for All Nuclides, MAN2LF for JF-1 to 4, MAN2L In Millirems/Year.

** AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MAN2LF FOR JF=1 TO 4, MAN2L FOR TOTAL, IN MILLIREMS/YEAR

TOTAL FOR ALL NUCLIDES — TOT BODY

ZONE= 1

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER	TOTAL
0.	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0
40.	2.70E-03	2.83E-05	0.0	0.0	2.70E-03
50.	2.94E-03	4.40E-05	0.0	0.0	2.98E-03
60.	2.96E-03	5.31E-05	0.0	0.0	3.02E-03
70.	2.88E-03	5.63E-05	0.0	0.0	2.94E-03
80.	2.75E-03	6.15E-05	0.0	0.0	2.81E-03
90.	2.61E-03	6.36E-05	0.0	0.0	2.67E-03
100.	2.49E-03	6.61E-05	0.0	0.0	2.55E-03
200.	3.70E-03	1.28E-04	0.0	0.0	3.83E-03
300.	3.23E-03	1.58E-04	0.0	0.0	3.41E-03
400.	3.53E-03	1.59E-04	0.0	0.0	3.73E-03
500.	3.62E-03	2.37E-04	0.0	0.0	4.06E-03
600.	4.09E-03	2.71E-04	0.0	0.0	4.36E-03
700.	4.21E-03	2.61E-04	0.0	0.0	4.61E-03
800.	4.47E-03	3.27E-04	0.0	0.0	4.80E-03
900.	4.59E-03	3.45E-04	0.0	0.0	4.94E-03
1000.	4.67E-03	3.70E-04	0.0	0.0	5.04E-03
2000.	7.34E-03	6.44E-04	0.0	0.0	7.98E-03
3000.	7.81E-03	7.80E-04	0.0	0.0	8.59E-03
4000.	9.07E-03	9.14E-04	0.0	0.0	9.98E-03
5000.	1.03E-02	1.02E-03	0.0	0.0	1.13E-02
6000.	1.12E-02	1.10E-03	0.0	0.0	1.23E-02
7000.	1.20E-02	1.15E-03	0.0	0.0	1.32E-02
8000.	1.27E-02	1.19E-03	0.0	0.0	1.38E-02
9000.	1.32E-02	1.22E-03	0.0	0.0	1.44E-02
10000.	1.36E-02	1.24E-03	0.0	0.0	1.48E-02
20000.	2.04E-02	1.71E-03	0.0	0.0	2.21E-02
30000.	1.58E-02	9.66E-04	0.0	0.0	1.68E-02
40000.	1.21E-02	4.57E-04	0.0	0.0	1.25E-02
50000.	9.80E-03	2.60E-04	0.0	0.0	1.00E-02
60000.	8.18E-03	1.11E-04	0.0	0.0	8.29E-03
70000.	6.62E-03	7.46E-05	0.0	0.0	6.69E-03
80000.	5.63E-03	6.18E-05	0.0	0.0	5.69E-03
90000.	4.63E-03	5.77E-05	0.0	0.0	4.69E-03
100000.	3.65E-03	5.71E-05	0.0	0.0	3.91E-03
200000.	6.59E-03	1.57E-04	0.0	0.0	7.14E-03
300000.	5.22E-03	1.75E-04	0.0	0.0	5.39E-03
400000.	5.52E-03	1.86E-04	0.0	0.0	5.70E-03
500000.	5.63E-03	1.91E-04	0.0	0.0	5.82E-03
600000.	5.65E-03	1.91E-04	0.0	0.0	5.79E-03
700000.	5.49E-03	1.89E-04	0.0	0.0	5.63E-03
800000.	5.33E-03	1.84E-04	0.0	0.0	5.52E-03
900000.	5.15E-03	1.79E-04	0.0	0.0	5.33E-03
1000000.	4.95E-03	1.74E-04	0.0	0.0	5.12E-03

ZONE= 2

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER	TOTAL
0.	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0
40.	2.61E-05	4.79E-07	2.83E-04	0.0	3.09E-04
50.	3.44E-05	7.45E-07	4.39E-04	0.0	4.75E-04
60.	3.92E-05	9.00E-07	5.19E-04	0.0	5.58E-04
70.	3.93E-05	9.89E-07	5.45E-04	0.0	5.85E-04
80.	3.89E-05	1.04E-06	5.36E-04	0.0	5.76E-04
90.	3.79E-05	1.08E-06	5.06E-04	0.0	5.45E-04
100.	3.69E-05	1.12E-06	4.65E-04	0.0	5.03E-04
200.	5.91E-05	2.17E-06	5.82E-04	0.0	6.43E-04
300.	5.31E-05	2.67E-06	2.06E-04	0.0	2.62E-04
400.	5.91E-05	3.37E-06	1.86E-04	0.0	2.48E-04
500.	6.33E-05	4.32E-06	2.05E-04	0.0	2.72E-04
600.	6.80E-05	4.50E-06	2.22E-04	0.0	2.95E-04
700.	7.18E-05	5.10E-06	2.35E-04	0.0	3.12E-04
800.	7.47E-05	5.54E-06	2.42E-04	0.0	3.22E-04
900.	7.68E-05	5.92E-06	2.44E-04	0.0	3.27E-04
1000.	7.83E-05	6.26E-06	2.45E-04	0.0	3.29E-04
2000.	1.24E-04	1.09E-05	3.60E-04	0.0	4.95E-04
3000.	1.32E-04	1.32E-05	3.37E-04	1.32E-27	4.82E-04
4000.	1.53E-04	1.55E-05	3.74E-04	2.40E-17	5.43E-04
5000.	1.73E-04	1.73E-05	4.12E-04	2.94E-12	6.02E-04
6000.	1.90E-04	1.86E-05	4.45E-04	7.95E-10	6.51E-04
7000.	2.03E-04	1.95E-05	4.67E-04	8.29E-09	6.89E-04
8000.	2.14E-04	2.02E-05	4.84E-04	5.49E-08	7.19E-04
9000.	2.23E-04	2.07E-05	4.99E-04	1.86E-07	7.43E-04
10000.	2.30E-04	2.10E-05	5.12E-04	3.05E-07	7.63E-04
20000.	3.46E-04	2.90E-05	7.31E-04	2.41E-08	1.11E-03
30000.	2.67E-04	1.67E-05	5.22E-04	2.93E-07	8.06E-04
40000.	2.04E-04	7.74E-06	3.91E-04	2.83E-07	6.03E-04
50000.	1.66E-04	3.52E-06	3.61E-04	2.74E-07	5.30E-04
60000.	1.39E-04	1.88E-06	3.01E-04	2.65E-07	5.21E-04
70000.	1.15E-04	1.26E-06	4.18E-04	2.57E-07	5.35E-04
80000.	9.53E-05	1.05E-06	4.56E-04	2.49E-07	5.53E-04
90000.	7.84E-05	9.77E-07	4.92E-04	2.41E-07	5.72E-04
100000.	6.53E-05	9.08E-07	5.24E-04	2.34E-07	5.90E-04
200000.	1.19E-04	2.66E-06	1.26E-03	2.47E-09	1.38E-03
300000.	8.83E-05	3.96E-06	1.48E-03	2.11E-07	1.57E-03
400000.	9.34E-05	3.16E-06	1.39E-03	1.52E-07	1.40E-03
500000.	9.34E-05	3.23E-06	1.04E-03	1.08E-07	1.18E-03
600000.	9.48E-05	3.23E-06	3.78E-04	7.50E-08	9.76E-04
700000.	9.33E-05	3.19E-06	7.18E-04	5.51E-08	8.14E-04
800000.	9.03E-05	3.13E-06	1.39E-03	8.94E-07	1.48E-03
900000.	8.73E-05	3.04E-06	3.41E-02	5.76E-05	5.43E-02
1000000.	8.39E-05	2.94E-06	8.18E-01	9.73E-04	8.19E-01

Table K-3. (Continued)

** AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MAN2LF FOR JF=1 TO 4, MAN2L FOR TOTAL, IN MILLIREMS/YEAR

TOTAL FOR ALL NUCLIDES

ZONE= 3

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER	TOTAL
0.	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0
40.	2.45E-06	4.47E-08	1.34E-05	0.0	1.59E-05
50.	3.21E-06	6.95E-08	2.05E-05	0.0	2.38E-05
60.	3.55E-06	8.40E-08	2.38E-05	0.0	2.74E-05
70.	3.63E-06	9.23E-08	2.45E-05	0.0	2.83E-05
80.	3.57E-06	9.73E-08	2.37E-05	0.0	2.74E-05
90.	3.47E-06	1.01E-07	2.20E-05	0.0	2.55E-05
100.	3.36E-06	1.05E-07	1.98E-05	0.0	2.33E-05
200.	5.29E-06	2.02E-07	2.17E-05	0.0	2.72E-05
300.	4.91E-06	2.49E-07	8.67E-06	0.0	1.38E-05
400.	5.42E-06	3.15E-07	8.69E-06	0.0	1.44E-05
500.	5.91E-06	3.75E-07	9.70E-06	0.0	1.60E-05
600.	6.35E-06	4.29E-07	1.06E-05	0.0	1.73E-05
700.	6.71E-06	4.76E-07	1.11E-05	0.0	1.83E-05
800.	6.97E-06	5.17E-07	1.15E-05	0.0	1.90E-05
900.	7.17E-06	5.52E-07	1.16E-05	0.0	1.93E-05
1000.	7.31E-06	5.85E-07	1.16E-05	0.0	1.95E-05
2000.	1.15E-05	1.02E-06	1.71E-05	0.0	2.96E-05
3000.	1.23E-05	1.23E-06	1.60E-05	0.0	2.95E-05
4000.	1.43E-05	1.43E-06	1.78E-05	0.0	3.35E-05
5000.	1.62E-05	1.59E-06	1.95E-05	0.0	3.73E-05
6000.	1.77E-05	1.70E-06	2.10E-05	0.0	4.04E-05
7000.	1.90E-05	1.79E-06	2.21E-05	0.0	4.29E-05
8000.	2.00E-05	1.84E-06	2.30E-05	0.0	4.48E-05
9000.	2.08E-05	1.88E-06	2.36E-05	0.0	4.63E-05
10000.	2.15E-05	1.91E-06	2.40E-05	0.0	4.74E-05
20000.	3.23E-05	2.22E-06	3.44E-05	0.0	6.89E-05
30000.	2.50E-05	9.39E-07	2.32E-05	0.0	4.91E-05
40000.	1.91E-05	3.89E-07	1.61E-05	0.0	3.56E-05
50000.	1.55E-05	1.90E-07	1.40E-05	0.0	2.97E-05
60000.	1.29E-05	1.19E-07	1.45E-05	0.0	2.76E-05
70000.	1.08E-05	9.48E-08	1.60E-05	0.0	2.68E-05
80000.	8.89E-06	8.77E-08	1.76E-05	0.0	2.66E-05
90000.	7.32E-06	8.67E-08	1.92E-05	0.0	2.66E-05
100000.	6.09E-06	8.83E-08	2.06E-05	0.0	2.68E-05
200000.	1.10E-05	2.48E-07	5.88E-05	0.0	7.01E-05
300000.	8.25E-06	2.76E-07	6.09E-05	0.0	6.94E-05
400000.	8.72E-06	2.95E-07	5.44E-05	0.0	6.34E-05
500000.	8.90E-06	3.02E-07	4.59E-05	0.0	5.51E-05
600000.	8.85E-06	3.02E-07	3.79E-05	0.0	4.71E-05
700000.	8.68E-06	2.98E-07	3.14E-05	0.0	4.03E-05
800000.	8.43E-06	2.92E-07	2.61E-05	0.0	3.49E-05
900000.	8.14E-06	2.84E-07	2.20E-05	0.0	3.04E-05
1000000.	7.83E-06	2.75E-07	1.87E-05	0.0	2.68E-05

TOT BODY

ZONE= 4

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER	TOTAL
0.	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0
40.	1.11E-06	2.07E-08	2.65E-14	0.0	1.13E-06
50.	1.47E-06	3.22E-08	4.16E-14	0.0	1.50E-06
60.	1.63E-06	3.89E-08	5.09E-14	0.0	1.67E-06
70.	1.67E-06	4.28E-08	5.69E-14	0.0	1.71E-06
80.	1.64E-06	4.51E-08	6.12E-14	0.0	1.69E-06
90.	1.60E-06	4.68E-08	6.51E-14	0.0	1.64E-06
100.	1.55E-06	4.85E-08	6.92E-14	0.0	1.60E-06
200.	2.45E-06	9.39E-08	1.44E-13	0.0	2.54E-06
300.	2.28E-06	1.16E-07	1.96E-13	0.0	2.39E-06
400.	2.51E-06	1.46E-07	2.55E-13	0.0	2.66E-06
500.	2.74E-06	1.74E-07	3.11E-13	0.0	2.91E-06
600.	2.94E-06	1.99E-07	3.63E-13	0.0	3.14E-06
700.	3.11E-06	2.21E-07	4.11E-13	0.0	3.33E-06
800.	3.23E-06	2.40E-07	4.55E-13	0.0	3.47E-06
900.	3.32E-06	2.56E-07	4.96E-13	0.0	3.58E-06
1000.	3.39E-06	2.71E-07	5.35E-13	0.0	3.66E-06
2000.	5.35E-06	4.72E-07	9.80E-13	0.0	5.82E-06
3000.	5.70E-06	5.68E-07	1.25E-12	0.0	6.27E-06
4000.	6.63E-06	6.64E-07	1.48E-12	0.0	7.29E-06
5000.	7.49E-06	7.37E-07	1.65E-12	0.0	8.23E-06
6000.	8.21E-06	7.90E-07	1.77E-12	0.0	9.00E-06
7000.	8.79E-06	8.28E-07	1.85E-12	0.0	9.62E-06
8000.	9.27E-06	8.54E-07	1.91E-12	0.0	1.01E-05
9000.	9.65E-06	8.73E-07	1.95E-12	0.0	1.05E-05
10000.	9.96E-06	8.85E-07	1.98E-12	0.0	1.08E-05
20000.	1.50E-05	1.03E-06	2.31E-12	0.0	1.60E-05
30000.	1.16E-05	4.36E-07	9.87E-13	0.0	1.20E-05
40000.	8.83E-06	1.80E-07	4.01E-13	0.0	9.02E-06
50000.	7.18E-06	8.79E-08	1.83E-13	0.0	7.27E-06
60000.	6.00E-06	5.51E-08	1.05E-13	0.0	6.05E-06
70000.	5.00E-06	4.39E-08	7.67E-14	0.0	5.04E-06
80000.	4.12E-06	4.07E-08	6.69E-14	0.0	4.16E-06
90000.	3.39E-06	4.02E-08	6.35E-14	0.0	3.43E-06
100000.	2.83E-06	4.09E-08	6.26E-14	0.0	2.87E-06
200000.	5.12E-06	1.15E-07	1.56E-13	0.0	5.24E-06
300000.	3.92E-06	1.28E-07	1.47E-13	0.0	3.95E-06
400000.	4.04E-06	1.37E-07	1.41E-13	0.0	4.18E-06
500000.	4.13E-06	1.40E-07	1.35E-13	0.0	4.27E-06
600000.	4.10E-06	1.40E-07	1.30E-13	0.0	4.24E-06
700000.	4.02E-06	1.38E-07	1.25E-13	0.0	4.16E-06
800000.	3.91E-06	1.35E-07	1.21E-13	0.0	4.05E-06
900000.	3.77E-06	1.31E-07	1.17E-13	0.0	3.91E-06
1000000.	3.63E-06	1.27E-07	1.13E-13	0.0	3.76E-06

Table K-3. (Continued)

** AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MAN2LF FOR JF=1 TO 4, MAN2L FOR TOTAL, IN MILLIREMS/YEAR

TOTAL FOR ALL NUCLIDES — TOT BODY

ZONE= 5

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER	TOTAL
0.	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0
40.	1.85E-06	3.38E-08	4.09E-14	0.0	1.89E-06
50.	2.43E-06	5.26E-08	6.40E-14	0.0	2.48E-06
60.	2.68E-06	6.35E-08	7.83E-14	0.0	2.74E-06
70.	2.74E-06	6.98E-08	8.76E-14	0.0	2.81E-06
80.	2.70E-06	7.35E-08	9.43E-14	0.0	2.77E-06
90.	2.62E-06	7.64E-08	1.00E-13	0.0	2.70E-06
100.	2.54E-06	7.91E-08	1.06E-13	0.0	2.62E-06
200.	4.00E-06	1.53E-07	2.21E-13	0.0	4.15E-06
300.	3.72E-06	1.89E-07	3.01E-13	0.0	3.90E-06
400.	4.10E-06	2.38E-07	3.93E-13	0.0	4.34E-06
500.	4.47E-06	2.84E-07	4.79E-13	0.0	4.75E-06
600.	4.80E-06	3.25E-07	5.59E-13	0.0	5.13E-06
700.	5.07E-06	3.60E-07	6.32E-13	0.0	5.43E-06
800.	5.27E-06	3.91E-07	7.00E-13	0.0	5.66E-06
900.	5.42E-06	4.18E-07	7.64E-13	0.0	5.84E-06
1000.	5.53E-06	4.42E-07	8.24E-13	0.0	5.97E-06
2000.	8.73E-06	7.69E-07	1.51E-12	0.0	9.50E-06
3000.	9.31E-06	9.27E-07	1.93E-12	0.0	1.02E-05
4000.	1.08E-05	1.08E-06	2.28E-12	0.0	1.19E-05
5000.	1.22E-05	1.20E-06	2.54E-12	0.0	1.34E-05
6000.	1.34E-05	1.29E-06	2.72E-12	0.0	1.47E-05
7000.	1.43E-05	1.35E-06	2.86E-12	0.0	1.57E-05
8000.	1.51E-05	1.39E-06	2.95E-12	0.0	1.65E-05
9000.	1.57E-05	1.42E-06	3.01E-12	0.0	1.72E-05
10000.	1.62E-05	1.44E-06	3.05E-12	0.0	1.77E-05
20000.	2.44E-05	1.68E-06	3.56E-12	0.0	2.61E-05
30000.	1.89E-05	7.10E-07	1.52E-12	0.0	1.96E-05
40000.	1.44E-05	2.94E-07	6.17E-13	0.0	1.47E-05
50000.	1.17E-05	1.43E-07	2.82E-13	0.0	1.19E-05
60000.	9.78E-06	8.99E-08	1.61E-13	0.0	9.87E-06
70000.	8.15E-06	7.17E-08	1.18E-13	0.0	8.22E-06
80000.	6.73E-06	6.63E-08	1.03E-13	0.0	6.79E-06
90000.	5.54E-06	6.56E-08	9.79E-14	0.0	5.60E-06
100000.	4.61E-06	6.67E-08	9.64E-14	0.0	4.67E-06
200000.	8.35E-06	1.88E-07	2.41E-13	0.0	8.54E-06
300000.	6.24E-06	2.09E-07	2.26E-13	0.0	6.44E-06
400000.	6.60E-06	2.23E-07	2.17E-13	0.0	6.82E-06
500000.	6.73E-06	2.28E-07	2.09E-13	0.0	6.96E-06
600000.	6.69E-06	2.28E-07	2.01E-13	0.0	6.92E-06
700000.	6.56E-06	2.25E-07	1.93E-13	0.0	6.79E-06
800000.	6.38E-06	2.21E-07	1.86E-13	0.0	6.60E-06
900000.	6.16E-06	2.14E-07	1.80E-13	0.0	6.37E-06
1000000.	5.92E-06	2.08E-07	1.74E-13	0.0	6.13E-06

ZONE= 6

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER	TOTAL
0.	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0
40.	1.35E-05	2.40E-07	2.92E-13	0.0	1.38E-05
50.	1.75E-05	3.73E-07	4.57E-13	0.0	1.79E-05
60.	1.93E-05	4.51E-07	5.59E-13	0.0	1.97E-05
70.	1.97E-05	4.96E-07	6.25E-13	0.0	2.01E-05
80.	1.93E-05	5.22E-07	6.73E-13	0.0	1.98E-05
90.	1.87E-05	5.42E-07	7.16E-13	0.0	1.93E-05
100.	1.81E-05	5.61E-07	7.60E-13	0.0	1.87E-05
200.	2.85E-05	1.09E-06	1.58E-12	0.0	2.96E-05
300.	2.64E-05	1.34E-06	2.15E-12	0.0	2.78E-05
400.	2.91E-05	1.69E-06	2.80E-12	0.0	3.08E-05
500.	3.18E-05	2.02E-06	3.42E-12	0.0	3.38E-05
600.	3.41E-05	2.31E-06	3.99E-12	0.0	3.64E-05
700.	3.60E-05	2.56E-06	4.51E-12	0.0	3.86E-05
800.	3.75E-05	2.77E-06	5.00E-12	0.0	4.02E-05
900.	3.85E-05	2.97E-06	5.45E-12	0.0	4.15E-05
1000.	3.93E-05	3.14E-06	5.88E-12	0.0	4.24E-05
2000.	6.20E-05	5.46E-06	1.08E-11	0.0	6.75E-05
3000.	6.61E-05	6.58E-06	1.38E-11	0.0	7.27E-05
4000.	7.68E-05	7.69E-06	1.63E-11	0.0	8.45E-05
5000.	8.68E-05	8.53E-06	1.81E-11	0.0	9.53E-05
6000.	9.51E-05	9.15E-06	1.94E-11	0.0	1.04E-04
7000.	1.02E-04	9.39E-06	2.04E-11	0.0	1.11E-04
8000.	1.07E-04	9.89E-06	2.10E-11	0.0	1.17E-04
9000.	1.12E-04	1.01E-05	2.15E-11	0.0	1.22E-04
10000.	1.15E-04	1.02E-05	2.18E-11	0.0	1.26E-04
20000.	1.73E-04	1.19E-05	2.54E-11	0.0	1.85E-04
30000.	1.34E-04	5.05E-06	1.08E-11	0.0	1.39E-04
40000.	1.02E-04	2.09E-06	4.40E-12	0.0	1.04E-04
50000.	8.32E-05	1.02E-06	2.01E-12	0.0	8.42E-05
60000.	6.95E-05	6.38E-07	1.15E-12	0.0	7.01E-05
70000.	5.79E-05	5.09E-07	8.43E-13	0.0	5.84E-05
80000.	4.78E-05	4.71E-07	7.35E-13	0.0	4.82E-05
90000.	3.93E-05	4.66E-07	6.98E-13	0.0	3.98E-05
100000.	3.27E-05	4.74E-07	6.88E-13	0.0	3.32E-05
200000.	5.93E-05	1.33E-06	1.72E-12	0.0	6.07E-05
300000.	4.43E-05	1.48E-06	1.61E-12	0.0	4.58E-05
400000.	4.68E-05	1.58E-06	1.55E-12	0.0	4.84E-05
500000.	4.78E-05	1.62E-06	1.49E-12	0.0	4.94E-05
600000.	4.75E-05	1.62E-06	1.43E-12	0.0	4.91E-05
700000.	4.66E-05	1.60E-06	1.38E-12	0.0	4.82E-05
800000.	4.53E-05	1.57E-06	1.33E-12	0.0	4.69E-05
900000.	4.37E-05	1.52E-06	1.28E-12	0.0	4.52E-05
1000000.	4.20E-05	1.47E-06	1.24E-12	0.0	4.35E-05

Table K-3. (Continued)

** AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MAR2LF FOR JF=1 TO 4, MAR2L FOR TOTAL, IN MILLIREMS/YEAR

TOTAL FOR ALL NUCLIDES — TOT BODY

ZONE= 7

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER	TOTAL
0.	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0
40.	1.02E-06	3.02E-08	1.81E-05	0.0	1.98E-05
50.	2.15E-06	4.70E-08	2.77E-05	0.0	2.99E-05
60.	2.38E-06	5.67E-08	3.22E-05	0.0	3.46E-05
70.	2.44E-06	6.24E-08	3.32E-05	0.0	3.57E-05
80.	2.40E-06	6.57E-08	3.21E-05	0.0	3.45E-05
90.	2.35E-06	6.82E-08	2.97E-05	0.0	3.21E-05
100.	2.26E-06	7.07E-08	2.68E-05	0.0	2.91E-05
200.	3.57E-06	1.37E-07	2.93E-05	0.0	3.30E-05
300.	3.32E-06	1.69E-07	1.17E-05	0.0	1.52E-05
400.	3.66E-06	2.13E-07	1.17E-05	0.0	1.56E-05
500.	3.99E-06	2.54E-07	1.31E-05	0.0	1.74E-05
600.	4.29E-06	2.90E-07	1.43E-05	0.0	1.88E-05
700.	4.53E-06	3.22E-07	1.50E-05	0.0	1.99E-05
800.	4.71E-06	3.49E-07	1.55E-05	0.0	2.05E-05
900.	4.84E-06	3.73E-07	1.57E-05	0.0	2.09E-05
1000.	4.94E-06	3.95E-07	1.57E-05	0.0	2.10E-05
2000.	7.80E-06	6.88E-07	2.31E-05	0.0	3.16E-05
3000.	8.32E-06	8.29E-07	2.16E-05	0.0	3.07E-05
4000.	9.00E-06	9.67E-07	2.40E-05	0.0	3.46E-05
5000.	1.09E-05	1.07E-06	2.64E-05	0.0	3.84E-05
6000.	1.20E-05	1.15E-06	2.84E-05	0.0	4.15E-05
7000.	1.28E-05	1.21E-06	2.99E-05	0.0	4.39E-05
8000.	1.35E-05	1.24E-06	3.10E-05	0.0	4.58E-05
9000.	1.41E-05	1.27E-06	3.19E-05	0.0	4.72E-05
10000.	1.45E-05	1.29E-06	3.25E-05	0.0	4.83E-05
20000.	2.18E-05	1.50E-06	4.64E-05	0.0	6.97E-05
30000.	1.69E-05	6.25E-07	3.14E-05	0.0	4.89E-05
40000.	1.29E-05	2.03E-07	2.18E-05	0.0	3.49E-05
50000.	1.05E-05	1.28E-07	1.90E-05	0.0	2.96E-05
60000.	8.74E-06	8.03E-08	1.96E-05	0.0	2.85E-05
70000.	7.28E-06	6.40E-08	2.16E-05	0.0	2.89E-05
80000.	6.01E-06	5.93E-08	2.36E-05	0.0	2.98E-05
90000.	4.95E-06	5.86E-08	2.59E-05	0.0	3.09E-05
100000.	4.12E-06	5.96E-08	2.78E-05	0.0	3.20E-05
200000.	7.46E-06	1.68E-07	7.96E-05	0.0	8.71E-05
300000.	5.57E-06	1.87E-07	8.23E-05	0.0	8.80E-05
400000.	5.89E-06	1.99E-07	7.35E-05	0.0	7.96E-05
500000.	6.02E-06	2.04E-07	6.20E-05	0.0	6.82E-05
600000.	5.96E-06	2.04E-07	5.13E-05	0.0	5.75E-05
700000.	5.87E-06	2.02E-07	4.24E-05	0.0	4.85E-05
800000.	5.70E-06	1.97E-07	3.52E-05	0.0	4.12E-05
900000.	5.50E-06	1.92E-07	2.97E-05	0.0	3.54E-05
1000000.	5.29E-06	1.86E-07	2.53E-05	0.0	3.04E-05

ZONE= 8

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER	TOTAL
0.	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0
40.	1.59E-05	3.10E-07	3.67E-03	0.0	5.29E-05
50.	2.14E-05	4.88E-07	4.23E-03	0.0	6.42E-05
60.	2.41E-05	5.94E-07	3.86E-03	0.0	6.33E-05
70.	2.50E-05	6.56E-07	3.23E-03	0.0	5.80E-05
80.	2.48E-05	6.94E-07	2.62E-03	0.0	5.17E-05
90.	2.42E-05	7.22E-07	2.09E-03	0.0	4.58E-05
100.	2.36E-05	7.49E-07	1.63E-03	0.0	4.09E-05
200.	3.60E-05	1.43E-06	4.66E-05	0.0	8.40E-05
300.	3.38E-05	1.76E-06	1.44E-03	0.0	4.99E-05
400.	3.76E-05	2.24E-06	1.15E-03	0.0	5.13E-05
500.	4.13E-05	2.68E-06	1.07E-03	0.0	5.47E-05
600.	4.46E-05	3.07E-06	9.88E-06	0.0	5.76E-05
700.	4.74E-05	3.41E-06	9.01E-06	0.0	5.98E-05
800.	4.94E-05	3.71E-06	8.13E-06	0.0	6.13E-05
900.	5.09E-05	3.97E-06	7.31E-06	0.0	6.22E-05
1000.	5.21E-05	4.20E-06	6.59E-06	0.0	6.29E-05
2000.	7.95E-05	7.20E-06	2.64E-03	0.0	1.13E-04
3000.	8.51E-05	8.69E-06	2.31E-03	0.0	1.17E-04
4000.	9.06E-05	1.02E-05	2.22E-05	0.0	1.33E-04
5000.	1.13E-04	1.13E-05	2.09E-05	0.0	1.45E-04
6000.	1.25E-04	1.22E-05	1.94E-03	0.0	1.56E-04
7000.	1.34E-04	1.28E-05	1.80E-05	2.32E-31	1.65E-04
8000.	1.43E-04	1.32E-05	1.66E-03	2.13E-22	1.71E-04
9000.	1.43E-04	1.35E-05	1.53E-03	7.27E-18	1.77E-04
10000.	1.53E-04	1.37E-05	1.43E-03	4.84E-14	1.81E-04
20000.	2.22E-04	1.56E-05	5.81E-03	4.69E-06	2.95E-04
30000.	1.72E-04	6.58E-06	3.94E-03	4.12E-08	2.18E-04
40000.	1.32E-04	2.73E-06	4.53E-03	8.37E-07	1.81E-04
50000.	1.08E-04	1.34E-06	5.49E-03	8.13E-07	1.65E-04
60000.	9.01E-05	9.45E-07	5.89E-03	7.88E-07	1.51E-04
70000.	7.53E-05	6.78E-07	6.04E-03	7.61E-07	1.37E-04
80000.	6.22E-05	6.31E-07	6.08E-03	7.36E-07	1.24E-04
90000.	5.13E-05	6.26E-07	6.07E-03	7.11E-07	1.13E-04
100000.	4.27E-05	6.38E-07	6.06E-03	6.93E-07	1.05E-04
200000.	7.36E-05	1.73E-06	1.56E-04	1.10E-08	2.31E-04
300000.	5.48E-05	1.92E-06	2.69E-04	4.55E-07	3.27E-04
400000.	5.79E-05	2.05E-06	2.28E-04	3.26E-07	2.89E-04
500000.	5.91E-05	2.10E-06	1.81E-04	2.32E-07	2.43E-04
600000.	5.80E-05	2.10E-06	1.43E-04	1.65E-07	2.04E-04
700000.	5.77E-05	2.08E-06	1.13E-04	1.18E-07	1.73E-04
800000.	5.60E-05	2.03E-06	9.09E-03	8.57E-08	1.49E-04
900000.	5.41E-05	1.97E-06	7.39E-03	6.27E-08	1.30E-04
1000000.	5.20E-05	1.91E-06	6.11E-03	4.65E-08	1.15E-04

Table K-3. (Continued)

** AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MAN2NF FOR JF=1 TO 4, MAN2N FOR TOTAL,

TOTAL FOR ALL NUCLIDES TOT BODY

IN MANREMS/YEAR

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER	TOTAL
0.	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0
25.	0.0	0.0	0.0	0.0	0.0
30.	0.0	0.0	0.0	0.0	0.0
40.	0.0	1.30E-01	2.76E-02	0.0	1.57E-01
50.	0.0	1.01E-01	4.14E-02	0.0	1.42E-01
60.	0.0	7.98E-02	4.77E-02	0.0	1.27E-01
70.	0.0	6.29E-02	4.92E-02	0.0	1.12E-01
80.	0.0	4.96E-02	4.78E-02	0.0	9.73E-02
90.	0.0	3.90E-02	4.45E-02	0.0	8.35E-02
100.	0.0	3.07E-02	4.02E-02	0.0	7.09E-02
200.	0.0	1.57E-02	5.03E-02	0.0	6.60E-02
300.	0.0	3.32E-03	7.06E-03	0.0	1.04E-02
400.	0.0	2.13E-03	1.21E-03	0.0	3.33E-03
500.	0.0	1.83E-03	4.63E-04	0.0	2.29E-03
600.	0.0	1.64E-03	3.80E-04	0.0	2.02E-03
700.	0.0	1.47E-03	3.86E-04	0.0	1.86E-03
800.	0.0	1.32E-03	3.96E-04	0.0	1.72E-03
900.	0.0	1.19E-03	4.03E-04	0.0	1.59E-03
1000.	0.0	1.07E-03	4.06E-04	0.0	1.47E-03
2000.	0.0	7.74E-04	6.51E-04	0.0	1.42E-03
3000.	0.0	4.86E-04	7.59E-04	3.13E-24	1.25E-03
4000.	0.0	4.10E-04	1.07E-03	5.66E-14	1.48E-03
5000.	0.0	3.65E-04	1.50E-03	6.94E-09	1.86E-03
6000.	0.0	3.32E-04	2.04E-03	1.88E-06	2.38E-03
7000.	0.0	3.04E-04	2.85E-03	1.96E-05	3.17E-03
8000.	0.0	2.80E-04	4.77E-03	1.30E-04	5.18E-03
9000.	0.0	2.60E-04	9.63E-03	4.38E-04	1.03E-02
10000.	0.0	2.42E-04	1.71E-02	7.18E-04	1.81E-02
20000.	0.0	1.82E-04	3.47E-02	7.49E-05	3.49E-02
30000.	0.0	1.07E-04	1.18E-01	7.08E-04	1.19E-01
40000.	0.0	7.91E-05	2.21E-01	9.89E-04	2.22E-01
50000.	0.0	7.47E-05	3.02E-01	9.59E-04	3.03E-01
60000.	0.0	7.84E-05	3.56E-01	9.28E-04	3.57E-01
70000.	0.0	8.44E-05	3.93E-01	8.98E-04	3.94E-01
80000.	0.0	9.04E-05	4.21E-01	8.69E-04	4.22E-01
90000.	0.0	9.58E-05	4.40E-01	8.40E-04	4.41E-01
100000.	0.0	1.01E-04	4.56E-01	8.18E-04	4.57E-01
200000.	0.0	1.12E-04	6.17E-01	1.01E-05	6.17E-01
300000.	0.0	1.16E-04	1.23E 00	6.72E-04	1.23E 00
400000.	0.0	1.01E-04	1.02E 00	4.84E-04	1.03E 00
500000.	0.0	8.30E-05	7.91E-01	3.42E-04	7.91E-01
600000.	0.0	6.62E-05	6.03E-01	2.42E-04	6.03E-01
700000.	0.0	5.25E-05	4.62E-01	1.72E-04	4.63E-01
800000.	0.0	4.17E-05	3.60E-01	1.25E-04	3.60E-01
900000.	0.0	3.33E-05	3.45E-01	1.58E-04	3.45E-01
1000000.	0.0	2.69E-05	1.19E 00	1.10E-03	1.19E 00

APPENDIX L

SUMMARY TABLES OF DOSE CALCULATION OUTPUT

BASE CASE

Summary tables at selected times are given in Tables L-1 through L-3 from output Section 6 as follows, for Base Case 48.

Section 6. Dose Summary Tables

1. Average Annual Local Dose to Individual, MAN1L, in Zone 1, mrem/y (Table L-1).
2. Average Annual Local Dose to Individual, MAN1L, in Zone 8, mrem/y (Table L-2).
3. Average Annual Nonspecific Dose to Population, MAN1N, man-rem/y (Table L-3).

Table L-1. Average Annual Local Dose to Individual, MAN1L, in Zone 1, In Millirems/Year

100. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	8.36E-12	1.05E-10	2.80E-12	0.0	1.17E-09	4.46E-11	4.46E-11	0.0
2	SR-90	3.67E-04	7.35E-06	3.67E-04	0.0	2.00E-03	5.51E-03	5.51E-03	0.0
3	Y-90	2.39E-07	1.47E-05	2.39E-07	0.0	7.24E-06	8.79E-06	8.79E-06	0.0
4	ZR-93	5.16E-11	8.02E-11	5.16E-11	1.10E-10	8.02E-10	1.96E-09	1.96E-09	0.0
5	NB-93M	9.15E-11	1.12E-10	9.15E-11	3.71E-10	1.14E-09	1.14E-09	1.14E-09	0.0
6	TC-99	3.62E-12	2.06E-09	3.62E-12	1.34E-11	2.92E-08	3.56E-11	3.56E-11	0.0
7	I-129	2.76E-12	5.78E-13	3.79E-12	1.04E-12	1.87E-12	4.51E-12	4.20E-12	8.75E-12
8	CS-135	3.99E-11	3.55E-11	3.99E-11	8.37E-11	1.04E-11	9.70E-11	9.70E-11	0.0
9	CS-137	1.42E-05	9.04E-06	1.42E-05	2.17E-05	1.24E-03	1.59E-05	1.59E-05	0.0
	SUB TOTAL	3.82E-04	3.11E-05	3.82E-04	2.17E-05	3.25E-03	5.54E-03	5.54E-03	8.75E-12
10	PB-210	1.03E-13	9.87E-15	9.93E-14	7.32E-13	1.49E-11	7.70E-12	7.70E-12	2.03E-14
11	RA-225	7.96E-13	9.79E-13	7.96E-13	5.06E-15	1.06E-10	5.42E-12	5.42E-12	0.0
12	RA-226	1.52E-12	1.19E-14	1.52E-12	1.20E-14	4.39E-12	1.78E-11	1.78E-11	1.53E-14
13	TH-229	1.73E-09	1.14E-12	1.73E-09	7.23E-10	1.51E-08	1.10E-07	1.10E-07	0.0
14	TH-230	2.83E-10	2.14E-13	2.83E-10	4.66E-10	9.50E-10	1.05E-08	1.05E-08	3.02E-13
15	NP-237	5.98E-07	2.63E-08	3.43E-07	8.09E-06	5.35E-06	2.05E-05	2.05E-05	4.57E-08
16	NP-239	1.74E-05	1.15E-05	2.02E-05	1.31E-05	1.50E-05	2.81E-05	2.80E-05	1.82E-05
17	PU-238	5.24E-04	3.72E-07	3.18E-04	7.80E-03	6.19E-03	1.82E-02	1.82E-02	1.49E-07
18	PU-239	4.63E-06	2.54E-09	2.50E-06	6.75E-05	4.41E-05	1.69E-04	1.69E-04	8.39E-10
19	PU-240	9.07E-05	5.52E-08	4.91E-05	1.32E-03	8.65E-04	3.31E-03	3.31E-03	2.26E-08
20	PU-241	5.04E-07	4.28E-10	4.80E-07	3.48E-06	1.78E-07	2.05E-05	2.05E-05	0.0
21	AM-241	6.65E-04	1.10E-05	3.75E-04	9.40E-03	6.41E-03	2.25E-02	2.25E-02	2.27E-05
22	AM-242M	4.51E-05	5.32E-09	2.44E-05	6.27E-04	1.82E-04	1.60E-03	1.60E-03	0.0
23	AM-243	1.47E-04	2.22E-06	8.00E-05	2.05E-03	1.35E-03	5.10E-03	5.10E-03	4.54E-06
24	CM-242	6.75E-07	2.55E-08	6.71E-07	1.24E-05	1.04E-04	2.31E-05	2.31E-05	6.55E-09
25	CM-244	6.76E-04	7.65E-06	5.41E-04	1.04E-02	1.48E-02	2.26E-02	2.25E-02	1.42E-05
	SUB TOTAL	2.17E-03	3.28E-05	1.41E-03	3.17E-02	3.00E-02	7.36E-02	7.36E-02	5.99E-05
	TOTAL	2.55E-03	6.39E-05	1.79E-03	3.17E-02	3.32E-02	7.92E-02	7.91E-02	5.99E-05

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table L-1. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 1, IN MILLIREMS/YEAR

1000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	8.76E-11	1.10E-09	2.93E-11	0.0	1.23E-08	4.67E-10	4.67E-10	0.0
2	SR-90	6.36E-12	1.27E-13	6.36E-12	0.0	3.47E-11	9.54E-11	9.54E-11	0.0
3	Y-90	4.13E-15	2.54E-13	4.13E-15	0.0	1.25E-13	1.52E-13	1.52E-13	0.0
4	ZR-93	5.99E-10	9.31E-10	5.99E-10	1.28E-09	9.31E-09	2.28E-08	2.28E-08	0.0
5	NB-93M	1.10E-09	1.34E-09	1.10E-09	4.44E-09	1.37E-08	1.36E-08	1.36E-08	0.0
6	TC-99	4.18E-11	2.38E-08	4.18E-11	1.55E-10	3.37E-07	4.11E-10	4.11E-10	0.0
7	I-129	3.79E-11	7.92E-12	5.21E-11	1.43E-11	2.47E-11	6.20E-11	5.76E-11	1.08E-10
8	CS-135	4.63E-10	4.12E-10	4.63E-10	9.73E-10	1.21E-10	1.13E-09	1.13E-09	0.0
9	CS-137	9.21E-13	5.47E-13	9.21E-13	1.31E-12	7.47E-11	9.62E-13	9.62E-13	0.0
	SUB TOTAL	2.33E-09	2.76E-08	2.29E-09	6.86E-09	3.73E-07	3.86E-08	3.86E-08	1.08E-10
10	PB-210	3.15E-10	3.41E-11	3.02E-10	2.15E-09	4.36E-08	2.26E-08	2.26E-08	7.01E-11
11	RA-225	1.00E-10	1.23E-10	1.00E-10	6.37E-13	1.34E-08	6.83E-10	6.83E-10	0.0
12	RA-226	2.87E-09	2.63E-11	2.88E-09	2.69E-11	8.31E-09	3.38E-08	3.38E-08	3.43E-11
13	TH-229	2.18E-07	1.43E-10	2.18E-07	9.09E-08	1.90E-06	1.38E-05	1.38E-05	0.0
14	TH-230	8.03E-08	6.91E-11	8.03E-08	1.32E-07	2.70E-07	2.99E-06	2.99E-06	1.01E-10
15	NP-237	8.14E-06	4.18E-07	4.71E-06	1.09E-04	7.20E-05	2.76E-04	2.76E-04	7.26E-07
16	NP-239	2.21E-04	1.46E-04	2.57E-04	1.66E-04	1.91E-04	3.57E-04	3.56E-04	2.32E-04
17	PU-238	2.48E-05	1.83E-08	1.50E-05	3.69E-04	2.93E-04	8.64E-04	8.64E-04	8.35E-09
18	PU-239	8.94E-05	5.03E-08	4.83E-05	1.30E-03	8.52E-04	3.27E-03	3.27E-03	1.92E-08
19	PU-240	1.01E-03	6.39E-07	5.46E-04	1.47E-02	9.62E-03	3.68E-02	3.68E-02	2.97E-07
20	PU-241	1.21E-06	1.03E-09	1.15E-06	8.35E-06	4.27E-07	4.93E-05	4.93E-05	0.0
21	AM-241	2.09E-03	4.04E-05	1.18E-03	2.93E-02	2.00E-02	7.04E-02	7.04E-02	8.39E-05
22	AM-242M	1.06E-05	1.26E-09	5.77E-06	1.48E-04	4.30E-05	3.78E-04	3.78E-04	0.0
23	AM-243	1.59E-03	2.80E-05	8.68E-04	2.21E-02	1.45E-02	5.49E-02	5.48E-02	5.77E-05
24	CM-242	1.62E-07	6.18E-09	1.60E-07	2.92E-06	2.47E-05	5.46E-06	5.46E-06	1.83E-09
25	CM-244	2.02E-16	2.69E-18	1.62E-16	3.10E-15	4.41E-15	6.72E-15	6.72E-15	5.06E-18
	SUB TOTAL	5.04E-03	2.15E-04	2.93E-03	6.82E-02	4.56E-02	1.67E-01	1.67E-01	3.74E-04
	TOTAL	5.04E-03	2.15E-04	2.93E-03	6.82E-02	4.56E-02	1.67E-01	1.67E-01	3.74E-04

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table L-1. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 1, IN MILLIREMS/YEAR

10000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	2.88E-10	3.63E-09	9.66E-11	0.0	4.04E-08	1.54E-09	1.54E-09	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	5.51E-09	8.56E-09	5.51E-09	1.17E-08	8.56E-08	2.10E-07	2.10E-07	0.0
5	NB-93M	1.01E-08	1.23E-08	1.01E-08	4.08E-08	1.26E-07	1.25E-07	1.25E-07	0.0
6	TC-99	3.77E-10	2.15E-07	3.77E-10	1.40E-09	3.04E-06	3.71E-09	3.71E-09	0.0
7	I-129	3.56E-10	7.43E-11	4.89E-10	1.34E-10	2.31E-10	5.82E-10	5.41E-10	1.00E-09
8	CS-135	4.29E-09	3.81E-09	4.29E-09	9.00E-09	1.12E-09	1.04E-08	1.04E-08	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	2.09E-08	2.43E-07	2.08E-08	6.31E-08	3.30E-06	3.51E-07	3.51E-07	1.00E-09
10	PB-210	1.52E-07	1.66E-08	1.46E-07	1.04E-06	2.10E-05	1.09E-05	1.09E-05	3.42E-08
11	RA-225	8.71E-09	1.07E-08	8.71E-09	5.53E-11	1.16E-06	5.93E-08	5.93E-08	0.0
12	RA-226	1.38E-06	1.27E-08	1.38E-06	1.30E-08	3.98E-06	1.62E-05	1.62E-05	1.67E-08
13	TH-229	1.91E-05	1.25E-08	1.91E-05	7.93E-06	1.66E-04	1.21E-03	1.21E-03	0.0
14	TH-230	8.21E-06	7.14E-09	8.21E-06	1.35E-05	2.76E-05	3.05E-04	3.05E-04	1.05E-08
15	NP-237	8.01E-05	4.16E-06	4.64E-05	1.07E-03	7.08E-04	2.71E-03	2.71E-03	7.23E-06
16	NP-239	9.51E-04	6.27E-04	1.11E-03	7.15E-04	8.22E-04	1.54E-03	1.53E-03	9.97E-04
17	PU-238	6.28E-21	4.66E-24	3.81E-21	9.35E-20	7.41E-20	2.19E-19	2.19E-19	2.14E-24
18	PU-239	2.70E-03	1.52E-06	1.46E-03	3.93E-02	2.57E-02	9.86E-02	9.86E-02	5.85E-07
19	PU-240	3.90E-03	2.47E-06	2.11E-03	5.68E-02	3.71E-02	1.42E-01	1.42E-01	1.16E-06
20	PU-241	5.49E-06	4.66E-09	5.23E-06	3.79E-05	1.94E-06	2.24E-04	2.24E-04	0.0
21	AM-241	4.22E-04	8.26E-06	2.39E-04	5.93E-03	4.05E-03	1.42E-02	1.42E-02	1.72E-05
22	AM-242M	3.68E-21	4.35E-25	1.99E-21	5.12E-20	1.49E-20	1.31E-19	1.31E-19	0.0
23	AM-243	6.76E-03	1.21E-04	3.70E-03	9.38E-02	6.16E-02	2.33E-01	2.33E-01	2.49E-04
24	CM-242	5.60E-23	2.15E-24	5.56E-23	1.01E-21	8.54E-21	1.89E-21	1.89E-21	6.42E-25
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.48E-02	7.65E-04	8.69E-03	1.98E-01	1.30E-01	4.94E-01	4.94E-01	1.27E-03
	TOTAL	1.48E-02	7.65E-04	8.69E-03	1.98E-01	1.30E-01	4.94E-01	4.94E-01	1.27E-03

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table L-1. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MAN1L, IN ZONE 1, IN MILLIREMS/YEAR

100000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	5.06E-14	6.37E-13	1.69E-14	0.0	7.08E-12	2.69E-13	2.69E-13	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	2.58E-08	4.01E-08	2.58E-08	5.50E-08	4.01E-07	9.84E-07	9.84E-07	0.0
5	NB-93M	4.70E-08	5.76E-08	4.70E-08	1.91E-07	5.87E-07	5.85E-07	5.85E-07	0.0
6	TC-99	1.38E-09	7.86E-07	1.38E-09	5.12E-09	1.12E-05	1.36E-08	1.36E-08	0.0
7	I-129	1.72E-09	3.60E-10	2.37E-09	6.49E-10	1.12E-09	2.82E-09	2.62E-09	4.85E-09
8	CS-135	2.04E-08	1.81E-08	2.04E-08	4.28E-08	5.33E-09	4.96E-08	4.96E-08	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	9.63E-08	9.02E-07	9.69E-08	2.94E-07	1.21E-05	1.63E-06	1.63E-06	4.85E-09
10	PB-210	6.12E-06	6.70E-07	5.87E-06	4.17E-05	8.44E-04	4.38E-04	4.38E-04	1.38E-06
11	RA-225	3.22E-07	3.96E-07	3.22E-07	2.05E-09	4.30E-05	2.19E-06	2.19E-06	0.0
12	RA-226	5.53E-05	5.12E-07	5.55E-05	5.24E-07	1.60E-04	6.50E-04	6.50E-04	6.70E-07
13	TH-229	7.04E-04	4.62E-07	7.04E-04	2.93E-04	6.14E-03	4.46E-02	4.46E-02	0.0
14	TH-230	2.51E-04	2.18E-07	2.51E-04	4.13E-04	8.42E-04	9.32E-03	9.32E-03	3.20E-07
15	NP-237	3.85E-04	2.00E-05	2.23E-04	5.15E-03	3.40E-03	1.30E-02	1.30E-02	3.48E-05
16	NP-239	2.00E-06	1.32E-06	2.33E-06	1.50E-06	1.73E-06	3.23E-06	3.22E-06	2.10E-06
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	2.49E-03	1.40E-06	1.34E-03	3.63E-02	2.37E-02	9.10E-02	9.10E-02	5.41E-07
19	PU-240	3.17E-06	2.01E-09	1.71E-06	4.62E-05	3.02E-05	1.15E-04	1.15E-04	9.45E-10
20	PU-241	2.33E-08	1.98E-11	2.22E-08	1.61E-07	8.24E-09	9.50E-07	9.50E-07	0.0
21	AM-241	1.78E-06	3.49E-08	1.01E-06	2.50E-05	1.71E-05	6.00E-05	6.00E-05	7.25E-08
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	1.42E-05	2.54E-07	7.75E-06	1.97E-04	1.29E-04	4.90E-04	4.89E-04	5.22E-07
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	3.91E-03	2.53E-05	2.60E-03	4.25E-02	3.53E-02	1.60E-01	1.60E-01	4.04E-05
	TOTAL	3.91E-03	2.62E-05	2.60E-03	4.25E-02	3.53E-02	1.60E-01	1.60E-01	4.04E-05

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table L-1. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 1, IN MILLIREMS/YEAR

1000000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	4.40E-08	6.84E-08	4.40E-08	9.38E-08	6.84E-07	1.68E-06	1.68E-06	0.0
5	NB-93M	8.00E-08	9.80E-08	8.00E-08	3.24E-07	9.99E-07	9.96E-07	9.96E-07	0.0
6	TC-99	2.13E-10	1.22E-07	2.13E-10	7.92E-10	1.72E-06	2.10E-09	2.10E-09	0.0
7	I-129	4.22E-09	8.82E-10	5.80E-09	1.59E-09	2.74E-09	6.90E-09	6.42E-09	1.19E-08
8	CS-135	4.24E-08	3.77E-08	4.24E-08	8.90E-08	1.11E-08	1.03E-07	1.03E-07	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.71E-07	3.27E-07	1.72E-07	5.10E-07	3.42E-06	2.78E-06	2.78E-06	1.19E-08
10	PB-210	3.46E-06	3.79E-07	3.32E-06	2.36E-05	4.78E-04	2.48E-04	2.48E-04	7.81E-07
11	RA-225	1.92E-06	2.36E-06	1.92E-06	1.22E-08	2.56E-04	1.31E-05	1.31E-05	0.0
12	RA-226	3.13E-05	2.89E-07	3.14E-05	2.97E-07	9.04E-05	3.67E-04	3.67E-04	3.79E-07
13	TH-229	4.20E-03	2.76E-06	4.20E-03	1.75E-03	3.66E-02	2.66E-01	2.66E-01	0.0
14	TH-230	1.42E-04	1.24E-07	1.42E-04	2.34E-04	4.76E-04	5.28E-03	5.28E-03	1.81E-07
15	NP-237	7.43E-04	3.86E-05	4.31E-04	9.92E-03	6.57E-03	2.52E-02	2.52E-02	6.71E-05
16	NP-239	1.09E-09	7.22E-10	1.27E-09	8.22E-10	9.45E-10	1.77E-09	1.76E-09	1.15E-09
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	1.33E-08	7.49E-12	7.18E-09	1.94E-07	1.27E-07	4.86E-07	4.86E-07	2.89E-12
19	PU-240	8.11E-11	5.15E-14	4.38E-11	1.18E-09	7.73E-10	2.96E-09	2.96E-09	2.42E-14
20	PU-241	4.02E-34	3.42E-37	3.83E-34	2.78E-33	1.42E-34	1.64E-32	1.64E-32	0.0
21	AM-241	3.83E-32	7.51E-34	2.17E-32	5.38E-31	3.68E-31	1.29E-30	1.29E-30	1.56E-33
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	7.55E-09	1.35E-10	4.13E-09	1.05E-07	6.87E-08	2.61E-07	2.61E-07	2.78E-10
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	5.12E-03	4.46E-05	4.81E-03	1.19E-02	4.45E-02	2.97E-01	2.97E-01	6.85E-05
	TOTAL	5.12E-03	4.49E-05	4.81E-03	1.19E-02	4.45E-02	2.97E-01	2.97E-01	6.85E-05

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table L-2. Average Annual Local Dose to Individual, MAN1L, In Zone 8, In Millirems/Year

100. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	3.23E-12	5.47E-11	1.07E-12	3.15E-12	1.46E-11	1.62E-11	1.62E-11	3.15E-12
2	SR-90	1.22E-05	2.70E-06	1.22E-05	0.0	1.62E-05	5.03E-04	5.03E-04	0.0
3	Y-90	2.35E-09	5.76E-06	2.35E-09	0.0	7.06E-08	8.62E-08	8.62E-08	0.0
4	ZR-93	5.14E-13	2.65E-11	5.14E-13	1.10E-12	7.81E-12	1.96E-11	1.96E-11	0.0
5	NB-93M	9.13E-13	5.11E-11	9.13E-13	3.70E-12	1.11E-11	1.14E-11	1.14E-11	0.0
6	TC-99	4.10E-12	8.08E-10	4.10E-12	1.52E-11	2.86E-10	1.06E-11	1.06E-11	0.0
7	I-129	3.34E-14	9.41E-15	4.51E-14	1.26E-14	2.04E-14	5.21E-14	4.85E-14	1.62E-12
8	CS-135	1.53E-11	1.84E-11	1.53E-11	3.44E-11	3.93E-12	3.73E-11	3.73E-11	0.0
9	CS-137	4.26E-06	4.70E-06	4.26E-06	1.07E-05	1.32E-05	7.86E-06	7.86E-06	0.0
	SUB TOTAL	1.64E-05	1.32E-05	1.64E-05	1.07E-05	2.94E-05	5.11E-04	5.11E-04	4.77E-12
10	PB-210	4.36E-15	1.75E-16	4.32E-15	3.78E-14	1.45E-13	4.01E-13	4.01E-13	2.30E-16
11	RA-225	1.33E-12	3.20E-13	1.33E-12	8.26E-15	1.03E-12	9.18E-12	9.18E-12	0.0
12	RA-226	3.30E-13	7.89E-16	3.30E-13	1.95E-16	4.28E-14	3.93E-12	3.93E-12	1.74E-16
13	TH-229	1.73E-11	5.28E-13	1.73E-11	7.19E-12	1.48E-10	1.10E-09	1.10E-09	0.0
14	TH-230	2.79E-12	2.92E-14	2.79E-12	4.61E-12	9.26E-12	1.04E-10	1.04E-10	3.42E-15
15	NP-237	7.08E-09	4.19E-10	4.04E-09	9.62E-08	5.22E-08	2.43E-07	2.43E-07	5.18E-10
16	NP-239	1.97E-07	1.38E-07	2.29E-07	1.48E-07	1.70E-07	3.18E-07	3.17E-07	2.07E-07
17	PU-238	5.14E-06	1.27E-07	3.12E-06	7.65E-05	6.03E-05	1.79E-04	1.79E-04	1.69E-09
18	PU-239	4.54E-08	9.54E-10	2.45E-08	6.62E-07	4.30E-07	1.66E-06	1.66E-06	9.52E-12
19	PU-240	8.90E-07	1.88E-08	4.81E-07	1.30E-05	8.43E-06	3.25E-05	3.25E-05	2.56E-10
20	PU-241	4.95E-09	2.22E-10	4.71E-09	3.42E-08	1.74E-09	2.01E-07	2.01E-07	0.0
21	AM-241	7.88E-06	2.49E-07	4.44E-06	1.12E-04	6.25E-05	2.68E-04	2.68E-04	2.58E-07
22	AM-242M	5.35E-07	3.07E-09	2.90E-07	7.43E-06	1.77E-06	1.90E-05	1.90E-05	0.0
23	AM-243	1.74E-06	5.28E-08	9.49E-07	2.44E-05	1.31E-05	6.05E-05	6.05E-05	5.15E-08
24	CM-242	8.22E-09	1.14E-08	7.98E-09	1.43E-07	1.02E-06	2.75E-07	2.75E-07	7.42E-11
25	CM-244	8.02E-06	3.82E-07	6.43E-06	1.23E-04	1.44E-04	2.67E-04	2.67E-04	1.61E-07
	SUB TOTAL	2.45E-05	9.84E-07	1.60E-05	3.57E-04	2.92E-04	8.29E-04	8.28E-04	6.79E-07
	TOTAL	4.09E-05	1.41E-05	3.24E-05	3.68E-04	3.21E-04	1.34E-03	1.34E-03	6.79E-07

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table L-2. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 8, IN MILLIREMS/YEAR

1000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	2.95E-11	4.98E-10	9.80E-12	2.85E-11	1.65E-10	1.48E-10	1.48E-10	2.85E-11
2	SR-90	8.06E-14	2.12E-14	8.06E-14	0.0	3.84E-14	3.77E-12	3.77E-12	0.0
3	Y-90	4.63E-17	8.66E-14	4.63E-17	0.0	1.39E-15	1.70E-15	1.70E-15	0.0
4	ZR-93	6.79E-12	2.68E-10	6.79E-12	1.45E-11	1.04E-10	2.59E-10	2.59E-10	0.0
5	NB-93M	1.24E-11	5.32E-10	1.24E-11	5.04E-11	1.52E-10	1.55E-10	1.55E-10	0.0
6	TC-99	4.10E-11	8.13E-09	4.10E-11	1.52E-10	3.77E-09	1.07E-10	1.07E-10	0.0
7	I-129	4.52E-13	1.19E-13	6.14E-13	1.71E-13	2.79E-13	7.15E-13	6.65E-13	1.65E-11
8	CS-135	1.55E-10	1.86E-10	1.55E-10	3.48E-10	3.97E-11	3.78E-10	3.78E-10	0.0
9	CS-137	2.25E-13	2.47E-13	2.25E-13	5.61E-13	8.94E-13	4.13E-13	4.13E-13	0.0
	SUB TOTAL	2.45E-10	9.61E-09	2.26E-10	5.94E-10	4.23E-09	1.05E-09	1.05E-09	4.51E-11
10	PB-210	1.19E-11	5.48E-13	1.18E-11	1.01E-10	4.85E-10	1.08E-09	1.08E-09	7.98E-13
11	RA-225	1.45E-10	3.51E-11	1.45E-10	9.01E-13	1.49E-10	1.00E-09	1.00E-09	0.0
12	RA-226	5.48E-10	1.37E-12	5.48E-10	4.01E-13	9.26E-11	6.52E-09	6.52E-09	3.90E-13
13	TH-229	2.47E-09	5.77E-11	2.47E-09	1.03E-09	2.12E-08	1.57E-07	1.57E-07	0.0
14	TH-230	9.03E-10	7.37E-12	9.03E-10	1.49E-09	3.00E-09	3.35E-08	3.35E-08	1.15E-12
15	NP-237	1.05E-07	6.16E-09	6.00E-08	1.41E-06	8.02E-07	3.58E-06	3.58E-06	8.25E-09
16	NP-239	2.51E-06	1.73E-06	2.93E-06	1.89E-06	2.17E-06	4.06E-06	4.05E-06	2.63E-06
17	PU-238	2.78E-07	5.25E-09	1.68E-07	4.14E-06	3.26E-06	9.68E-06	9.68E-06	9.49E-11
18	PU-239	1.00E-06	1.61E-08	5.41E-07	1.46E-05	9.49E-06	3.66E-05	3.66E-05	2.18E-10
19	PU-240	1.13E-05	1.82E-07	6.11E-06	1.65E-04	1.07E-04	4.12E-04	4.12E-04	3.38E-09
20	PU-241	1.35E-08	4.63E-10	1.29E-08	9.35E-08	4.76E-09	5.52E-07	5.52E-07	0.0
21	AM-241	2.70E-05	7.97E-07	1.52E-05	3.81E-04	2.23E-04	9.14E-04	9.14E-04	9.54E-07
22	AM-242M	1.38E-07	6.29E-10	7.48E-08	1.92E-06	4.79E-07	4.91E-06	4.91E-06	0.0
23	AM-243	2.05E-05	5.77E-07	1.12E-05	2.86E-04	1.61E-04	7.11E-04	7.11E-04	6.56E-07
24	CM-242	2.12E-09	2.33E-09	2.07E-09	3.72E-08	2.75E-07	7.09E-08	7.09E-08	2.08E-11
25	CM-244	2.65E-18	1.08E-19	2.12E-18	4.07E-17	4.97E-17	8.81E-17	8.81E-17	5.76E-20
	SUB TOTAL	6.29E-05	3.32E-06	3.63E-05	8.56E-04	5.08E-04	2.10E-03	2.10E-03	4.26E-06
	TOTAL	6.29E-05	3.33E-06	3.63E-05	8.56E-04	5.08E-04	2.10E-03	2.10E-03	4.26E-06

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table L-2. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 8, IN MILLIREMS/YEAR

10000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW#	BONE	THYROID
1	C-14	1.01E-10	1.71E-09	3.36E-11	9.80E-11	5.23E-10	5.05E-10	5.05E-10	9.80E-11
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	6.31E-11	2.60E-09	6.31E-11	1.34E-10	9.63E-10	2.40E-09	2.40E-09	0.0
5	NB-93M	1.15E-10	5.17E-09	1.15E-10	4.68E-10	1.41E-09	1.43E-09	1.43E-09	0.0
6	TC-99	3.91E-10	7.75E-08	3.91E-10	1.45E-09	3.43E-08	1.02E-09	1.02E-09	0.0
7	I-129	4.25E-12	1.13E-12	5.77E-12	1.61E-12	2.62E-12	6.71E-12	6.24E-12	1.62E-10
8	CS-135	1.51E-09	1.82E-09	1.51E-09	3.40E-09	3.88E-10	3.69E-09	3.69E-09	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	2.19E-09	8.88E-08	2.12E-09	5.56E-09	3.76E-08	9.06E-09	9.06E-09	2.60E-10
10	PB-210	6.00E-09	2.71E-10	5.93E-09	5.12E-08	2.36E-07	5.43E-07	5.43E-07	3.89E-10
11	RA-225	1.33E-08	3.22E-09	1.33E-08	8.28E-11	1.31E-08	9.19E-08	9.19E-08	0.0
12	RA-226	2.77E-07	6.89E-10	2.77E-07	1.97E-10	4.48E-08	3.29E-06	3.29E-06	1.89E-10
13	TH-229	2.18E-07	5.33E-09	2.18E-07	9.07E-08	1.87E-06	1.38E-05	1.38E-05	0.0
14	TH-230	9.32E-08	7.94E-10	9.32E-08	1.54E-07	3.10E-07	3.46E-06	3.46E-06	1.19E-10
15	NP-237	1.04E-06	6.19E-08	6.00E-07	1.41E-05	7.96E-06	3.58E-05	3.58E-05	8.22E-08
16	NP-239	1.04E-05	7.23E-06	1.22E-05	7.84E-06	9.02E-06	1.69E-05	1.68E-05	1.09E-05
17	PU-238	7.11E-23	1.40E-24	4.31E-23	1.06E-21	8.34E-22	2.47E-21	2.47E-21	2.44E-26
18	PU-239	3.05E-05	5.12E-07	1.65E-05	4.45E-04	2.89E-04	1.11E-03	1.11E-03	6.65E-09
19	PU-240	4.40E-05	7.43E-07	2.38E-05	6.42E-04	4.17E-04	1.61E-03	1.61E-03	1.32E-08
20	PU-241	6.21E-08	2.22E-09	5.91E-08	4.28E-07	2.18E-08	2.53E-06	2.53E-06	0.0
21	AM-241	5.54E-06	1.66E-07	3.13E-06	7.82E-05	4.55E-05	1.88E-04	1.88E-04	1.95E-07
22	AM-242M	4.86E-23	2.31E-25	2.63E-23	6.76E-22	1.67E-22	1.73E-21	1.73E-21	0.0
23	AM-243	8.87E-05	2.53E-06	4.84E-05	1.24E-03	6.92E-04	3.07E-03	3.07E-03	2.83E-06
24	CM-242	7.48E-25	8.56E-25	7.29E-25	1.31E-23	9.61E-23	2.50E-23	2.50E-23	7.29E-27
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.81E-04	1.13E-05	1.05E-04	2.43E-03	1.46E-03	6.06E-03	6.06E-03	1.41E-05
	TOTAL	1.81E-04	1.13E-05	1.05E-04	2.43E-03	1.46E-03	6.06E-03	6.06E-03	1.41E-05

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table L-2. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 8, IN MILLIREMS/YEAR

100000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	1.85E-14	3.15E-13	6.14E-15	1.84E-14	3.53E-14	9.24E-14	9.24E-14	1.84E-14
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	2.96E-10	2.10E-08	2.96E-10	6.30E-10	4.45E-09	1.13E-08	1.13E-08	0.0
5	NB-93M	5.38E-10	4.18E-06	5.38E-10	2.18E-09	6.51E-09	6.70E-09	6.70E-09	0.0
6	TC-99	3.99E-05	7.74E-03	3.99E-05	1.48E-04	6.02E-05	1.01E-04	1.01E-04	0.0
7	I-129	3.15E-08	3.28E-08	3.47E-08	1.22E-08	5.11E-09	2.42E-08	2.33E-08	1.66E-05
8	CS-135	1.24E-08	1.50E-08	1.24E-08	2.79E-08	3.19E-09	3.03E-08	3.03E-08	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	3.99E-05	7.74E-03	3.99E-05	1.48E-04	6.02E-05	1.01E-04	1.01E-04	1.66E-05
10	PB-210	3.70E-07	1.33E-08	3.67E-07	3.24E-06	9.36E-06	3.49E-05	3.44E-05	1.56E-08
11	RA-225	8.57E-07	2.05E-07	8.57E-07	5.34E-09	4.76E-07	5.93E-06	5.93E-06	0.0
12	RA-226	1.90E-05	4.40E-08	1.90E-05	9.32E-09	1.77E-06	2.26E-04	2.26E-04	7.56E-09
13	TH-229	8.04E-06	3.41E-07	8.04E-06	3.35E-06	6.81E-05	5.10E-04	5.10E-04	0.0
14	TH-230	2.83E-06	4.06E-08	2.83E-06	4.67E-06	9.33E-06	1.05E-04	1.05E-04	3.61E-09
15	NP-237	5.48E-06	3.49E-07	3.13E-06	7.47E-05	3.70E-05	1.89E-04	1.89E-04	3.93E-07
16	NP-239	7.49E-09	5.86E-09	8.72E-09	5.62E-09	6.47E-09	1.21E-08	1.21E-08	7.85E-09
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	2.78E-05	8.15E-07	1.50E-05	4.06E-04	2.63E-04	1.02E-03	1.02E-03	6.10E-09
19	PU-240	3.54E-08	1.04E-09	1.92E-08	5.17E-07	3.35E-07	1.29E-06	1.29E-06	1.07E-11
20	PU-241	2.61E-10	1.64E-11	2.49E-10	1.80E-09	9.14E-11	1.06E-08	1.06E-08	0.0
21	AM-241	2.56E-08	9.27E-10	1.44E-08	3.62E-07	1.89E-07	8.69E-07	8.69E-07	8.19E-10
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	2.04E-07	7.13E-09	1.11E-07	2.86E-06	1.43E-06	7.06E-06	7.07E-06	5.89E-09
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	6.47E-05	1.82E-06	4.94E-05	4.96E-04	3.92E-04	2.10E-03	2.10E-03	4.40E-07
	TOTAL	1.05E-04	7.74E-03	8.94E-05	6.44E-04	4.52E-04	2.20E-03	2.20E-03	1.70E-05

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table L-2. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 8, IN MILLIREMS/YEAR

1000000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	5.01E-10	8.84E-08	5.01E-10	1.07E-09	7.18E-09	1.91E-08	1.91E-08	0.0
5	NB-93M	9.14E-10	1.76E-07	9.14E-10	3.71E-09	1.05E-08	1.14E-08	1.14E-08	0.0
6	TC-99	1.25E-05	2.42E-03	1.25E-05	4.65E-05	4.07E-06	3.15E-05	3.15E-05	0.0
7	I-129	1.17E-07	1.55E-07	1.18E-07	4.55E-08	1.23E-09	5.58E-08	5.55E-08	8.21E-05
8	CS-135	6.40E-08	7.74E-08	6.40E-08	1.44E-07	1.64E-08	1.56E-07	1.56E-07	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.27E-05	2.42E-03	1.27E-05	4.67E-05	4.11E-06	3.17E-05	3.17E-05	8.21E-05
10	PB-210	4.64E-07	1.23E-08	4.63E-07	4.19E-06	5.02E-06	4.45E-05	4.45E-05	8.58E-09
11	RA-225	1.28E-05	3.02E-06	1.28E-05	7.95E-08	2.69E-06	8.84E-05	8.84E-05	0.0
12	RA-226	2.63E-05	5.73E-08	2.63E-05	8.07E-09	9.50E-07	3.13E-04	3.13E-04	4.16E-09
13	TH-229	4.76E-05	5.04E-06	4.76E-05	1.98E-05	3.85E-04	3.02E-03	3.02E-03	0.0
14	TH-230	1.55E-06	5.53E-08	1.55E-06	2.59E-06	5.00E-06	5.77E-05	5.77E-05	1.99E-09
15	NP-237	1.37E-05	1.02E-06	7.67E-06	1.90E-04	6.90E-05	4.77E-04	4.77E-04	7.38E-07
16	NP-239	1.18E-11	9.50E-12	1.37E-11	8.85E-12	1.02E-11	1.90E-11	1.90E-11	1.24E-11
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	1.43E-10	1.08E-11	7.72E-11	2.09E-09	1.33E-09	5.23E-09	5.23E-09	3.18E-14
19	PU-240	8.72E-13	6.57E-14	4.72E-13	1.27E-11	8.11E-12	3.18E-11	3.18E-11	2.66E-16
20	PU-241	4.58E-36	8.65E-38	4.36E-36	3.16E-35	1.61E-36	1.86E-34	1.86E-34	0.0
21	AM-241	4.72E-34	1.20E-35	2.67E-34	6.65E-33	4.17E-33	1.60E-32	1.60E-32	1.78E-35
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	1.41E-10	7.16E-12	7.68E-11	2.00E-09	7.22E-10	4.93E-09	4.93E-09	3.06E-12
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.02E-04	9.20E-06	9.64E-05	2.16E-04	4.67E-04	4.00E-03	4.00E-03	7.52E-07
	TOTAL	1.15E-04	2.43E-03	1.09E-04	2.63E-04	4.72E-04	4.03E-03	4.03E-03	8.29E-05

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table L-3. Average Annual Nonspecific Dose to Population, MAN1N, In Man-rems/Year

AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MAN1N, IN MANREMS/YEAR

100. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	4.39E-08	7.48E-07	1.46E-08	4.39E-08	4.39E-08	2.19E-07	2.19E-07	4.39E-08
2	SR-90	2.19E-02	6.28E-03	2.19E-02	0.0	0.0	1.09E 00	1.09E 00	0.0
3	Y-90	1.73E-08	6.78E-03	1.73E-08	0.0	0.0	6.50E-07	6.50E-07	0.0
4	ZR-93	1.25E-10	2.78E-07	1.25E-10	2.67E-10	0.0	4.79E-09	4.79E-09	0.0
5	NB-93M	1.40E-09	3.31E-06	1.40E-09	5.68E-09	0.0	1.74E-08	1.74E-08	0.0
6	TC-99	4.03E-07	7.83E-05	4.03E-07	1.50E-06	1.27E-07	1.02E-06	1.02E-06	0.0
7	I-129	1.93E-11	2.60E-11	1.93E-11	7.52E-12	0.0	8.75E-12	8.75E-12	1.38E-08
8	CS-135	1.61E-07	1.96E-07	1.61E-07	3.63E-07	4.14E-08	3.93E-07	3.93E-07	0.0
9	CS-137	4.37E-02	4.90E-02	4.37E-02	1.11E-01	1.24E-02	8.18E-02	8.18E-02	0.0
	SUB TOTAL	6.56E-02	6.21E-02	6.56E-02	1.11E-01	1.24E-02	1.17E 00	1.17E 00	5.77E-08
10	PB-210	6.95E-12	1.32E-13	6.95E-12	6.40E-11	0.0	6.81E-10	6.81E-10	0.0
11	RA-225	1.72E-08	4.05E-09	1.72E-08	1.07E-10	0.0	1.19E-07	1.19E-07	0.0
12	RA-226	5.14E-09	1.07E-11	5.14E-09	9.51E-13	0.0	6.12E-08	6.12E-08	0.0
13	TH-229	5.89E-10	8.62E-10	5.89E-10	2.53E-10	0.0	3.87E-08	3.87E-08	0.0
14	TH-230	5.30E-11	4.48E-11	5.30E-11	1.09E-10	0.0	1.92E-09	1.92E-09	0.0
15	NP-237	1.98E-06	2.02E-07	1.06E-06	2.90E-05	0.0	7.24E-05	7.24E-05	0.0
16	NP-239	8.65E-12	2.37E-06	8.65E-12	1.36E-11	0.0	1.32E-10	1.32E-10	0.0
17	PU-238	5.40E-05	2.00E-04	3.27E-05	8.05E-04	0.0	1.88E-03	1.88E-03	0.0
18	PU-239	4.80E-07	1.51E-06	2.59E-07	6.99E-06	0.0	1.75E-05	1.75E-05	0.0
19	PU-240	9.37E-06	2.96E-05	5.07E-06	1.37E-04	0.0	3.43E-04	3.43E-04	0.0
20	PU-241	5.22E-08	3.53E-07	4.96E-08	3.60E-07	0.0	2.18E-06	2.18E-06	0.0
21	AM-241	2.27E-03	2.09E-04	1.26E-03	3.32E-02	0.0	7.97E-02	7.97E-02	0.0
22	AM-242M	1.59E-04	5.02E-06	8.60E-05	2.21E-03	0.0	5.67E-03	5.67E-03	0.0
23	AM-243	5.05E-04	4.63E-05	2.72E-04	7.31E-03	0.0	1.79E-02	1.79E-02	0.0
24	CM-242	2.40E-06	1.71E-05	2.12E-06	3.53E-05	0.0	7.58E-05	7.58E-05	0.0
25	CM-244	2.34E-03	4.92E-04	1.90E-03	3.65E-02	0.0	7.91E-02	7.91E-02	0.0
	SUB TOTAL	5.35E-03	1.00E-03	3.56E-03	8.03E-02	0.0	1.85E-01	1.85E-01	0.0
	TOTAL	7.09E-02	6.31E-02	6.92E-02	1.91E-01	1.24E-02	1.36E 00	1.36E 00	5.77E-08

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table L-3. (Continued)

AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MAMIN, IN MANREMS/YEAR

1000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	5.35E-07	9.12E-06	1.78E-07	5.35E-07	5.35E-07	2.67E-06	2.67E-06	5.35E-07
2	SR-90	5.74E-11	1.65E-11	5.74E-11	0.0	0.0	2.87E-09	2.87E-09	0.0
3	Y-90	2.80E-16	1.09E-10	2.80E-16	0.0	0.0	1.05E-14	1.05E-14	0.0
4	ZR-93	1.13E-09	2.52E-06	1.13E-09	2.43E-09	0.0	4.35E-08	4.35E-08	0.0
5	NB-93M	1.75E-08	4.15E-05	1.75E-08	7.13E-08	0.0	2.18E-07	2.18E-07	0.0
6	TC-99	5.35E-06	1.04E-03	5.35E-06	1.99E-05	1.69E-06	1.35E-05	1.35E-05	0.0
7	I-129	1.36E-10	1.83E-10	1.36E-10	5.31E-11	0.0	6.17E-11	6.17E-11	9.76E-08
8	CS-135	1.73E-06	2.10E-06	1.73E-06	3.89E-06	4.43E-07	4.22E-06	4.22E-06	0.0
9	CS-137	2.48E-09	2.78E-09	2.48E-09	6.30E-09	7.04E-10	4.64E-09	4.64E-09	0.0
	SUB TOTAL	7.63E-06	1.09E-03	7.27E-06	2.44E-05	2.67E-06	2.06E-05	2.06E-05	6.33E-07
10	PB-210	6.48E-09	1.23E-10	6.48E-09	5.98E-08	0.0	6.36E-07	6.36E-07	0.0
11	RA-225	2.34E-06	5.50E-07	2.34E-06	1.46E-08	0.0	1.62E-05	1.62E-05	0.0
12	RA-226	8.58E-06	1.78E-08	8.58E-06	1.59E-09	0.0	1.02E-04	1.02E-04	0.0
13	TH-229	8.50E-09	1.24E-08	8.50E-09	3.64E-09	0.0	5.58E-07	5.58E-07	0.0
14	TH-230	1.72E-09	1.46E-09	1.72E-09	3.54E-09	0.0	6.24E-08	6.24E-08	0.0
15	NP-237	3.05E-06	3.11E-07	1.64E-06	4.47E-05	0.0	1.12E-04	1.12E-04	0.0
16	NP-239	2.35E-11	6.46E-06	2.35E-11	3.70E-11	0.0	3.60E-10	3.60E-10	0.0
17	PU-238	2.27E-07	8.40E-07	1.38E-07	3.39E-06	0.0	7.92E-06	7.92E-06	0.0
18	PU-239	8.24E-07	2.59E-06	4.44E-07	1.20E-05	0.0	3.00E-05	3.00E-05	0.0
19	PU-240	9.26E-06	2.92E-05	5.01E-06	1.36E-04	0.0	3.39E-04	3.39E-04	0.0
20	PU-241	1.11E-08	7.52E-08	1.06E-08	7.67E-08	0.0	4.65E-07	4.65E-07	0.0
21	AM-241	8.14E-04	7.48E-05	4.51E-04	1.19E-02	0.0	2.85E-02	2.85E-02	0.0
22	AM-242M	4.32E-06	1.36E-07	2.33E-06	5.98E-05	0.0	1.54E-04	1.54E-04	0.0
23	AM-243	6.22E-04	5.71E-05	3.35E-04	9.00E-03	0.0	2.21E-02	2.21E-02	0.0
24	CM-242	6.62E-08	4.72E-07	5.84E-08	9.74E-07	0.0	2.09E-06	2.09E-06	0.0
25	CM-244	8.12E-17	1.71E-17	6.59E-17	1.27E-15	0.0	2.74E-15	2.74E-15	0.0
	SUB TOTAL	1.46E-03	1.73E-04	8.07E-04	2.12E-02	0.0	5.14E-02	5.14E-02	0.0
	TOTAL	1.47E-03	1.26E-03	8.14E-04	2.12E-02	2.67E-06	5.14E-02	5.14E-02	6.33E-07

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table L-3. (Continued)

AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MANIN, IN MANREMS/YEAR

10000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	1.72E-06	2.93E-05	5.71E-07	1.72E-06	1.72E-06	8.58E-06	8.58E-06	1.72E-06
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	1.02E-08	2.26E-05	1.02E-08	2.16E-08	0.0	3.90E-07	3.90E-07	0.0
5	NB-93M	1.62E-07	3.83E-04	1.62E-07	6.58E-07	0.0	2.01E-06	2.01E-06	0.0
6	TC-99	1.27E-02	2.47E 00	1.27E-02	4.74E-02	4.03E-03	3.21E-02	3.21E-02	0.0
7	I-129	4.16E-08	5.59E-08	4.16E-08	1.62E-08	0.0	1.88E-08	1.88E-08	2.98E-05
8	CS-135	1.60E-05	1.93E-05	1.60E-05	3.59E-05	4.09E-06	3.89E-05	3.89E-05	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.28E-02	2.47E 00	1.28E-02	4.75E-02	4.03E-03	3.22E-02	3.22E-02	3.15E-05
10	PB-210	2.57E-06	4.89E-08	2.57E-06	2.37E-05	0.0	2.52E-04	2.52E-04	0.0
11	RA-225	2.05E-04	4.82E-05	2.05E-04	1.28E-06	0.0	1.42E-03	1.42E-03	0.0
12	RA-226	4.07E-03	8.47E-06	4.07E-03	7.53E-07	0.0	4.84E-02	4.84E-02	0.0
13	TH-229	2.60E-07	3.81E-07	2.60E-07	1.12E-07	0.0	1.71E-05	1.71E-05	0.0
14	TH-230	6.19E-08	5.24E-08	6.19E-08	1.27E-07	0.0	2.24E-06	2.24E-06	0.0
15	NP-237	1.05E-05	1.07E-06	5.65E-06	1.54E-04	0.0	3.85E-04	3.85E-04	0.0
16	NP-239	7.46E-11	2.05E-05	7.46E-11	1.17E-10	0.0	1.14E-09	1.14E-09	0.0
17	PU-238	7.95E-24	2.94E-23	4.82E-24	1.19E-22	0.0	2.77E-22	2.77E-22	0.0
18	PU-239	3.43E-06	1.08E-05	1.85E-06	5.00E-05	0.0	1.25E-04	1.25E-04	0.0
19	PU-240	4.94E-06	1.56E-05	2.67E-06	7.22E-05	0.0	1.81E-04	1.81E-04	0.0
20	PU-241	6.97E-09	4.71E-08	6.63E-09	4.81E-08	0.0	2.92E-07	2.92E-07	0.0
21	AM-241	5.78E-05	5.31E-06	3.20E-05	8.45E-04	0.0	2.03E-03	2.03E-03	0.0
22	AM-242M	5.26E-22	1.66E-23	2.84E-22	7.28E-21	0.0	1.87E-20	1.87E-20	0.0
23	AM-243	9.29E-04	8.53E-05	5.01E-04	1.34E-02	0.0	3.29E-02	3.29E-02	0.0
24	CM-242	8.41E-24	6.00E-23	7.42E-24	1.24E-22	0.0	2.66E-22	2.66E-22	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	5.28E-03	1.96E-04	4.82E-03	1.46E-02	0.0	8.58E-02	8.58E-02	0.0
	TOTAL	1.81E-02	2.47E 00	1.76E-02	6.21E-02	4.03E-03	1.18E-01	1.18E-01	3.15E-05

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table L-3. (Continued)

AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MANIN, IN MANREMS/YEAR

100000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	1.70E-10	2.89E-09	5.63E-11	1.70E-10	1.70E-10	8.46E-10	8.46E-10	1.70E-10
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	4.76E-08	1.06E-04	4.76E-08	1.02E-07	0.0	1.83E-06	1.83E-06	0.0
5	NB-93M	7.59E-07	1.80E-03	7.59E-07	3.09E-06	0.0	9.44E-06	9.44E-06	0.0
6	TC-99	2.82E-01	5.47E 01	2.82E-01	1.05E 00	8.91E-02	7.11E-01	7.11E-01	0.0
7	I-129	8.51E-06	1.14E-05	8.51E-06	3.31E-06	0.0	3.85E-06	3.85E-06	6.09E-03
8	CS-135	7.93E-05	9.62E-05	7.93E-05	1.79E-04	2.03E-05	1.93E-04	1.93E-04	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	2.82E-01	5.47E 01	2.82E-01	1.05E 00	8.91E-02	7.11E-01	7.11E-01	6.09E-03
10	PB-210	1.06E-04	2.01E-06	1.06E-04	9.75E-04	0.0	1.04E-02	1.04E-02	0.0
11	RA-225	7.75E-03	1.82E-03	7.75E-03	4.83E-05	0.0	5.37E-02	5.37E-02	0.0
12	RA-226	1.67E-01	3.48E-04	1.67E-01	3.09E-05	0.0	1.99E 00	1.99E 00	0.0
13	TH-229	7.96E-06	1.16E-05	7.96E-06	3.41E-06	0.0	5.23E-04	5.23E-04	0.0
14	TH-230	1.56E-06	1.32E-06	1.56E-06	3.21E-06	0.0	5.66E-05	5.66E-05	0.0
15	NP-237	4.19E-05	4.27E-06	2.24E-05	6.14E-04	0.0	1.53E-03	1.53E-03	0.0
16	NP-239	1.28E-13	3.51E-08	1.28E-13	2.01E-13	0.0	1.95E-12	1.95E-12	0.0
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	1.28E-06	4.03E-06	6.91E-07	1.87E-05	0.0	4.67E-05	4.67E-05	0.0
19	PU-240	1.62E-05	5.13E-09	8.80E-10	2.38E-08	0.0	5.94E-08	5.94E-08	0.0
20	PU-241	1.20E-11	8.13E-11	1.14E-11	8.30E-11	0.0	5.03E-10	5.03E-10	0.0
21	AM-241	2.02E-07	1.85E-08	1.12E-07	2.95E-06	0.0	7.07E-06	7.07E-06	0.0
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	1.61E-06	1.48E-07	8.69E-07	2.33E-05	0.0	5.72E-05	5.72E-05	0.0
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.75E-01	2.20E-03	1.75E-01	1.72E-03	0.0	2.05E 00	2.05E 00	0.0
	TOTAL	4.57E-01	5.47E 01	4.57E-01	1.05E 00	8.91E-02	2.76E 00	2.76E 00	6.09E-03

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table L-3. (Continued)

AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MANIN, IN MANREMS/YEAR

1000000. YEARS*

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	8.19E-08	1.83E-04	8.19E-08	1.76E-07	0.0	3.15E-06	3.15E-06	0.0
5	NB-93M	1.31E-06	3.10E-03	1.31E-06	5.32E-06	0.0	1.63E-05	1.63E-05	0.0
6	TC-99	7.18E-02	1.39E 01	7.18E-02	2.67E-01	2.27E-02	1.81E-01	1.81E-01	0.0
7	I-129	4.08E-05	5.48E-05	4.08E-05	1.59E-05	0.0	1.85E-05	1.85E-05	2.92E-02
8	CS-135	1.90E-04	2.31E-04	1.90E-04	4.29E-04	4.88E-05	4.64E-04	4.64E-04	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	7.21E-02	1.39E 01	7.21E-02	2.68E-01	2.28E-02	1.82E-01	1.82E-01	2.92E-02
10	PB-210	6.86E-05	1.30E-06	6.86E-05	6.32E-04	0.0	6.72E-03	6.72E-03	0.0
11	RA-225	4.99E-02	1.17E-02	4.99E-02	3.11E-04	0.0	3.46E-01	3.46E-01	0.0
12	RA-226	1.02E-01	2.12E-04	1.02E-01	1.88E-05	0.0	1.21E 00	1.21E 00	0.0
13	TH-229	4.69E-05	6.85E-05	4.69E-05	2.01E-05	0.0	3.08E-03	3.03E-03	0.0
14	TH-230	8.73E-07	7.39E-07	8.73E-07	1.79E-06	0.0	3.16E-05	3.16E-05	0.0
15	NP-237	9.66E-01	9.86E-02	5.18E-01	1.42E 01	0.0	3.54E 01	3.54E 01	0.0
16	NP-239	1.28E-11	3.50E-06	1.28E-11	2.00E-11	0.0	1.95E-10	1.95E-10	0.0
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	5.51E-12	1.73E-11	2.97E-12	8.02E-11	0.0	2.01E-10	2.01E-10	0.0
19	PU-240	3.35E-14	1.06E-13	1.81E-14	4.90E-13	0.0	1.22E-12	1.22E-12	0.0
20	PU-241	1.18E-37	7.96E-37	1.12E-37	8.13E-37	0.0	4.93E-36	4.93E-36	0.0
21	AM-241	3.93E-33	3.62E-34	2.18E-33	5.76E-32	0.0	1.38E-31	1.38E-31	0.0
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	8.47E-10	7.77E-11	4.56E-10	1.23E-08	0.0	3.00E-08	3.00E-08	0.0
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.12E 00	1.11E-01	6.70E-01	1.42E 01	0.0	3.69E 01	3.69E 01	0.0
	TOTAL	1.19E 00	1.41E 01	7.42E-01	1.44E 01	2.28E-02	3.71E 01	3.71E 01	2.92E-02

*TIME SINCE START OF REPOSITORY OPERATIONS.

APPENDIX M

SUMMARY TABLES OF DOSE CALCULATION OUTPUT

CASE 32

Summary tables at selected times are given in Tables M-1 through M-3 from output Section 6 as follows for volcanic explosion release to air, Case 32.

1. Average Annual Local Dose to Individual, MAN1L, In Zone 1, mrem/y (Table M-1).
2. Average Annual Local Dose to Individual, MAN1L, in Zone 8, mrem/y (Table M-2).
3. Average Annual Nonspecific Dose to Population, MAN1N, man-rem/y (Table M-3).

Table M-1. Average Annual Local Dose to Individual, MANIL, In Zone 1, In Millirems/Year

1000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	1.98E-02	2.49E-01	6.63E-03	0.0	2.77E 00	1.05E-01	1.05E-01	0.0
2	SR-90	1.44E-03	2.87E-05	1.44E-03	0.0	7.84E-03	2.16E-02	2.16E-02	0.0
3	Y-90	9.32E-07	5.73E-05	9.32E-07	0.0	2.82E-05	3.43E-05	3.43E-05	0.0
4	ZR-93	1.35E-01	2.10E-01	1.35E-01	2.88E-01	2.10E 00	5.16E 00	5.16E 00	0.0
5	NB-93M	2.47E-01	3.03E-01	2.47E-01	1.00E 00	3.09E 00	3.08E 00	3.08E 00	0.0
6	TC-99	9.43E-03	5.37E 00	9.43E-03	3.50E-02	7.62E 01	9.28E-02	9.28E-02	0.0
7	I-129	6.62E-03	1.39E-03	9.10E-03	2.50E-03	4.59E-03	1.08E-02	1.01E-02	2.23E-02
8	CS-135	1.05E-01	9.31E-02	1.05E-01	2.20E-01	2.74E-02	2.55E-01	2.55E-01	0.0
9	CS-137	1.87E-04	1.24E-04	1.87E-04	2.96E-04	1.69E-02	2.17E-04	2.17E-04	0.0
	SUB TOTAL	5.25E-01	6.23E 00	5.14E-01	1.55E 00	8.43E 01	8.72E 00	8.72E 00	2.23E-02
10	PB-210	6.68E-02	5.98E-03	6.46E-02	4.84E-01	9.84E 00	5.10E 00	5.09E 00	1.23E-02
11	RA-225	2.27E-02	2.79E-02	2.27E-02	1.44E-04	3.02E 00	1.54E-01	1.54E-01	0.0
12	RA-226	6.47E-01	4.71E-03	6.49E-01	4.70E-03	1.88E 00	7.63E 00	7.63E 00	6.00E-03
13	TH-229	4.90E 01	3.24E-02	4.90E 01	2.05E 01	4.30E 02	3.13E 03	3.13E 03	0.0
14	TH-230	1.81E 01	1.28E-02	1.81E 01	2.99E 01	6.09E 01	6.74E 02	6.74E 02	1.77E-02
15	NP-237	1.81E 03	7.32E 01	1.03E 03	2.46E 04	1.62E 04	6.23E 04	6.23E 04	1.27E 02
16	NP-239	3.86E 04	2.55E 04	4.50E 04	2.90E 04	3.34E 04	6.23E 04	6.22E 04	4.05E 04
17	PU-238	5.61E 03	3.91E 00	3.40E 03	8.35E 04	6.62E 04	1.95E 05	1.95E 05	1.46E 00
18	PU-239	2.02E 04	1.09E 01	1.09E 04	2.95E 05	1.92E 05	7.39E 05	7.39E 05	3.35E 00
19	PU-240	2.28E 05	1.36E 02	1.23E 05	3.33E 06	2.17E 06	8.32E 06	8.32E 06	5.19E 01
20	PU-241	2.73E 02	2.32E-01	2.60E 02	1.89E 03	9.65E 01	1.11E 04	1.11E 04	0.0
21	AM-241	4.67E 05	7.10E 03	2.63E 05	6.63E 06	4.52E 06	1.59E 07	1.59E 07	1.47E 04
22	AM-242M	2.40E 03	2.84E-01	1.30E 03	3.34E 04	9.71E 03	8.55E 04	8.55E 04	0.0
23	AM-243	3.56E 05	4.94E 03	1.94E 05	4.98E 06	3.27E 06	1.24E 07	1.24E 07	1.01E 04
24	CM-242	3.57E 01	1.34E 00	3.56E 01	6.59E 02	5.57E 03	1.23E 03	1.23E 03	3.19E-01
25	CM-244	4.61E-08	4.81E-10	3.68E-08	7.10E-07	1.01E-06	1.54E-06	1.54E-06	8.84E-10
	SUB TOTAL	1.12E 06	3.77E 04	6.42E 05	1.54E 07	1.03E 07	3.78E 07	3.78E 07	6.54E 04
	TOTAL	1.12E 06	3.77E 04	6.42E 05	1.54E 07	1.03E 07	3.78E 07	3.78E 07	6.54E 04

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table M-1. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 1, IN MILLIREMS/YEAR

10000. YEARS#

K	NUCLIDE	TOT.BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	4.41E-03	5.55E-02	1.48E-03	0.0	6.17E-01	2.35E-02	2.35E-02	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	8.41E-02	1.31E-01	8.41E-02	1.79E-01	1.31E 00	3.21E 00	3.21E 00	0.0
5	NB-93M	1.54E-01	1.88E-01	1.54E-01	6.23E-01	1.92E 00	1.91E 00	1.91E 00	0.0
6	TC-99	5.75E-03	3.28E 00	5.75E-03	2.14E-02	4.65E 01	5.66E-02	5.66E-02	0.0
7	I-129	5.44E-03	1.14E-03	7.48E-03	2.05E-03	3.53E-03	8.89E-03	8.27E-03	1.53E-02
8	CS-135	6.54E-02	5.82E-02	6.54E-02	1.37E-01	1.71E-02	1.59E-01	1.59E-01	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	3.19E-01	3.71E 00	3.18E-01	9.63E-01	5.03E 01	5.37E 00	5.37E 00	1.53E-02
10	PB-210	2.32E 00	2.54E-01	2.23E 00	1.53E 01	3.20E 02	1.66E 02	1.66E 02	5.23E-01
11	RA-225	1.33E-01	1.64E-01	1.33E-01	8.45E-04	1.77E 01	9.05E-01	9.05E-01	0.0
12	RA-226	2.10E 01	1.95E-01	2.11E 01	1.99E-01	6.08E 01	2.47E 02	2.47E 02	2.55E-01
13	TH-229	2.91E 02	1.91E-01	2.91E 02	1.21E 02	2.54E 03	1.84E 04	1.84E 04	0.0
14	TH-230	1.25E 02	1.09E-01	1.25E 02	2.07E 02	4.21E 02	4.66E 03	4.66E 03	1.60E-01
15	NP-237	1.22E 03	6.37E 01	7.09E 02	1.63E 04	1.08E 04	4.15E 04	4.15E 04	1.11E 02
16	NP-239	1.46E 04	9.60E 03	1.69E 04	1.09E 04	1.26E 04	2.35E 04	2.34E 04	1.53E 04
17	PU-238	9.60E-14	7.13E-17	5.82E-14	1.43E-12	1.13E-12	3.34E-12	3.34E-12	3.28E-17
18	PU-239	4.12E 04	2.32E 01	2.22E 04	6.01E 05	3.92E 05	1.51E 06	1.51E 06	8.95E 00
19	PU-240	5.95E 04	3.78E 01	3.22E 04	8.68E 05	5.67E 05	2.17E 06	2.17E 06	1.78E 01
20	PU-241	8.38E 01	7.12E-02	7.98E 01	5.79E 02	2.96E 01	3.41E 03	3.41E 03	0.0
21	AM-241	6.45E 03	1.26E 02	3.65E 03	9.06E 04	6.18E 04	2.17E 05	2.17E 05	2.63E 02
22	AM-242M	5.63E-14	6.65E-18	3.05E-14	7.83E-13	2.27E-13	2.00E-12	2.00E-12	0.0
23	AM-243	1.03E 05	1.85E 03	5.64E 04	1.43E 06	9.40E 05	3.56E 06	3.56E 06	3.90E 03
24	CM-242	8.57E-16	3.28E-17	8.50E-16	1.55E-14	1.31E-13	2.89E-14	2.89E-14	9.31E-18
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	2.27E 05	1.17E 04	1.33E 05	3.02E 06	1.99E 06	7.55E 06	7.55E 06	1.95E 04
	TOTAL	2.27E 05	1.17E 04	1.33E 05	3.02E 06	1.99E 06	7.55E 06	7.55E 06	1.95E 04

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table M-1. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 1, IN MILLIREMS/YEAR

100000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	2.23E-08	2.80E-07	7.46E-09	0.0	3.12E-06	1.19E-07	1.19E-07	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	1.14E-02	1.77E-02	1.14E-02	2.42E-02	1.77E-01	4.33E-01	4.33E-01	0.0
5	NB-93M	2.07E-02	2.54E-02	2.07E-02	8.39E-02	2.58E-01	2.58E-01	2.58E-01	0.0
6	TC-99	6.08E-04	3.46E-01	6.08E-04	2.26E-03	4.91E 00	5.98E-03	5.93E-03	0.0
7	I-129	7.58E-04	1.59E-04	1.04E-03	2.80E-04	4.92E-04	1.24E-03	1.15E-03	2.14E-03
8	CS-135	8.98E-03	7.99E-03	8.98E-03	1.83E-02	2.35E-03	2.18E-02	2.18E-02	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	4.24E-02	3.97E-01	4.27E-02	1.30E-01	5.35E 00	7.20E-01	7.20E-01	2.14E-03
10	PB-210	2.69E 00	2.95E-01	2.58E 00	1.84E 01	3.72E 02	1.93E 02	1.93E 02	6.07E-01
11	RA-228	1.42E-01	1.74E-01	1.42E-01	9.01E-04	1.89E 01	9.65E-01	9.65E-01	0.0
12	RA-226	2.44E 01	2.26E-01	2.44E 01	2.31E-01	7.04E 01	2.86E 02	2.86E 02	2.95E-01
13	TH-229	3.10E 02	2.04E-01	3.10E 02	1.29E 02	2.70E 03	1.96E 04	1.96E 04	0.0
14	TH-230	1.10E 02	9.61E-02	1.10E 02	1.82E 02	3.71E 02	4.10E 03	4.10E 03	1.41E-01
15	NP-237	1.70E 02	8.82E 00	9.83E 01	2.27E 03	1.50E 03	5.75E 03	5.75E 03	1.53E 01
16	NP-239	8.81E-01	5.81E-01	1.03E 00	6.62E-01	7.61E-01	1.42E 00	1.42E 00	9.23E-01
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	1.10E 03	6.18E-01	5.92E 02	1.60E 04	1.04E 04	4.01E 04	4.01E 04	2.36E-01
19	PU-240	1.39E 00	8.85E-04	7.54E-01	2.03E 01	1.33E 01	5.09E 01	5.09E 01	4.16E-04
20	PU-241	1.03E-02	8.73E-06	9.79E-03	7.10E-02	3.63E-03	4.18E-01	4.18E-01	0.0
21	AM-241	7.85E-01	1.54E-02	4.44E-01	1.10E 01	7.52E 00	2.64E 01	2.64E 01	3.20E-02
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	6.25E 00	1.12E-01	3.41E 00	8.67E 01	5.69E 01	2.16E 02	2.16E 02	2.30E-01
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.72E 03	1.11E 01	1.14E 03	1.87E 04	1.56E 04	7.04E 04	7.04E 04	1.78E 01
	TOTAL	1.72E 03	1.15E 01	1.14E 03	1.87E 04	1.56E 04	7.04E 04	7.04E 04	1.78E 01

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table M-1. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 1, IN MILLIREMS/YEAR

1000000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	2.20E-11	3.42E-11	2.20E-11	4.09E-11	3.42E-10	8.38E-10	8.38E-10	0.0
5	NB-93M	4.00E-11	4.90E-11	4.00E-11	1.62E-10	4.99E-10	4.98E-10	4.98E-10	0.0
6	TC-99	1.07E-13	6.08E-11	1.07E-13	3.96E-13	8.62E-10	1.05E-12	1.05E-12	0.0
7	I-129	2.11E-12	4.41E-13	2.90E-12	7.96E-13	1.37E-12	3.45E-12	3.21E-12	5.95E-12
8	CS-135	2.12E-11	1.89E-11	2.12E-11	4.45E-11	5.55E-12	5.16E-11	5.16E-11	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	8.54E-11	1.63E-10	8.62E-11	2.55E-10	1.71E-09	1.39E-09	1.39E-09	5.95E-12
10	PB-210	1.73E-09	1.90E-10	1.66E-09	1.18E-08	2.39E-07	1.24E-07	1.24E-07	3.90E-10
11	RA-225	9.62E-10	1.18E-09	9.62E-10	6.11E-12	1.28E-07	6.54E-09	6.54E-09	0.0
12	RA-226	1.56E-08	1.45E-10	1.57E-08	1.48E-10	4.52E-08	1.84E-07	1.84E-07	1.89E-10
13	TH-229	2.10E-06	1.38E-09	2.10E-06	8.75E-07	1.83E-05	1.33E-04	1.33E-04	0.0
14	TH-230	7.10E-08	6.18E-11	7.10E-08	1.17E-07	2.38E-07	2.64E-06	2.64E-06	9.07E-11
15	NP-237	3.72E-07	1.93E-08	2.15E-07	4.96E-06	3.28E-06	1.26E-05	1.26E-05	3.36E-08
16	NP-239	5.47E-13	3.61E-13	6.37E-13	4.11E-13	4.73E-13	8.84E-13	8.82E-13	5.74E-13
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	6.64E-12	3.75E-15	3.59E-12	9.69E-11	6.33E-11	2.43E-10	2.43E-10	1.44E-15
19	PU-240	4.05E-14	2.57E-17	2.19E-14	5.92E-13	3.86E-13	1.48E-12	1.48E-12	1.21E-17
20	PU-241	2.00E-34	1.70E-37	1.90E-34	1.38E-33	7.05E-35	8.13E-33	8.13E-33	0.0
21	AM-241	1.90E-32	3.73E-34	1.08E-32	2.67E-31	1.82E-31	6.41E-31	6.41E-31	7.75E-34
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	3.78E-12	6.76E-14	2.06E-12	5.24E-11	3.44E-11	1.30E-10	1.30E-10	1.39E-13
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	2.56E-06	2.23E-08	2.41E-06	5.97E-06	2.23E-05	1.49E-04	1.49E-04	3.42E-08
	TOTAL	2.56E-06	2.24E-08	2.41E-06	5.97E-06	2.23E-05	1.49E-04	1.49E-04	3.42E-08

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table M-2. Average Annual Local Dose to Individual, MAN1L, in Zone 8, In Millirems/Year

1000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	7.19E-03	1.22E-01	2.39E-03	7.13E-03	1.53E-02	3.59E-02	3.59E-02	7.13E-03
2	SR-90	4.06E-05	1.06E-05	4.08E-05	0.0	2.31E-05	1.89E-03	1.89E-03	0.0
3	Y-90	2.80E-09	2.11E-05	2.80E-09	0.0	8.32E-08	1.03E-07	1.03E-07	0.0
4	ZR-93	4.28E-04	6.51E-02	4.28E-04	9.12E-04	6.20E-03	1.63E-02	1.63E-02	0.0
5	NB-93M	7.84E-04	1.30E-01	7.84E-04	3.18E-03	9.11E-03	9.76E-03	9.76E-03	0.0
6	TC-99	1.02E-02	1.98E 00	1.02E-02	3.76E-02	2.28E-01	2.58E-02	2.58E-02	0.0
7	I-129	2.69E-05	1.17E-05	3.49E-05	1.02E-05	1.45E-05	3.76E-05	3.51E-05	3.90E-03
8	CS-135	3.78E-02	4.57E-02	3.78E-02	8.49E-02	9.68E-03	9.20E-02	9.20E-02	0.0
9	CS-137	5.43E-05	6.06E-05	5.43E-05	1.37E-04	6.50E-05	1.01E-04	1.01E-04	0.0
	SUB TOTAL	5.64E-02	2.34E 00	5.16E-02	1.34E-01	2.68E-01	1.82E-01	1.82E-01	1.10E-02
10	PB-210	2.30E-03	5.94E-05	2.30E-03	2.08E-02	2.90E-02	2.21E-01	2.21E-01	3.98E-05
11	RA-225	3.59E-02	8.53E-03	3.59E-02	2.24E-04	8.91E-03	2.49E-01	2.49E-01	0.0
12	RA-226	1.31E-01	2.84E-04	1.31E-01	3.91E-05	5.53E-03	1.56E 00	1.56E 00	1.95E-05
13	TH-229	1.54E-01	1.41E-02	1.54E-01	6.46E-02	1.27E 00	9.84E 00	9.84E 00	0.0
14	TH-230	5.54E-02	1.69E-03	5.54E-02	9.21E-02	1.80E-01	2.06E 00	2.06E 00	5.74E-05
15	NP-237	8.80E 00	5.89E-01	4.92E 00	1.23E 02	4.79E 01	3.10E 02	3.10E 02	4.12E-01
16	NP-239	1.25E 02	1.02E 02	1.46E 02	9.42E 01	1.08E 02	2.02E 02	2.02E 02	1.31E 02
17	PU-238	1.69E 01	1.27E 00	1.02E 01	2.51E 02	1.95E 02	5.87E 02	5.87E 02	4.73E-03
18	PU-239	6.08E 01	3.91E 00	3.28E 01	8.86E 02	5.67E 02	2.22E 03	2.22E 03	1.09E-02
19	PU-240	6.86E 02	4.42E 01	3.71E 02	1.00E 04	6.41E 03	2.50E 04	2.50E 04	1.69E-01
20	PU-241	8.22E-01	1.14E-01	7.83E-01	5.68E 00	2.85E-01	3.35E 01	3.35E 01	0.0
21	AM-241	2.30E 03	1.08E 02	1.29E 03	3.30E 04	1.33E 04	7.91E 04	7.91E 04	4.76E 01
22	AM-242M	1.20E 01	1.55E-01	6.48E 00	1.66E 02	2.86E 01	4.26E 02	4.26E 02	0.0
23	AM-243	1.75E 03	8.05E 01	9.52E 02	2.49E 04	9.63E 03	6.14E 04	6.14E 04	3.27E 01
24	CM-242	1.65E-01	5.70E-01	1.76E-01	3.11E 00	1.64E 01	6.15E 00	6.15E 00	1.04E-03
25	CM-244	2.26E-10	2.09E-11	1.84E-10	3.53E-09	2.98E-09	7.65E-09	7.65E-09	2.87E-12
	SUB TOTAL	4.97E 03	3.41E 02	2.81E 03	6.94E 04	3.03E 04	1.69E 05	1.69E 05	2.12E 02
	TOTAL	4.97E 03	3.43E 02	2.81E 03	6.94E 04	3.03E 04	1.69E 05	1.69E 05	2.12E 02

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table M-2. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 8, IN MILLIREMS/YEAR

10000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	1.90E-05	2.59E-04	6.37E-06	4.07E-06	2.10E-03	1.00E-04	1.00E-04	4.07E-06
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	2.86E-04	5.47E-04	2.86E-04	6.10E-04	4.45E-03	1.09E-02	1.09E-02	0.0
5	NB-93M	5.22E-04	8.46E-04	5.22E-04	2.12E-03	6.52E-03	6.50E-03	6.50E-03	0.0
6	TC-99	3.54E-05	1.42E-02	3.54E-05	1.31E-04	1.58E-01	2.32E-04	2.32E-04	0.0
7	I-129	1.85E-05	3.88E-06	2.54E-05	6.98E-06	1.20E-05	3.02E-05	2.81E-05	5.82E-05
8	CS-135	2.82E-04	2.71E-04	2.82E-04	6.02E-04	7.36E-05	6.88E-04	6.88E-04	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.16E-03	1.61E-02	1.16E-03	3.47E-03	1.71E-01	1.85E-02	1.84E-02	6.23E-05
10	PB-210	8.07E-03	8.68E-04	7.75E-03	5.54E-02	1.09E 00	5.82E-01	5.82E-01	1.78E-03
11	RA-225	9.92E-04	6.83E-04	9.92E-04	6.23E-06	6.03E-02	6.81E-03	6.81E-03	0.0
12	RA-226	8.22E-02	6.84E-04	8.24E-02	6.60E-04	2.07E-01	9.67E-01	9.67E-01	8.66E-04
13	TH-229	9.90E-01	8.62E-04	9.90E-01	4.12E-01	8.63E 00	6.27E 01	6.27E 01	0.0
14	TH-230	4.26E-01	4.00E-04	4.26E-01	7.03E-01	1.43E 00	1.58E 01	1.58E 01	5.45E-04
15	NP-237	4.17E 00	2.17E-01	2.41E 00	5.57E 01	3.68E 01	1.41E 02	1.41E 02	3.76E-01
16	NP-239	4.95E 01	3.26E 01	5.76E 01	3.72E 01	4.27E 01	7.99E 01	7.97E 01	5.19E 01
17	PU-238	3.27E-16	2.98E-19	1.98E-16	4.86E-15	3.85E-15	1.14E-14	1.14E-14	1.11E-19
18	PU-239	1.40E 02	9.92E-02	7.56E 01	2.04E 03	1.33E 03	5.12E 03	5.12E 03	3.04E-02
19	PU-240	2.02E 02	1.58E-01	1.09E 02	2.95E 03	1.93E 03	7.38E 03	7.38E 03	6.04E-02
20	PU-241	2.85E-01	3.31E-04	2.71E-01	1.97E 00	1.01E-01	1.16E 01	1.16E 01	0.0
21	AM-241	2.20E 01	4.33E-01	1.24E 01	3.08E 02	2.10E 02	7.40E 02	7.40E 02	8.93E-01
22	AM-242M	1.92E-16	3.18E-20	1.04E-16	2.67E-15	7.73E-16	6.81E-15	6.81E-15	0.0
23	AM-243	3.52E 02	6.33E 00	1.92E 02	4.88E 03	3.20E 03	1.21E 04	1.21E 04	1.29E 01
24	CM-242	2.92E-18	1.46E-19	2.89E-18	5.26E-17	4.44E-16	9.85E-17	9.85E-17	3.34E-20
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	7.71E 02	3.99E 01	4.51E 02	1.03E 04	6.76E 03	2.57E 04	2.57E 04	6.51E 01
	TOTAL	7.71E 02	3.99E 01	4.51E 02	1.03E 04	6.76E 03	2.57E 04	2.57E 04	6.61E 01

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table M-2. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 8, IN MILLIREMS/YEAR

100000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	7.57E-11	9.54E-10	2.54E-11	4.01E-14	1.06E-08	4.04E-10	4.04E-10	4.01E-14
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	3.87E-05	6.01E-05	3.87E-05	8.24E-05	6.01E-04	1.47E-03	1.47E-03	0.0
5	NB-93M	7.04E-05	8.62E-05	7.04E-05	2.85E-04	8.79E-04	8.76E-04	8.75E-04	0.0
6	TC-99	2.07E-06	1.18E-03	2.07E-06	7.68E-06	1.67E-02	2.03E-05	2.03E-05	0.0
7	I-129	2.58E-06	5.39E-07	3.54E-06	9.72E-07	1.67E-06	4.22E-06	3.92E-06	7.27E-06
8	CS-135	3.05E-05	2.72E-05	3.05E-05	6.41E-05	7.99E-06	7.43E-05	7.43E-05	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.44E-04	1.35E-03	1.45E-04	4.41E-04	1.82E-02	2.45E-03	2.45E-03	7.27E-06
10	PB-210	9.16E-03	1.00E-03	8.78E-03	6.24E-02	1.26E 00	6.56E-01	6.55E-01	2.06E-03
11	RA-225	4.83E-04	5.93E-04	4.83E-04	3.07E-06	6.43E-02	3.29E-03	3.29E-03	0.0
12	RA-226	8.28E-02	7.67E-04	8.31E-02	7.86E-04	2.59E-01	9.74E-01	9.74E-01	1.00E-03
13	TH-229	1.05E 00	6.93E-04	1.05E 00	4.39E-01	9.19E 00	6.68E 01	6.68E 01	0.0
14	TH-230	3.75E-01	3.27E-04	3.75E-01	6.18E-01	1.26E 00	1.40E 01	1.40E 01	4.80E-04
15	NP-237	5.77E-01	3.00E-02	3.34E-01	7.70E 00	5.10E 00	1.95E 01	1.95E 01	5.21E-02
16	NP-239	3.00E-03	1.98E-03	3.49E-03	2.25E-03	2.59E-03	4.84E-03	4.82E-03	3.14E-03
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	3.73E 00	2.10E-03	2.01E 00	5.44E 01	3.55E 01	1.36E 02	1.36E 02	8.10E-04
19	PU-240	4.74E-03	3.01E-06	2.56E-03	6.92E-02	4.52E-02	1.73E-01	1.73E-01	1.42E-06
20	PU-241	3.49E-05	2.97E-08	3.33E-05	2.41E-04	1.23E-05	1.42E-03	1.42E-03	0.0
21	AM-241	2.67E-03	5.23E-05	1.51E-03	3.75E-02	2.56E-02	8.99E-02	8.99E-02	1.09E-04
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	2.12E-02	3.80E-04	1.16E-02	2.95E-01	1.93E-01	7.33E-01	7.33E-01	7.92E-04
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	5.86E 00	3.79E-02	3.89E 00	6.36E 01	5.29E 01	2.39E 02	2.39E 02	6.05E-02
	TOTAL	5.86E 00	3.93E-02	3.89E 00	6.36E 01	5.29E 01	2.39E 02	2.39E 02	6.05E-02

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table M-2. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE B, IN MILLIREMS/YEAR

1000000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	7.48E-14	1.16E-13	7.48E-14	1.59E-13	1.16E-12	2.85E-12	2.85E-12	0.0
5	NB-93M	1.36E-13	1.67E-13	1.36E-13	5.51E-13	1.70E-12	1.69E-12	1.69E-12	0.0
6	TC-99	3.63E-16	2.07E-13	3.63E-16	1.35E-15	2.93E-12	3.57E-15	3.57E-15	0.0
7	I-129	7.17E-15	1.50E-15	9.86E-15	2.71E-15	4.65E-15	1.17E-14	1.09E-14	2.02E-14
8	CS-135	7.21E-14	6.41E-14	7.21E-14	1.51E-13	1.89E-14	1.75E-13	1.75E-13	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	2.90E-13	5.55E-13	2.93E-13	8.66E-13	5.82E-12	4.73E-12	4.73E-12	2.02E-14
10	PB-210	5.89E-12	6.45E-13	5.65E-12	4.01E-11	8.13E-10	4.21E-10	4.21E-10	1.33E-12
11	RA-225	3.27E-12	4.02E-12	3.27E-12	2.08E-14	4.36E-10	2.22E-11	2.22E-11	0.0
12	RA-226	5.32E-11	4.92E-13	5.33E-11	5.04E-13	1.54E-10	6.25E-10	6.25E-10	6.44E-13
13	TH-229	7.14E-09	4.69E-12	7.15E-09	2.97E-09	6.23E-08	4.53E-07	4.53E-07	0.0
14	TH-230	2.41E-10	2.10E-13	2.41E-10	3.98E-10	8.10E-10	8.97E-09	8.97E-09	3.08E-13
15	NP-237	1.26E-09	6.57E-11	7.32E-10	1.69E-08	1.12E-08	4.28E-08	4.28E-08	1.14E-10
16	NP-239	1.86E-15	1.23E-15	2.17E-15	1.40E-15	1.61E-15	3.00E-15	3.00E-15	1.95E-15
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	2.26E-14	1.27E-17	1.22E-14	3.30E-13	2.15E-13	8.26E-13	8.26E-13	4.91E-18
19	PU-240	1.38E-16	3.75E-20	7.45E-17	2.01E-15	1.31E-15	5.03E-15	5.03E-15	4.12E-20
20	PU-241	6.79E-37	5.77E-40	6.47E-37	4.69E-36	2.40E-37	2.76E-35	2.76E-35	0.0
21	AM-241	6.47E-35	1.27E-36	3.66E-35	9.09E-34	6.20E-34	2.18E-33	2.18E-33	2.63E-36
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	1.28E-14	2.30E-16	7.02E-15	1.78E-13	1.17E-13	4.43E-13	4.43E-13	4.73E-16
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	8.71E-09	7.58E-11	8.18E-09	2.03E-08	7.57E-08	5.06E-07	5.06E-07	1.16E-10
	TOTAL	8.71E-09	7.63E-11	8.18E-09	2.03E-08	7.57E-08	5.06E-07	5.06E-07	1.16E-10

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table M-3. Average Annual Nonspecific Dose to Population, MAN1N, In Man-rems/Year

1000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	3.06E 01	5.25E 02	1.02E 01	3.08E 01	3.08E 01	1.54E 02	1.54E 02	3.08E 01
2	SR-90	2.28E-02	6.54E-03	2.28E-02	0.0	0.0	1.14E 00	1.14E 00	0.0
3	Y-90	1.44E-08	5.63E-03	1.44E-08	0.0	0.0	5.39E-07	5.39E-07	0.0
4	ZR-93	7.21E-02	1.61E 02	7.21E-02	1.55E-01	0.0	2.77E 00	2.77E 00	0.0
5	NB-93M	8.16E-01	1.93E 03	8.16E-01	3.32E 00	0.0	1.01E 01	1.01E 01	0.0
6	TC-99	2.46E 02	4.77E 04	2.46E 02	9.15E 02	7.77E 01	6.20E 02	6.20E 02	0.0
7	I-129	1.49E-02	2.00E-02	1.49E-02	5.79E-03	0.0	6.74E-03	6.74E-03	1.07E 01
8	CS-135	1.38E 02	1.67E 02	1.38E 02	3.11E 02	3.54E 01	3.36E 02	3.36E 02	0.0
9	CS-137	1.95E-01	2.19E-01	1.95E-01	4.96E-01	5.55E-02	3.66E-01	3.66E-01	0.0
	SUB TOTAL	4.16E 02	5.05E 04	3.95E 02	1.26E 03	1.44E 02	1.12E 03	1.12E 03	4.14E 01
10	PB-210	1.16E 00	2.21E-02	1.16E 00	1.07E 01	0.0	1.14E 02	1.14E 02	0.0
11	RA-225	1.33E 02	3.14E 01	1.33E 02	8.30E-01	0.0	9.23E 02	9.23E 02	0.0
12	RA-226	5.86E 02	1.22E 00	5.86E 02	1.08E-01	0.0	6.97E 03	6.97E 03	0.0
13	TH-229	3.79E 00	5.55E 00	3.79E 00	1.63E 00	0.0	2.49E 02	2.49E 02	0.0
14	TH-230	7.70E-01	6.51E-01	7.70E-01	1.58E 00	0.0	2.79E 01	2.79E 01	0.0
15	NP-237	1.36E 03	1.39E 02	7.30E 02	2.00E 04	0.0	4.98E 04	4.98E 04	0.0
16	NP-239	4.74E-03	1.30E 03	4.74E-03	7.44E-03	0.0	7.24E-02	7.24E-02	0.0
17	PU-238	1.31E 02	4.84E 02	7.93E 01	1.95E 03	0.0	4.56E 03	4.56E 03	0.0
18	PU-239	4.75E 02	1.49E 03	2.56E 02	6.92E 03	0.0	1.73E 04	1.73E 04	0.0
19	PU-240	5.34E 03	1.68E 04	2.89E 03	7.81E 04	0.0	1.95E 05	1.95E 05	0.0
20	PU-241	6.41E 00	4.33E 01	6.09E 00	4.42E 01	0.0	2.68E 02	2.68E 02	0.0
21	AM-241	3.63E 05	3.34E 04	2.01E 05	5.31E 06	0.0	1.27E 07	1.27E 07	0.0
22	AM-242M	1.93E 03	6.06E 01	1.04E 03	2.67E 04	0.0	6.85E 04	6.85E 04	0.0
23	AM-243	2.78E 05	2.55E 04	1.50E 05	4.02E 06	0.0	9.85E 06	9.85E 06	0.0
24	CM-242	2.89E 01	2.06E 02	2.55E 01	4.26E 02	0.0	9.15E 02	9.15E 02	0.0
25	CM-244	3.62E-06	7.60E-09	2.94E-08	5.64E-07	0.0	1.22E-06	1.22E-06	0.0
	SUB TOTAL	6.51E 05	7.94E 04	3.56E 05	9.46E 06	0.0	2.29E 07	2.29E 07	0.0
	TOTAL	6.51E 05	1.30E 05	3.57E 05	9.46E 06	1.44E 02	2.29E 07	2.29E 07	4.14E 01

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table M-3. (Continued)

AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MANIN, IN MANREMS/YEAR

10000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	7.60E 00	1.30E 02	2.52E 00	7.60E 00	7.60E 00	3.79E 01	3.79E 01	7.60E 00
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	3.52E-02	7.84E 01	3.52E-02	7.55E-02	0.0	1.35E 00	1.35E 00	0.0
5	NB-93M	5.68E-01	1.34E 03	5.68E-01	2.31E 00	0.0	7.07E 00	7.07E 00	0.0
6	TC-99	1.81E 02	3.51E 04	1.81E 02	6.73E 02	5.72E 01	4.56E 02	4.56E 02	0.0
7	I-129	5.60E-03	7.52E-03	5.60E-03	2.18E-03	0.0	2.54E-03	2.54E-03	4.01E 00
8	CS-135	7.58E 01	9.19E 01	7.58E 01	1.71E 02	1.94E 01	1.85E 02	1.85E 02	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	2.65E 02	3.67E 04	2.60E 02	8.53E 02	8.42E 01	6.87E 02	6.87E 02	1.16E 01
10	PB-210	1.18E 01	2.24E-01	1.18E 01	1.09E 02	0.0	1.16E 03	1.16E 03	0.0
11	RA-225	8.34E 02	1.96E 02	8.34E 02	5.20E 00	0.0	5.77E 03	5.77E 03	0.0
12	RA-226	1.65E 04	3.44E 01	1.65E 04	3.06E 00	0.0	1.97E 05	1.97E 05	0.0
13	TH-229	7.23E-01	1.06E 00	7.23E-01	3.10E-01	0.0	4.75E 01	4.75E 01	0.0
14	TH-230	1.72E-01	1.45E-01	1.72E-01	3.53E-01	0.0	6.22E 00	6.22E 00	0.0
15	NP-237	2.92E 01	2.98E 00	1.57E 01	4.29E 02	0.0	1.07E 03	1.07E 03	0.0
16	NP-239	2.58E-04	7.09E 01	2.58E-04	4.06E-04	0.0	3.95E-03	3.95E-03	0.0
17	PU-238	7.63E-18	2.82E-17	4.62E-18	1.14E-16	0.0	2.66E-16	2.66E-16	0.0
18	PU-239	3.29E 00	1.03E 01	1.77E 00	4.79E 01	0.0	1.20E 02	1.20E 02	0.0
19	PU-240	4.73E 00	1.49E 01	2.56E 00	6.92E 01	0.0	1.73E 02	1.73E 02	0.0
20	PU-241	6.70E-03	4.53E-02	6.37E-03	4.62E-02	0.0	2.80E-01	2.80E-01	0.0
21	AM-241	1.60E 02	1.47E 01	3.88E 01	2.35E 03	0.0	5.63E 03	5.63E 03	0.0
22	AM-242M	1.46E-15	4.60E-17	7.88E-16	2.02E-14	0.0	5.19E-14	5.19E-14	0.0
23	AM-243	2.58E 03	2.37E 02	1.39E 03	3.73E 04	0.0	9.14E 04	9.14E 04	0.0
24	CM-242	2.36E-17	1.70E-16	2.10E-17	3.50E-16	0.0	7.52E-16	7.52E-16	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	2.02E 04	5.83E 02	1.89E 04	4.03E 04	0.0	3.02E 05	3.02E 05	0.0
	TOTAL	2.04E 04	3.73E 04	1.92E 04	4.12E 04	8.42E 01	3.03E 05	3.03E 05	1.16E 01

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table M-3. (Continued)

AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MANIN, IN MANREMS/YEAR

100000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	3.84E-05	6.55E-04	1.28E-05	3.84E-05	3.84E-05	1.92E-04	1.92E-04	3.84E-05
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	4.75E-03	1.06E 01	4.75E-03	1.02E-02	0.0	1.83E-01	1.83E-01	0.0
5	NB-93M	7.66E-02	1.81E 02	7.66E-02	3.11E-01	0.0	9.52E-01	9.52E-01	0.0
6	TC-99	1.91E 01	3.71E 03	1.91E 01	7.11E 01	6.04E 00	4.82E 01	4.82E 01	0.0
7	I-129	7.80E-04	1.05E-03	7.80E-04	3.04E-04	0.0	3.53E-04	3.53E-04	5.59E-01
8	CS-135	1.04E 01	1.26E 01	1.04E 01	2.34E 01	2.66E 00	2.53E 01	2.53E 01	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	2.96E 01	3.91E 03	2.96E 01	9.46E 01	8.70E 00	7.46E 01	7.46E 01	5.59E-01
10	PB-210	1.37E 01	2.60E-01	1.37E 01	1.26E 02	0.0	1.34E 03	1.34E 03	0.0
11	RA-225	8.89E 02	2.09E 02	8.89E 02	5.54E 00	0.0	6.16E 03	6.16E 03	0.0
12	RA-226	1.92E 04	3.99E 01	1.92E 04	3.54E 00	0.0	2.28E 05	2.28E 05	0.0
13	TH-229	7.70E-01	1.13E 00	7.70E-01	3.30E-01	0.0	5.06E 01	5.06E 01	0.0
14	TH-230	1.51E-01	1.28E-01	1.51E-01	3.10E-01	0.0	5.48E 00	5.48E 00	0.0
15	NP-237	4.05E 00	4.13E-01	2.17E 00	5.94E 01	0.0	1.48E 02	1.48E 02	0.0
16	NP-239	1.56E-08	4.29E-03	1.56E-08	2.46E-08	0.0	2.39E-07	2.39E-07	0.0
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	8.75E-02	2.75E-01	4.71E-02	1.27E 00	0.0	3.19E 00	3.19E 00	0.0
19	PU-240	1.11E-04	3.50E-04	6.00E-05	1.62E-03	0.0	4.05E-03	4.05E-03	0.0
20	PU-241	8.21E-07	5.55E-06	7.81E-07	5.66E-06	0.0	3.43E-05	3.43E-05	0.0
21	AM-241	1.95E-02	1.79E-03	1.08E-02	2.65E-01	0.0	6.84E-01	6.84E-01	0.0
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	1.56E-01	1.43E-02	8.41E-02	2.26E 00	0.0	5.53E 00	5.53E 00	0.0
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	2.01E 04	2.51E 02	2.01E 04	1.99E 02	0.0	2.36E 05	2.36E 05	0.0
	TOTAL	2.01E 04	4.16E 03	2.01E 04	2.94E 02	8.70E 00	2.36E 05	2.36E 05	5.59E-01

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table M-3. (Continued)

AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MANIN, IN MANREMS/YEAR

1000000. YEARS#

K	NUCLIDE	TOT. BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	9.20E-12	2.05E-08	9.20E-12	1.97E-11	0.0	3.54E-10	3.54E-10	0.0
5	NB-93M	1.48E-10	3.50E-07	1.48E-10	6.01E-10	0.0	1.84E-09	1.84E-09	0.0
6	TC-99	3.36E-09	6.51E-07	3.36E-09	1.25E-08	1.06E-09	8.46E-09	8.46E-09	0.0
7	I-129	2.17E-12	2.92E-12	2.17E-12	8.45E-13	0.0	9.83E-13	9.83E-13	1.55E-09
8	CS-135	2.45E-08	2.98E-08	2.45E-08	5.52E-08	6.29E-09	5.98E-08	5.98E-08	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	2.81E-08	1.05E-06	2.81E-08	6.83E-08	7.35E-09	7.05E-08	7.05E-08	1.55E-09
10	PB-210	8.78E-09	1.67E-10	8.78E-09	8.09E-08	0.0	8.61E-07	8.61E-07	0.0
11	RA-225	6.03E-06	1.42E-06	6.03E-06	3.76E-08	0.0	4.17E-05	4.17E-05	0.0
12	RA-226	1.23E-05	2.56E-08	1.23E-05	2.27E-09	0.0	1.46E-04	1.46E-04	0.0
13	TH-229	5.22E-09	7.63E-09	5.22E-09	2.24E-09	0.0	3.43E-07	3.43E-07	0.0
14	TH-230	9.72E-11	3.22E-11	9.72E-11	2.00E-10	0.0	3.52E-09	3.52E-09	0.0
15	NP-237	8.87E-09	9.05E-10	4.76E-09	1.30E-07	0.0	3.25E-07	3.25E-07	0.0
16	NP-239	9.72E-21	2.67E-15	9.72E-21	1.53E-20	0.0	1.48E-19	1.48E-19	0.0
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	5.30E-16	1.67E-15	2.86E-16	7.73E-15	0.0	1.93E-14	1.93E-14	0.0
19	PU-240	3.22E-18	1.02E-17	1.74E-18	4.71E-17	0.0	1.18E-16	1.18E-16	0.0
20	PU-241	1.35E-38	9.09E-38	1.28E-38	9.28E-38	0.0	5.63E-37	5.63E-37	0.0
21	AM-241	4.54E-34	4.17E-35	2.52E-34	6.64E-33	0.0	1.59E-32	1.59E-32	0.0
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	9.43E-14	8.65E-15	5.08E-14	1.36E-12	0.0	3.34E-12	3.34E-12	0.0
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.83E-05	1.45E-06	1.83E-05	2.53E-07	0.0	1.90E-04	1.90E-04	0.0
	TOTAL	1.84E-05	2.50E-06	1.84E-05	3.22E-07	7.35E-09	1.90E-04	1.90E-04	1.55E-09

#TIME SINCE START OF REPOSITORY OPERATIONS.

APPENDIX N

SUMMARY TABLES OF DOSE CALCULATION OUTPUT

CASE 50

Summary tables at selected times are given in Tables N-1 through N-3 from output Section 6 as follows for leach incident release to ground water beginning at 100 y, Case 50.

1. Average Annual Local Dose to Individual, MAN1L, in Zone 2, mrem/y (Table N-1).
2. Average Annual Local Dose to Individual, MAN1L, in Zone 8, mrem/y (Table N-2).
3. Average Annual Nonspecific Dose to Population, MAN1N, man-rem/y (Table N-3).

Table N-1. Average Annual Local Dose to Individual, MANIL, in Zone 2, in Millirems/Year.

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 2, IN MILLIREMS/YEAR

10000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	NB-93M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	TC-99	5.63E-02	1.09E 01	5.63E-02	2.09E-01	1.78E-02	1.42E-01	1.42E-01	0.0
7	I-129	2.47E-05	3.32E-05	2.47E-05	9.61E-06	8.37E-12	1.12E-05	1.12E-05	1.77E-02
8	CS-135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	5.63E-02	1.09E 01	5.63E-02	2.09E-01	1.78E-02	1.42E-01	1.42E-01	1.77E-02
10	PB-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	RA-225	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	RA-226	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	TH-229	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	TH-230	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	NP-237	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	NP-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	PU-240	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	PU-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	AM-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	5.63E-02	1.09E 01	5.63E-02	2.09E-01	1.78E-02	1.42E-01	1.42E-01	1.77E-02

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table N-1. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 2, IN MILLIREMS/YEAR

100000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	2.87E-11	4.89E-10	9.53E-12	2.87E-11	2.87E-11	1.43E-10	1.43E-10	2.87E-11
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	NB-93M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	TC-99	7.13E-02	1.38E 01	7.13E-02	2.65E-01	2.25E-02	1.80E-01	1.80E-01	0.0
7	I-129	4.09E-05	5.50E-05	4.09E-05	1.59E-05	1.44E-11	1.85E-05	1.85E-05	2.93E-02
8	CS-135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	7.13E-02	1.38E 01	7.13E-02	2.65E-01	2.25E-02	1.80E-01	1.80E-01	2.93E-02
10	PB-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	RA-225	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	RA-226	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	TH-229	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	TH-230	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	NP-237	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	NP-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	PU-240	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	PU-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	AM-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	7.13E-02	1.38E 01	7.13E-02	2.65E-01	2.25E-02	1.80E-01	1.80E-01	2.93E-02

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table N-1. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 2, IN MILLIREMS/YEAR

1000000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	NB-93M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	TC-99	1.51E-03	2.92E-01	1.51E-03	5.61E-03	4.76E-04	3.80E-03	3.80E-03	0.0
7	I-129	1.04E-05	1.40E-05	1.04E-05	4.06E-06	3.68E-12	4.72E-06	4.72E-06	7.47E-03
8	CS-135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.52E-03	2.92E-01	1.52E-03	5.61E-03	4.76E-04	3.80E-03	3.80E-03	7.47E-03
10	PB-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	RA-225	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	RA-226	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	TH-229	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	TH-230	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	NP-237	6.63E 02	6.77E 01	3.56E 02	9.73E 03	2.85E-05	2.43E 04	2.43E 04	3.82E-05
16	NP-239	3.43E-09	5.47E-04	3.67E-09	4.21E-09	1.24E-09	3.28E-08	3.28E-08	1.51E-09
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	PU-240	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	PU-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	AM-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	6.63E 02	6.77E 01	3.56E 02	9.73E 03	2.85E-05	2.43E 04	2.43E 04	3.82E-05
	TOTAL	6.63E 02	6.80E 01	3.56E 02	9.73E 03	5.05E-04	2.43E 04	2.43E 04	7.50E-03

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table N-2. Average Annual Local Dose to Individual, MAN1L, in Zone 8, in Millirems/Year

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MAN1L, IN ZONE 8, IN MILLIREMS/YEAR

10000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	NB-93M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	TC-99	1.31E-08	2.54E-06	1.31E-08	4.88E-08	4.14E-09	3.31E-08	3.31E-08	0.0
7	I-129	5.83E-12	7.83E-12	5.83E-12	2.27E-12	6.29E-17	2.64E-12	2.64E-12	4.17E-09
8	CS-135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.31E-08	2.54E-06	1.31E-08	4.88E-08	4.14E-09	3.31E-08	3.31E-08	4.17E-09
10	PB-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	RA-225	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	RA-226	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	TH-229	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	TH-230	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	NP-237	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	NP-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	PU-240	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	PU-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	AM-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	1.31E-08	2.54E-06	1.31E-08	4.88E-08	4.14E-09	3.31E-08	3.31E-08	4.17E-09

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table N-2. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 8, IN MILLIREMS/YEAR

100000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	NB-93M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	TC-99	2.85E-02	5.53E 00	2.85E-02	1.06E-01	4.65E-02	7.19E-02	7.19E-02	0.0
7	I-129	2.30E-05	2.36E-05	2.54E-05	8.87E-06	3.94E-06	1.80E-05	1.73E-05	1.19E-02
8	CS-135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	2.85E-02	5.53E 00	2.85E-02	1.06E-01	4.65E-02	7.19E-02	7.19E-02	1.19E-02
10	PB-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	RA-225	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	RA-226	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	TH-229	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	TH-230	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	NP-237	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	NP-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	PU-240	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	PU-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	AM-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	2.85E-02	5.53E 00	2.85E-02	1.06E-01	4.65E-02	7.19E-02	7.19E-02	1.19E-02

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table N-2. (Continued)

AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MANIL, IN ZONE 8, IN MILLIREMS/YEAR

1000000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	NB-93M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	TC-99	8.92E-04	1.73E-01	8.92E-04	3.32E-03	2.90E-04	2.25E-03	2.25E-03	0.0
7	I-129	8.35E-06	1.10E-05	8.41E-06	3.25E-06	8.54E-08	3.96E-06	3.96E-06	5.86E-03
8	CS-135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	9.01E-04	1.73E-01	9.01E-04	3.32E-03	2.90E-04	2.25E-03	2.25E-03	5.86E-03
10	PB-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	RA-225	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	RA-226	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	TH-229	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	TH-230	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	NP-237	9.79E-29	9.99E-30	5.25E-29	1.44E-27	4.19E-36	3.58E-27	3.58E-27	5.61E-36
16	NP-239	2.65E-40	4.24E-35	2.83E-40	3.26E-40	9.57E-41	2.54E-39	2.54E-39	1.16E-40
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	PU-240	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	PU-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	AM-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	9.79E-29	9.99E-30	5.25E-29	1.44E-27	4.19E-36	3.58E-27	3.58E-27	5.61E-36
	TOTAL	9.01E-04	1.73E-01	9.01E-04	3.32E-03	2.90E-04	2.25E-03	2.25E-03	5.86E-03

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table N-3. Average Annual Nonspecific Dose to Population, MANlN, in Man-rems/Year

AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MANIN, IN MANREMS/YEAR

10000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	NB-93M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	TC-99	1.33E 02	2.58E 04	1.33E 02	4.94E 02	4.20E 01	3.35E 02	3.35E 02	0.0
7	I-129	4.23E-04	5.68E-04	4.23E-04	1.64E-04	0.0	1.91E-04	1.91E-04	3.03E-01
8	CS-135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	1.33E 02	2.58E 04	1.33E 02	4.94E 02	4.20E 01	3.35E 02	3.35E 02	3.03E-01
10	PB-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	RA-225	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	RA-226	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	TH-229	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	TH-230	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	NP-237	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	NP-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	PU-240	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	PU-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	AM-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	1.33E 02	2.58E 04	1.33E 02	4.94E 02	4.20E 01	3.35E 02	3.35E 02	3.03E-01

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table N-3. (Continued)

AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MANIN, IN MANREMS/YEAR

100000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARRO#	BONE	THYROID
1	C-14	5.25E-09	8.94E-08	1.74E-09	5.25E-09	5.25E-09	2.62E-08	2.62E-08	5.25E-09
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	NB-93M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	TC-99	2.18E 02	4.23E 04	2.18E 02	8.11E 02	6.89E 01	5.49E 02	5.49E 02	0.0
7	I-129	6.14E-03	8.26E-03	6.14E-03	2.39E-03	0.0	2.78E-03	2.78E-03	4.40E 00
8	CS-135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	2.16E 02	4.23E 04	2.18E 02	8.11E 02	6.89E 01	5.49E 02	5.49E 02	4.40E 00
10	PB-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	RA-225	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	RA-226	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	TH-229	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	TH-230	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	NP-237	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	NP-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	PU-240	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	PU-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	AM-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	2.18E 02	4.23E 04	2.18E 02	8.11E 02	6.89E 01	5.49E 02	5.49E 02	4.40E 00

#TIME SINCE START OF REPOSITORY OPERATIONS.

Table N-3. (Continued)

AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MANIN, IN MANREMS/YEAR

1000000. YEARS#

K	NUCLIDE	TOT BODY	GI TRACT	GONADS	LIVER	LUNGS	MARROW	BONE	THYROID
1	C-14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	SR-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	Y-90	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	ZR-93	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	NB-93M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	TC-99	5.13E 00	9.95E 02	5.13E 00	1.91E 01	1.62E 00	1.29E 01	1.29E 01	0.0
7	I-129	2.91E-03	3.91E-03	2.91E-03	1.13E-03	0.0	1.32E-03	1.32E-03	2.08E 00
8	CS-135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	CS-137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	5.13E 00	9.95E 02	5.13E 00	1.91E 01	1.62E 00	1.29E 01	1.29E 01	2.08E 00
10	PB-210	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	RA-225	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	RA-226	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	TH-229	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	TH-230	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	NP-237	7.83E 02	7.99E 01	4.20E 02	1.15E 04	0.0	2.86E 04	2.86E 04	0.0
16	NP-239	2.35E-09	6.46E-04	2.35E-09	3.70E-09	0.0	3.60E-08	3.60E-08	0.0
17	PU-238	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	PU-239	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	PU-240	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	PU-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	AM-241	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	AM-242M	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	AM-243	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	CM-242	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	CM-244	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTAL	7.83E 02	7.99E 01	4.20E 02	1.15E 04	0.0	2.86E 04	2.86E 04	0.0
	TOTAL	7.88E 02	1.08E 03	4.25E 02	1.15E 04	1.62E 00	2.87E 04	2.87E 04	2.08E 00

#TIME SINCE START OF REPOSITORY OPERATIONS.

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PART 2

OTHER APPLICATIONS OF MODEL

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CHAPTER 9

APPLICATION TO REPOSITORY OPERATIONS

Assessment of a radioactive waste repository is best done by examining two phases: repository operations and terminal storage. The latter represents the long term period following accumulation of the total inventory, backfilling and sealing the repository. This phase can also be divided into near and far terms if needed. Implementation of AMRAW for terminal storage is presented in detail in Part 1 of this volume. Repository operations represents the period during which the repository is open and receiving waste. A preliminary demonstration of AMRAW to this phase is presented in this chapter.

The projection of accumulated high-level waste from reprocessing assumed for the reference repository is given in Table 6-2 in Part 1. This corresponds to an assumed repository operations period of 30 y. During this period, excavations are extended as required to accommodate waste receipts. Surface operations include receival, brief interim storage, and associated handling. Underground operations include lowering canisters via a mine hoist, transport through mine drifts, and emplacement of canisters in drilled holes in the formation. There may or may not be progressive backfill depending upon retrievability requirements. Ventilation air is circulated through zones of the mine (repository) and discharged through banks of HEPA filters at the surface. During these operations, corrective action may be taken to mitigate consequences of accidents or natural disruptive events. Analysis of repository operations considers release scenarios which apply only during the operations time period (here assumed to be 30 y), but evaluates environmental consequences during and subsequent to the operations period.

A complete assessment of the repository operations phase requires design details for the repository, including facilities, equipment and operating procedures. The application of AMRAW presented here is a preliminary demonstration and serves only to illustrate methods of data preparation and the form of output obtained.

A. DATA FOR AMRAW INPUT

The major difference in input data for repository operations from that for terminal storage is the input used by the Release Model (Subroutine FAULT). The short 30 y time period for releases during this phase precludes consideration of very low probability events such as volcanism and meteorite impact. Site selection studies eliminates volcanism as a possibility until well after the operations phase. In the absence of violent natural occurrences, any release directly to land surface is expected to involve only the geographic zone surrounding the repository (Zone 1); accordingly, the zone allotment factor for dispersion directly to land surface (ZONALO) is input as 1.0 for Zone 1 and zero for the other zones. As described later, because of an absence of surface water in Zone 1, the Release Model input provides no releases to this receptor; the corresponding zone allotment factors are therefore bypassed and may have any input values. Conservatively, the dispersion of releases to air and deposition from the air onto land surface and surface water in the various zones uses the same allotment factors (ZONALO, DEPGND, and DEPWTR) used for terminal storage. These, of course, may be changed as appropriate for a more detailed study of repository operations. The only other items of data changed from terminal storage for this demonstration are for calculation control. Release time increments are set starting with 0 - 5 y (ITRS = 2) through 25 - 30 y (ITRE = 7) and a flag (IW = 3) is set to denote repository operations. The latter controls a branch calculation of the radiodecay factor (DECFAC) when a time prior to the full repository inventory accumulation is involved.

Input data for the Release Model provides estimates of probabilities for component and the fraction of an <u>affected</u> inventory released to a given receptor by a release occurrence. During repository operations, the accumulated inventory at a given time is divided between: 1) surface storage and handling, 2) underground handling, and 3) emplaced underground storage. Accordingly, a time dependent factor is applied to express the effected inventory for each release scenario. This is explained in later paragraphs below. First, consider the release scenarios. Fault trees developed for repository operations by Logan [Lo74a] consider the following basic events for release to air or land surface:

1) Earthquake

2) Wind (tornados or hurricanes)

3) Sabotage

4) Aircraft impact

5) Flood

6) Handling accidents.

Each of these may occur with a range of severities and is subject to a conditional inhibit gate for probability of breech of containment for a given severity level. These events apply primarily to surface operations. For release to land surface, a factor designating fraction of "no cleanup" applies. Release to air from underground operations involves a handling accident in the mine, subject to an inhibit condition for breech of containment, plus improper ventilation system operation (failure of filters). Release to ground water considers flooding of the mine (or a portion) by water seepage into a shaft or into storage rooms, plus a failure of corrective repair.

For this demonstration, the six basic events listed above are considered to occur at two severity levels and are lumped together as "major events" and as "minor events," illustrated in the simplified fault trees in Fig. 9-1. No attempt is made here to evaluate probabilities for individual component basic events. The transfer coefficient as a function of time to a given preliminary environmental input receptor for a given release mechanism and radionuclide is defined by Eq. 4-2 in Vol. I as

$$A(t) = P(t)\ A1(t),\ y^{-1}\ . \qquad (9\text{-}1)$$

Multiplication of this coefficient by the length of a time increment considered gives the fraction of radionuclide inventory which is transferred during the time increment. A1 is the fraction of effected inventory transferred if a release occurs. For a major event at the surface or a handling accident in the mine, it is assumed that 1% of contents are released from 10% of canisters effected and A1 (the AMRAW variable is designated AA1) becomes 0.01 x 0.1 = .001. For a minor event at the

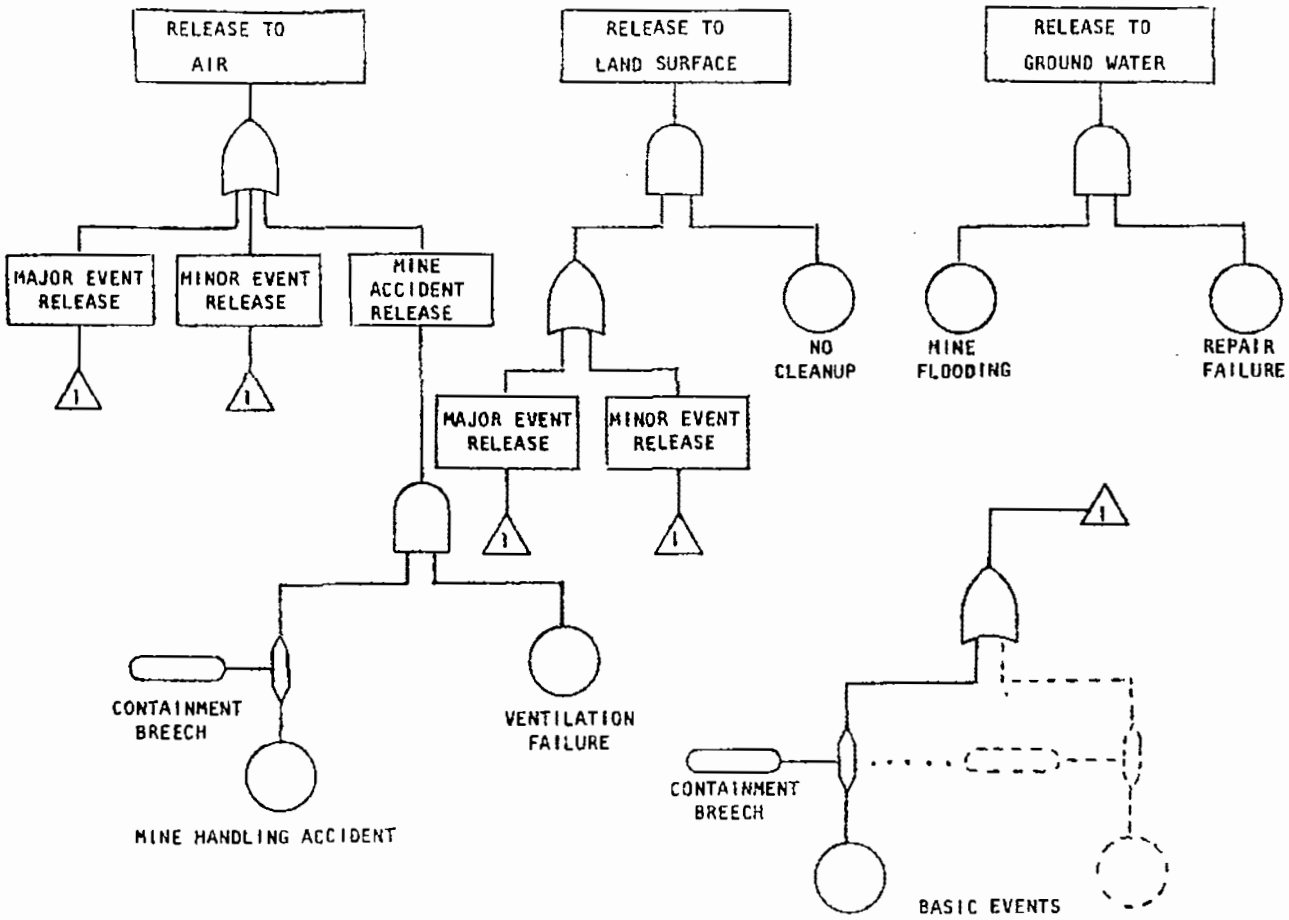


Figure 9-1. Simplified fault trees for repository operations demonstration.

surface, it is assumed that 0.1% of contents are released from 1 canister among 500 canisters exposed and A1 becomes $0.001 \times 1/500 = 2 \times 10^{-6}$. For release to ground water, A1 is calculated within AMRAW by a leach subroutine. Data input (CFAI) assumes 250 canisters are exposed to one leach incident.

In Eq. 9-1, P(t) is the annual probability of occurrence of release and is expressed by Eq. 3-3 in Vol. I as

$$P(t) = P_1(t)\ P_2(t)\ \ldots\ P_n(t), \tag{9-2}$$

where each component factor may be any of five functions of time. The first factor, $P_1(t)$, is used here to express the fraction of accumulated inventory which is exposed to the release scenario. While this factor is not a probability of event occurrence, the programmed flexibility in AMRAW makes it convenient to use the $P_1(t)$ component of P(t) to account for portions of the total inventory exposed to a given release scenario. Table 9-1 lists the total accumulated inventory in metric tons (MT) at each reference time and the assumed average quantities in handling at the surface and underground. It may be seen that the quantities handled at the surface are assumed to represent approximately 6 months' receipts at the beginning as operations get underway, with one canister at a time handled underground. As operations mature, surface inventory increases but represents a decrease to 1 months' receipts as underground operations level out at 10 canisters at a time. This handling quantity allows 5 hours per canister for emplacement at the peak receival rate. Figure 9-2 is a semi-log plot of the surface/total and mine/total handling ratios. The surface handling fraction is approximated by the straight line on the semi-log plot, represented by the equation

$$P_1(t) = \exp\left[-\ 0.0991(t + 18.8)\right]. \tag{9-3}$$

The corresponding underground fraction is

$$P_1(t) = \exp\left[-\ 0.140(t + 33.4)\right]. \tag{9-4}$$

Table 9-1. Repository Inventory Accumulation and Assumed Surface and Underground Handling Quantities

Reference Time y	Average Receipt Rate MT/y	Accumulated Inventory MT	Surface		Underground	
			Quantity Handled MT	Surface / Total	Quantity Handled MT (no. canisters)[a]	Mine / Total
0		0	0	0	0	0
	100					
5		5.01×10^{2}	50	9.98×10^{-2}	3 (1)	5.98×10^{-3}
	1,700					
10		9.01×10^{3}	500	5.55×10^{-2}	18 (6)	2.00×10^{-3}
	3,600					
15		2.70×10^{4}	900	3.33×10^{-2}	30 (10)	1.11×10^{-3}
	6,400					
20		5.90×10^{4}	1,200	2.03×10^{-2}	30 (10)	5.08×10^{-4}
	10,400					
25		1.10×10^{5}	1,500	1.35×10^{-2}	30 (10)	2.70×10^{-4}
	15,200					
30		1.87×10^{5}	1,500	8.02×10^{-3}	30 (10)	1.60×10^{-4}

[a]Canister capacity is waste from 3 MT spent fuel.

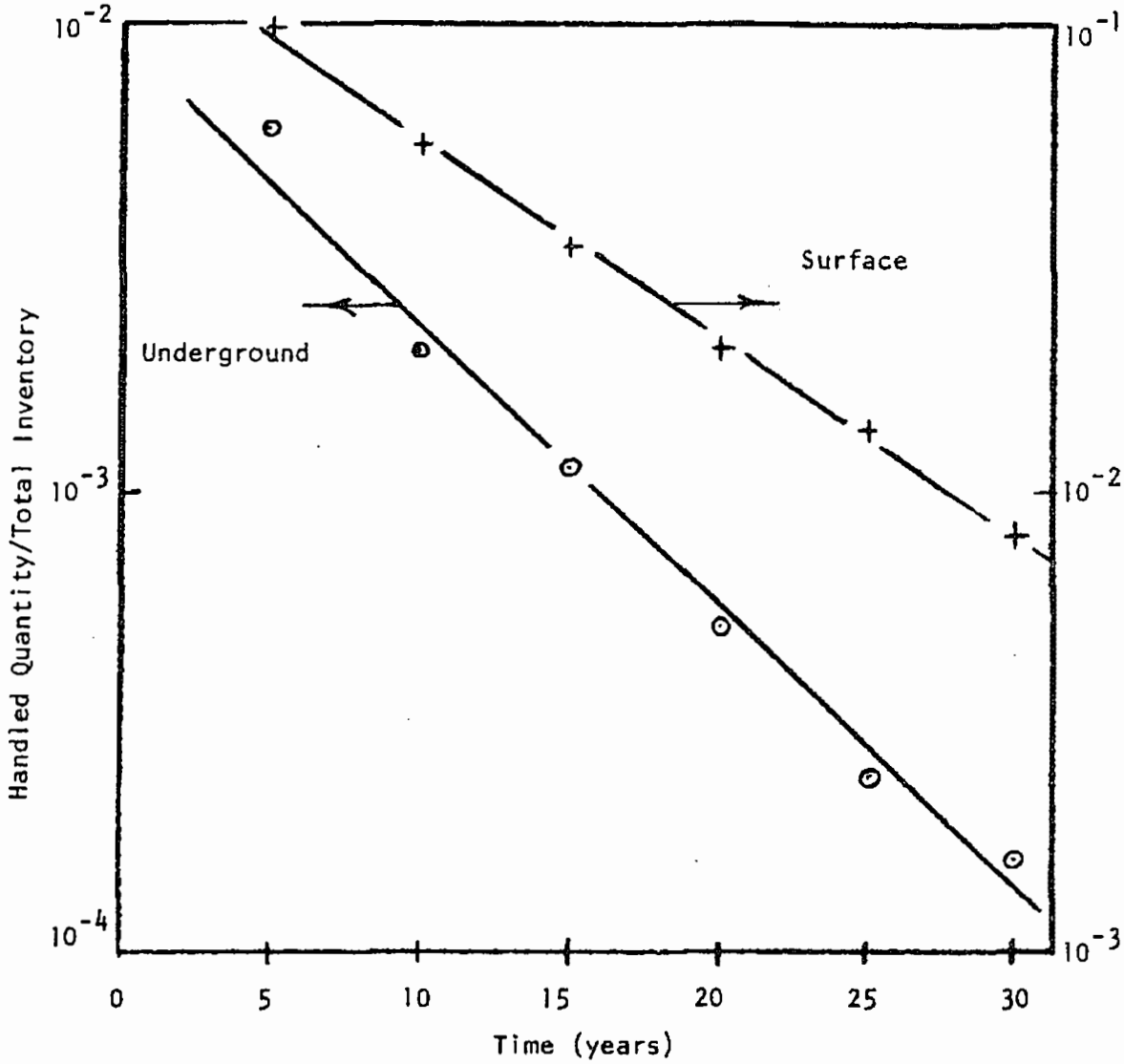


Figure 9 -2. Fraction of total inventory in handling at surface and underground.

These correspond to the exponential programmed function (see Section 4.C in Vol. I)

$$P_n(t) = C + \exp\left[B(t - t_p)\right], \tag{9-5}$$

where AMRAW input parameters and values become C = PROBB = 0.0, B = CP = -0.0991 and -0.140 respectively, and t_p = TP = -18.8 and -33.4 respectively. The data input to branch to this function is IFLAG = 3.

Next, the other component factors, $P_2(t)$ ... $P_n(t)$, must be estimated for each scenario. The balance of this paragraph continuously refers to Fig. 9-1. For this demonstration, it is assumed that the probability of occurrence of a basic event comprising a major event release to air or to land surface is $P_2(t) = 0.001/y$. It is then assumed that 1% of such events result in a breech of containment, or $P_3(t) = 0.01$ (see conditional gates Fig. 9-1). Similarly, minor events are assumed to be much more frequent, with $P_2(t) = 0.2/y$ and containment breech also $P_3(t) = 0.01$. For release to land surface, the factor representing "no cleanup" is represented by $P_3(t) = 0.50$. This assumes that 50% of spills on the land surface are cleaned up prior to dispersion. For the mine handling accident scenario, the accident probability is taken as $P_2(t) = 0.5/y$, containment breech: $P_3(t) = 0.01$, and the ventilation system is assumed to malfunction 1% of the time or $P_4(t) = 0.01$. Release to ground water assumes a mine flooding probability of $P_2(t) = 0.02/y$ and "repair failure" of 50% or $P_3(t) = 0.50$. Each of the factors $P_n(t)$ is input to AMRAW via the subscripted variable PROBB. A constant function of time is designated for each factor (IFLAG = 0).

The 6 release scenarios, or cutsets in Fig. 9-1, are summarized in Table 9-2. It is emphasized that the data input values listed in Table 9-2 and described in preceding paragraphs are used here to demonstrate methods for data preparation and operation of the AMRAW code applied to the repository operations phase.

Table 9-2. Summary of Demonstration Release Scenario for Repository Operations

Cutset	Scenario	Factor	Value
	Release to Air		
1	Major event at surface	A1	0.001
		$P_1(t)$	a
		$P_2(t)$	0.001
		$P_3(t)$	0.01
2	Minor event at surface	A1	2×10^{-6}
		$P_1(t)$	a
		$P_2(t)$	0.20
		$P_3(t)$	0.01
3	Handling accident in mine	A1	0.001
		$P_1(t)$	b
		$P_2(t)$	0.50
		$P_3(t)$	0.01
		$P_4(t)$	0.01
	Release to Land Surface		
4	Major event at surface	A1	0.001
		$P_1(t)$	a
		$P_2(t)$	0.001
		$P_3(t)$	0.01
		$P_4(t)$	0.50
5	Minor event at surface	A1	2×10^{-6}
		$P_1(t)$	a
		$P_2(t)$	0.20
		$P_3(t)$	0.01
		$P_4(t)$	0.50
	Release to Surface Water		
	None (no surface water in Zone 1)		
	Release to Ground Water		
6	Mine flooding	A1	c
		$P_1(t)$	0.02
		$P_2(t)$	0.50

[a] $P_1(t)$ designated by Eq. 9-3.

[b] $P_1(t)$ designated by Eq. 9-4.

[c] A1 calculated by leach subroutine.

B. RESULTS

The demonstration of AMRAW applied to the repository operations phase considers preliminary estimates of releases during a 30 y operation period. Results provide some indication of system response characteristics but a more complete analysis of repository design and operating procedures is needed for assessment of this waste management phase.

Figure 9-3 has plots of local total body dose rates in Zones 1 and 2 and the corresponding nonspecific dose rate, totaled for all nuclides. Dose rates increase as repository inventory increases. After the repository is sealed (assumed at 30 y), dose rates from accumulated releases during operation decrease over subsequent time. Consequences of any releases after the repository operations phase are calculated by the previously described application of AMRAW to the terminal storage phase. Table 9-3 lists the most significant radionuclides versus time as indicated by the calculations. Local dose rates reach an indicated maximum of 3.9 mrem/y in the vicinity of the repository (Zone 1) near the end of the operations period. In Zone 2, surrounding the repository zone, dose rates are lower by a factor of about 100. Over most of the long term period, only 5 radionuclides at any one time comprise over 99% of the total calculated dose rate (Table 9-3); this involves 10 nuclides altogether. The nonspecific dose rate is dominated by Cs-137 and Sr-90 at early times (less than 600 y), is sustained primarily by Americium in middle times, and after 10^4 y, is almost totally due to Tc-99 and Ra-226. The maximum indicated nonspecific dose rate is 27 man-rem/y, reached near the end of the operations period. As discussed in Part 1, the nonspecific dose is from exported agricultural products which represent the total food needs for about 10^6 persons; the maximum individual dose rate from this dose category then becomes approximately 0.03 mrem/y. The input data used includes a ground water velocity 6 times the estimated value to conservatively cover uncertainty. On the basis, neptunium breaks through in ground water in Zone 2 at times near 10^6 y, and is partially discharged to surface water assumed to be a drinking water source. This results in the rising curve in Fig. 9-3 at times near 10^6 y, representing both mrem/y local dose rate in Zone 2 and man-rem/y nonspecific dose rate.

Sample output breaking dose rates down by environmental receptors is given in Appendix O for Zones 1 and 2 and the nonspecific category. In Zone 1, releases to air dominate the results, with releases to land surface comprising 1 - 10% over the full time range. No surface water is assumed in Zone 1. In Zone 2, where surface water does exist, this receptor dominates with 70 - 100% of the total dose rate, followed by releases to air and then land surface. Ground water is negligible until some neptunium breakthrough at times near 10^6 y. For the nonspecific dose rate category, releases to land surface dominate with 70 - 90% of the total during repository operations. After the operations period, releases for this phase cease, and no further direct or indirect depositions occur. After repository operations, assumed persistence in surface water causes this receptor to comprise virtually the total source of dose rates over the long term. Breakthrough of Tc-99 in ground water (in Zone 2) causes this receptor to contribute up to 9% of the total (from drinking water to meat production) at times in the vicinity of 6,000 y. Ground water concentrations peak at 7,000 y from Tc-99 (and I-129), at 200,000 y from C-14, and Np-237 begins to buildup from breakthrough after 700,000 y.

Further detailed analysis of results for this case are not justified because of the preliminary nature of the estimated input data for the release scenarios.

Table 9-3. Most Significant Radionuclides Versus Time Based Upon Total Body Dose for Repository Operations[a]

10^2 y Nuclide[b],	Accum. %[c]	10^3 y Nuclide,	Accum. %	10^4 y Nuclide,	Accum. %	10^5 y Nuclide,	Accum. %	10^6 y Nuclide,	Accum. %
Local, Zone 1									
Am-241	28	Am-241	40	Am-243	47	Pu-239	65	Negligible	
Cm-244	55	Am-243	73	Pu-240	73	Th-229	79		
Pu-238	72	Pu-240	93	Pu-239	90	Np-237	90		
Sr-90	86	Np-239	98	Np-239	97	Th-230	98		
Am-243	92	Pu-239	99+	Am-241	99+	Ra-226	99+		
Nonspecific									
Cs-137	89	Am-241	53	Tc-99	98	Tc-99	88	Np-237	100
Sr-90	99+	Am-243	95	Ra-226	99+	Ra-226	99+		
Am-241		Ra-226	97	Am-243		Ra-225			
Cm-244		Tc-99	98	Ra-225		Pb-210			
Am-243		Cs-135	99+	Am-241		Cs-135			

[a]Case 56 is the preliminary demonstration to repository operations.

[b]Nuclides are ranked in order of dose rates, with the highest listed first.

[c]The accumulated percentage is percent of total dose rate from all 25 nuclides.

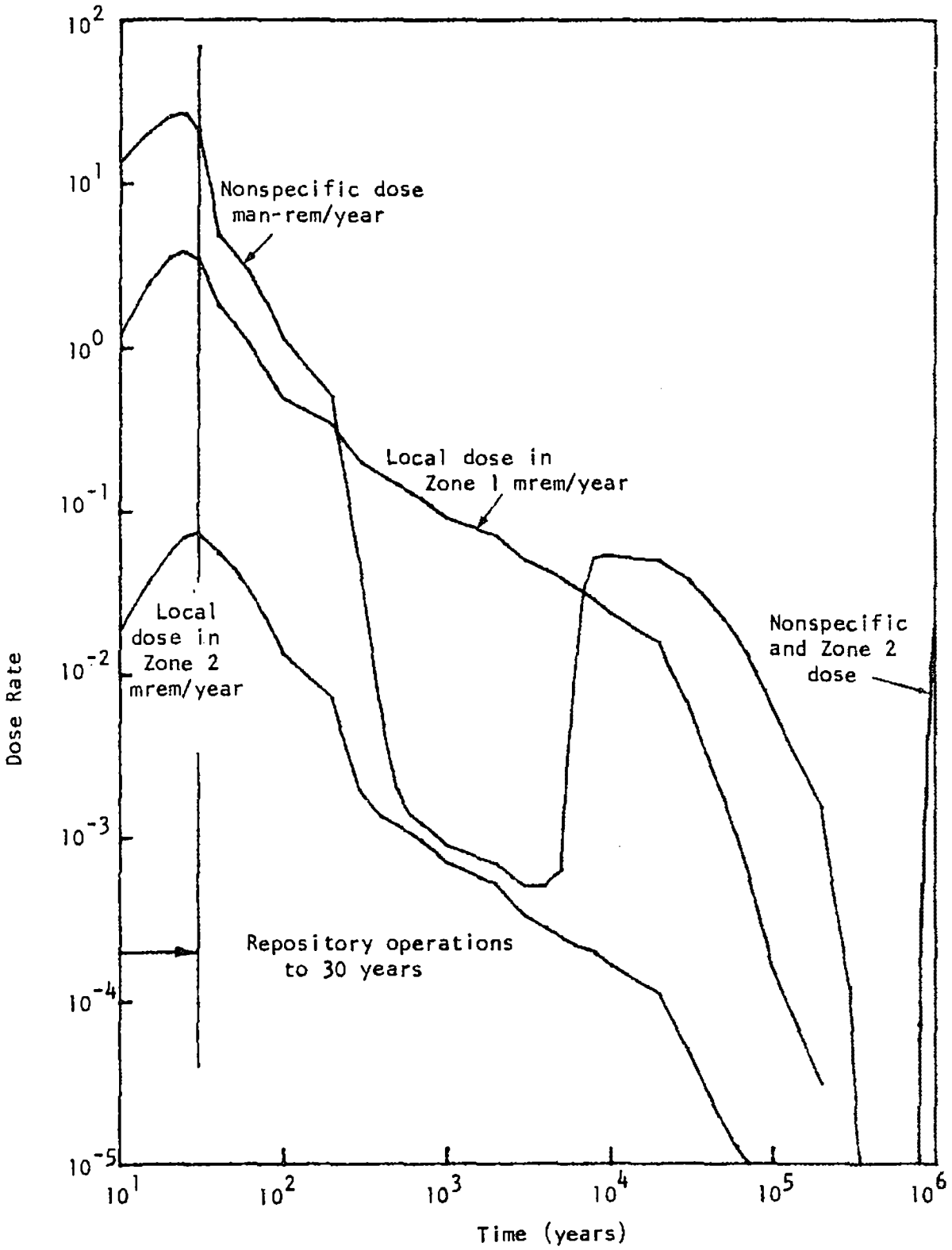


Figure 9-3. Repository operations: average annual local total body dose to individual in Zones 1 and 2 and nonspecific dose, total all nuclides.

CHAPTER 10

APPLICATION TO GROUND SURFACE STORAGE

The AMRAW computer code can be applied to each phase of the radioactive waste management sequence. Application to ground surface storage is similar to the application to repository operations in the previous chapter. The operating period of a surface storage facility is similar in concept to a repository operations period. It is preferred that the waste or spent fuel inventory and its accumulation over time for surface storage be established for a specific facility and input to AMRAW instead of the repository inventory. However, it may be appropriate if desired, to express the surface storage inventory as some function of the repository inventory, as was done for surface and underground handled quantities in Chapter 9.

Release scenarios for a surface storage facility may be constructed in a manner similar to the approach used for repository operations. Detailed designs of facilities are needed to accomplish this. Basic events to be considered include, as before: earthquakes, tornados, hurricanes, sabotage, aircraft impact, flooding, and handling accidents. Air or water cooling provisions, container corrosion and other factors associated with storage for up to decades enter into this analysis. In the absence of a specific facility design, a numerical application of AMRAW is not attempted here.

CHAPTER 11

PRELIMINARY DEMONSTRATION FOR ANOTHER GEOLOGIC SETTING

As part of the development of the generic AMRAW model and computer code, an application to terminal storage in a bedded salt model repository was completed. A preliminary demonstration for another geologic setting is presented here to illustrate the generic nature of the model.

In addition to bedded salt, other formations being studied for possible repository use include dome salt, shales (argillaceous material), basalt and granite. Complete implementation of AMRAW to a proposed repository in another geologic setting involves different demographic and agricultural data as well as different geologic and release scenario data. To demonstrate the differences in model application due only to a different geologic setting, this demonstration simply substitutes another structure for the bedded salt formation. For the purpose, the Denver Basin was selected and this formation, including a thick deposit of Pierre Shale, is assumed to be at the Los Medaños model site in lieu of the existing bedded salt formation.

A. SELECTION AND DESCRIPTION OF GEOLOGIC BASIN

Microcrystalline argillaceous material is attractive for the environment of a nuclear repository site, because of the relatively low permeability and porosity coefficients associated with shales, and the good sorption properties for shales which tend to prevent or retard radionuclide migration. The characteristics of the Denver Basin make it attractive for a nuclear repository site because of: 1) the massive sequences of moderately homogeneous argillaceous material, 2) the basin contains up to 4000 m (13,000 ft) of sediment in the western portion, thinning down to approximately 1200 m (4000 ft) of sediment in the eastern margin, and 3) only minor episodes of volcanism have occurred within the basin in the past 30 million years. The Denver Basin is a relatively stable structure, located at the western margin of the Great Plains in the east-central portion of Colorado, southeastern Wyoming, and the southwestern and western portions of South Dakota, Nebraska, and Kansas. Within the central area of the basin the Pierre Shale of Late Cretaceous Age, consisting of thick sequences of a lower gray and black shale, a middle section of shale-sandstone sequences, and an upper shale unit, was selected for this study. Massive sequences of microcrystalline-shale size material range from 1000 - 1900 m in thickness. Relatively minor amounts of macrocrystalline-sand size are interbedded within the shale. Davis [Dv75] suggests that a favorable site for a nuclear repository within the Denver Basin is near the eastern margin of the basin, characterized by relatively low basin relief and less complex geological structure.

Additional description of geographic and geologic features of the Denver Basin is presented in Appendix P.

B. DATA FOR AMRAW INPUT

Any change in the model repository due to differences in properties of the formation must first be defined. Then, input data for the Release Model and the Transport-to-Environment part of the Environmental Model are needed.

1. Model Repository. The thermal conductivity of shale is approximately one-third that of rock salt [Ck66]. This suggests that the thermal loading should be reduced in shale to limit maximum temperatures reached in the disposal horizon to a desired range. A complete thermal analysis considering all of the rock properties and the rock mechanical response to thermal loading is not available. For purposes here, it is assumed that the repository area is doubled from 10 km^2 (used for the bedded salt model repository) to 20 km^2 for high level waste from reprocessing of 187,000 MT of spent fuel. Assuming only 75% of the total repository area is actually used for disposal, this assumes a reduction of the initial heat load from 370 to 185 kw/hectare.

The repository is assumed to be in Pierre Shale corresponding to a site near the eastern margin of the Denver Basin, a region of nearly horizontal bedding and low basin relief. A burial depth of 800 m places the repository in the lower third of the Pierre Shale.

2. Release Model Data. The release scenarios and associated data used for the application to a bedded salt model repository are listed in Table 6-4 in Part 1. For this preliminary demonstration to a repository in shale, the same scenarios are appropriate and they are listed in Table 11-1. The determination of revised numerical values of parameters is presented in following paragraphs.

(a) Meteorite Impact. The probability of a direct strike by a meteorite of enough energy to exhume material from a depth of 800 m is shown in Appendix E to be 1×10^{-14} $(km^2 - y)^{-1}$. For a 20 km^2 repository, this becomes $(20)\ (1 \times 10^{-14}) = 2 \times 10^{-13}\ y^{-1}$. For the repository in bedded salt, it was estimated that a direct hit exhumes 5% of repository inventory to the air and 5% directly to land surface; the more dilute emplacement in shale reduces the fraction exhumed by a factor of two to 2.5% each to air and land surface. The annual

Table 11-1. Summary of Release Scenarios for Repository in Shale

CUT SET	RELEASE TO RECEPTOR	EVENT	ANNUAL PROBABILITY		ESTIMATED RELEASE FRACTION
			FUNCTION	ESTIMATED VALUE	
1	Air	Direct expulsion by meteorite impact	Constant	2×10^{-13}	0.025
2	Air	Direct expulsion by volcanic explosion	Constant	3×10^{-12}	0.045
3	Air	Direct expulsion by diatreme	Constant	3×10^{-12}	0.007
4	Land Surface	Surface reduced to waste by erosion	Ramp	0.0 for $t < 8.0 \times 10^6$ y; $(t - 8.0 \times 10^6) \times 5.6 \times 10^{-8}$; for $t > 8.0 \times 10^6$ y	[a] 2×10^{-5}
5	Land Surface	Transport to surface by meteorite impact	Constant	2×10^{-13}	0.025
6	Land Surface	Volcanogenic transport to surface	Constant	1×10^{-11}	0.045
7	[b] Surface Water	Surface reduced to waste by erosion	Ramp	0.0 for $t < 8.0 \times 10^6$ y $(t - 8.0 \times 10^6$ y; 5.6×10^{-8}; for $t > 8.0 \times 10^6$ y	[a] 2×10^{-5}

Table 11-1. Summary of Release Scenarios for Repository in Shale (continued)

CUT SET	RELEASE TO RECEPTOR	EVENT	ANNUAL PROBABILITY		ESTIMATED RELEASE FRACTION
			FUNCTION	ESTIMATED VALUE	
8	Surface Water	Transport to surface by meteorite impact	Constant	2×10^{-13}	0.025
9	Surface Water	Volcanogenic transport to surface	Constant	1×10^{-11}	0.045
10	Ground Water (see Fig. 7-1)	Faulting; not sealed, interconnecting aquifers	Constant	2×10^{-7}	[c]Calculated leach rates

NOTES: [a]Release fraction for exposure by erosion assumes vertical canisters eroded at same annual rate as land surface.

[b]The release to surface water corresponds to the same cut sets as for release to land surface plus the presence of surface water.

[c]The release fraction for release to ground water is the inventory fraction leached per year, as calculated by function RLEACH under subroutine FAULT in AMRAW.

probability and estimated release fraction are entered in Table 11-1 for cut set (release scenario) numbers 1, 5 and 8 (expulsion to air, transport to land surface, and transport to surface water, respectively).

(b) Volcanism. The equivalent radius of a 20 km^2 repository is approximately 2.5 km. Referring to the procedure in Appendix C and Figure C-1, the corresponding volcanism effect zone has a radius of $r_1 + 2r_2 = 4.7$ km (area 69.4 km^2), where $r_2 = 1.1$ km is taken as the average volcano radius. The probability of volcanism effecting the larger repository becomes $(5.0 \times 10^{-9})(69.4/3.1 \times 10^4) = 1.12 \times 10^{11}\ y^{-1}$ (use $1 \times 10^{-11}\ y^{-1}$). This is the probability for volcanogenic transport to land surface (cut set 6) and to surface water (cut set 9). The probability of a volcanic explosion or diatreme is 0.3 times the basic volcanism event or $3 \times 10^{-12}\ y^{-1}$. This applies to direct expulsion to air by volcanic explosion (cut set 2) or by diatreme.

The estimated release fraction is one-half of the expected value of area intersection of the repository by a volcano or diatreme. Approximating by Riemann sums, the expected intersection area for a volcano becomes 1.8 km^2 or a fraction of 1.8/20 = 0.09 and the estimated release fraction becomes 0.5 x 0.09 = 0.045 (cut sets 2, 6, and 9). For a diatreme, the intersection area is 0.28 km^2, fraction 0.28/20 = 0.014, and release fraction 0.5 x 0.014 = 0.007 (cut set 3).

(c) Surface Erosion. Denudation rates are calculated for drainage basins, which average 1500 square miles in an area and are underlain predominantly by sedimentary and metamorphic rocks. Average denudation rates range from 3 to 10 cm (0.1 to 0.3 feet) per 1000 years, whereas an average of maximum denudation rates is about 100 cm (3 feet) per 1000 years [Su56, Su61]. The denudation rates are an exponential function of drainage-basin relief, indicating that denudation rates increase rapidly with uplift. Denudation rates in humid climates are about four times slower. The relief/length ratio near the eastern margin of the Denver Basin is approximately 0.002 (the corresponding value in the Los Medaños area of southeastern New Mexico is approximately 0.008). A graph by Schumm [Su56] indicates that the range of average dunation rates stated above corresponds to a relief/length range of 0.02 to 0.05. It is therefore conservative (by a factor of about 30 for the high rate) to

use the average rates for lower relief of the Denver Basin. This represents approximately the same factor of conservatism previously used for the bedded salt application (10 - 50 cm/1000 y) with relief four times as great.

The time required to expose the waste horizon at a depth of 800 m at the upper end of the denudation rates, 10 cm/1000 y, is

$$\frac{800 \times 10^2}{10/1000} = 8.0 \times 10^6 \text{ y} . \qquad (11\text{-}1)$$

The probability is zero for exposure at shorter times. The probability is assumed to be 1.0 that exposure will occur from the low end of the rates, 3 cm/1000 y, in

$$\frac{800 \times 10^2}{3/1000} = 2.6 \times 10^7 \text{ y} . \qquad (11\text{-}2)$$

A ramp function of probability between these two times has a slope of

$$\frac{1.0 - 0.0}{2.6 \times 10^7 - 8.0 \times 10^6} = 5.6 \times 10^{-8} \text{ y}^{-1} . \qquad (11\text{-}3)$$

Therefore, AMRAW input for surface erosion cutsets 4 and 7 in Table 11-1 is: initial probability (PROBB) 0.0, function type (IFLAG) 2 for ramp function, time at start of probability increase (TP) 8.0×10^6 y, and slope of increase (CP) 5.6×10^{-8}. The release fraction for exposure by erosion assumes vertical canisters eroded at the same annual rate as land surface. The estimated release fraction (annual in this case) for 300 cm long canisters at a mean rate of 6 cm/1000 y becomes

$$\frac{6/1000}{300} = 2 \times 10^{-5} \text{ y}^{-1} \qquad (11\text{-}4)$$

and is the input value for AA1.

It should be noted that a calculation range of 10^6 y does not reach a time when contributions to release commence from this release scenario.

(d) Offset Faulting. Cutset 10 in Table 11-1 is a scenario for offset faulting causing a fracture to pass through the repository horizon and interconnect aquifer strata above and below the repository

(Fig. 11-1). Aquifers in this case may consist of multiple distributed thin porous bedding components spaced through the shale. Attempts to obtain seismic and hydrologic data for the Denver Basin from the USGS and from petroleum companies were not successful. For this demonstration it is assumed that the seismic data applied to the Los Medaños area for the bedded salt structure may also be used for the Denver Basin, and only adjustment for repository size is required.

Referring to Appendix D, the long-term average of fault surface over which some movement occurs becomes 0.012 km^2/y, and the total surface of Permian-Pennsylvanian faults considered is 10^4 km^2. Well sampling in the Los Medaños area indicates an old fault density beneath the area of one per 5 km. Assuming the 20 km^2 repository in shale may be represented by a linear dimension of $\sqrt{20}$ = 4.5 km, the probability of an old fracture beneath the repository is 4.5/5 = 0.9. Again assuming the probability of movement on such an old fault penetrating the repository to be 0.2, the annual probability of a fault penetrating the repository becomes

$$\frac{\text{Average Fault Surface with Movement/y}}{\text{Total Surface of Permian-Penn. Faults}} \times \begin{pmatrix}\text{Prob. of fracture}\\ \text{beneath repository}\end{pmatrix} \times \begin{pmatrix}\text{Prob. of}\\ \text{movement}\\ \text{on fault}\end{pmatrix}$$

$$= \frac{0.012\ km^2/y}{10^4\ km^2} \times 0.9 \times 0.2 = 2.2 \times 10^{-7}\ y^{-1}\ . \qquad (11\text{-}5)$$

This compares with $1.4 \times 10^{-7}\ y^{-1}$ obtained for the smaller bedded salt repository.

The waste form is assumed to be borosilicate glass, as before, and no data revisions for leach rate calculations are made. Effective diffusivities are paired with corresponding dissolution rate constants to represent experimentally measured leach data (see Vol. I). Appendix C comments on diffusivities in a shale host rock based upon Oklo natural reactor data.

3. Environmental Model Data. Input data is needed for the Transport-to-Environment part of the Environmental Model, or more specifically, for ground water transport. As mentioned earlier, hydrologic data is not available for the Denver Basin. The input data for ground water transport

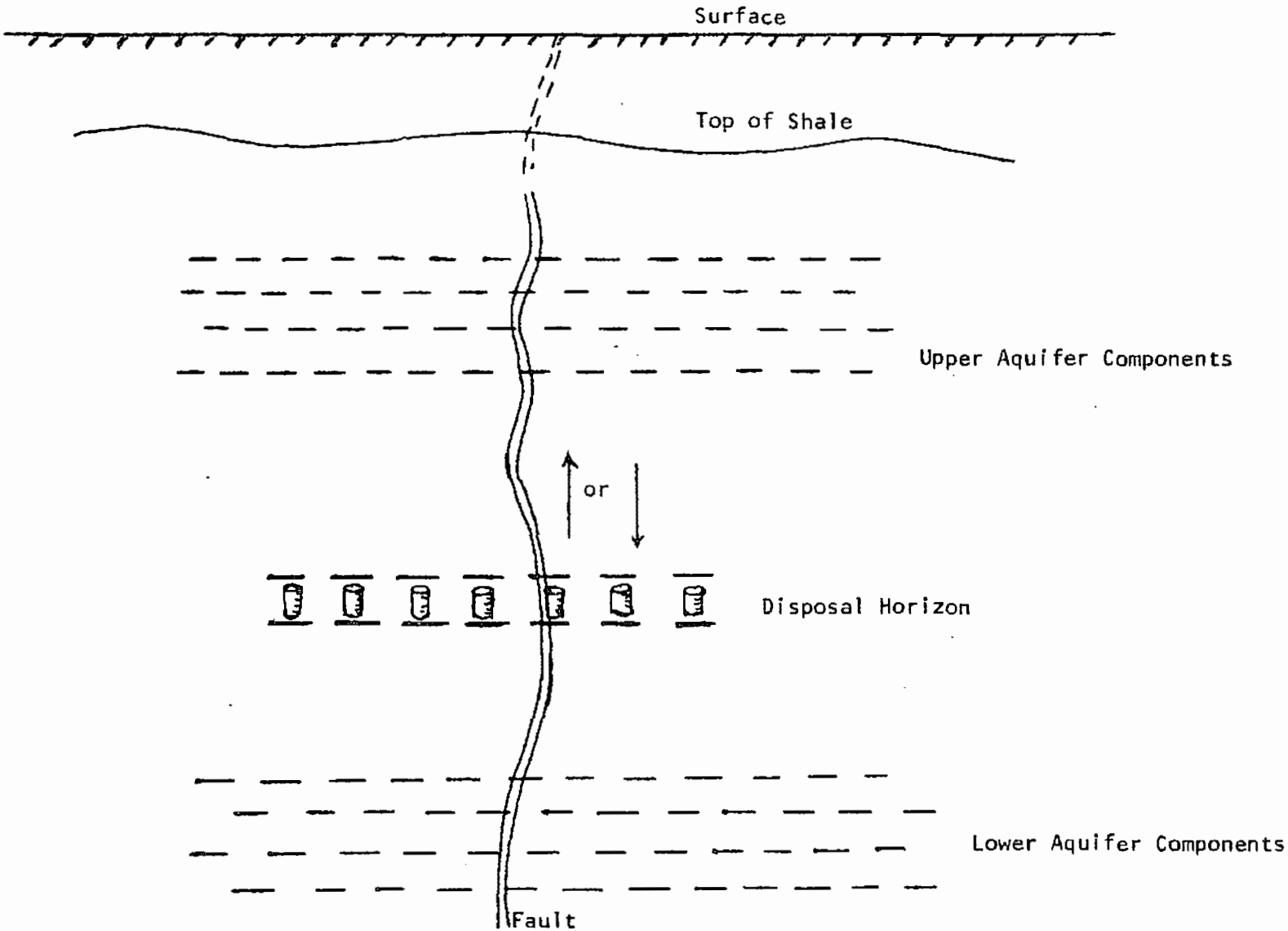


Figure 11-1. Interconnection of upper and lower aquifer bands in shale by offset faulting.

model parameters used for the formations overlying the bedded salt at Los Medaños are also assumed here for demonstration purposes (see Table 6-9). This includes a water velocity of 4×10^{-3} m/d (1.51 m/y). The exception is K_d values. Appendix C presents estimated K_d values for shale based upon Oklo natural reactor data. The values listed in Column 2 of Table C-2, plus 600 for Cm, are used here. For comparison, the values listed in Column 1 (but reduced by 30%) were used for the bedded salt application. As discussed in Part 1, a K_d value of only slightly over 10 results in retardation sufficient to prevent discharge within 10^6 y. The only nuclide listed with an estimated K_d less than 200 for shale is I-129; this becomes the only nuclide for which calculations can show discharge.

C. RESULTS AND COMPARISON WITH BEDDED SALT

The repository in shale is assumed to occupy double the area of the corresponding model repository in bedded salt. This leads to some increase in the probabilities for disruptive event occurrences but generally results in reduced releases if an event does occur. Table 11-2 lists ratios which compare release parameters for shale from Table 11-1 to those for bedded salt from Table 6-4. For meteorite impact, the doubled probability for doubled area is offset by the halved release (concentration in shale repository one-half that in bedded salt) and the net transfer coefficient (product of probability and release fraction) is therefore the same for both geologic settings (ratio of 1.00). The transfer coefficients for volcanism events for shale become 0.75 to 0.83 times those for bedded salt. The conditions for leaching are input as being unchanged and the transfer coefficient for faulting and leaching shows an increase for shale corresponding to the greater probability that the larger area will be penetrated by a fracture.

The only nuclide listed with an estimated K_d less than 20 cm^3/g is I-129. As a value only slightly over 10 results in retardation sufficient to prevent discharge within 10^6 y, I-129 is the only nuclide which contributes to consequences via ground water in shale.

Figure 11-2 summarizes results with graphs of total body local dose rates in Zones 1 and 2 and nonspecific dose rate, totaled for all nuclides. Earlier results for bedded salt are added to Fig. 11-2 for comparison with the results obtained for shale. Dose rates are seen to be consistently lower for shale, but not dramatically lower. This follows from the lower volcanism calculated contributions and improved sorption properties of shale which prevent discharge of C-14, Tc-99, and Np-237. In particular, breakthrough of Np for the bedded salt case commencing at 700,000 y (note the spike in Fig. 7-2 near 10^6 y) does not occur for the shale case.

Various other categories of AMRAW output are reduced for the shale case by the relative amounts indicated by Fig. 11-2. Because of the preliminary nature of this demonstration, input data uncertainty is such that detailed analysis of the output is not justified. The objective

Table 11-2. Ratios of Release Parameters for Shale to Those for Bedded Salt

Cut Sets[a]	Event	Annual Probability P	Release Fraction A1	Transfer Coefficient P x A1
1, 5, 8	Meteorite Impact	2.00	0.05	1.00
2	Volcanic Explosion	1.25	0.60	0.75
3	Diatreme	1.25	0.67[b]	0.83
6, 9	Volcanogenic Transport	1.23	0.60	0.74
10	Faulting and Leaching	1.43	1.00	1.43

[a]Cut sets 4 and 7, surface erosion, do not contribute to calculated release and are omitted here.

[b]Based upon a corrected value of A1 = .0105 for bedded salt.

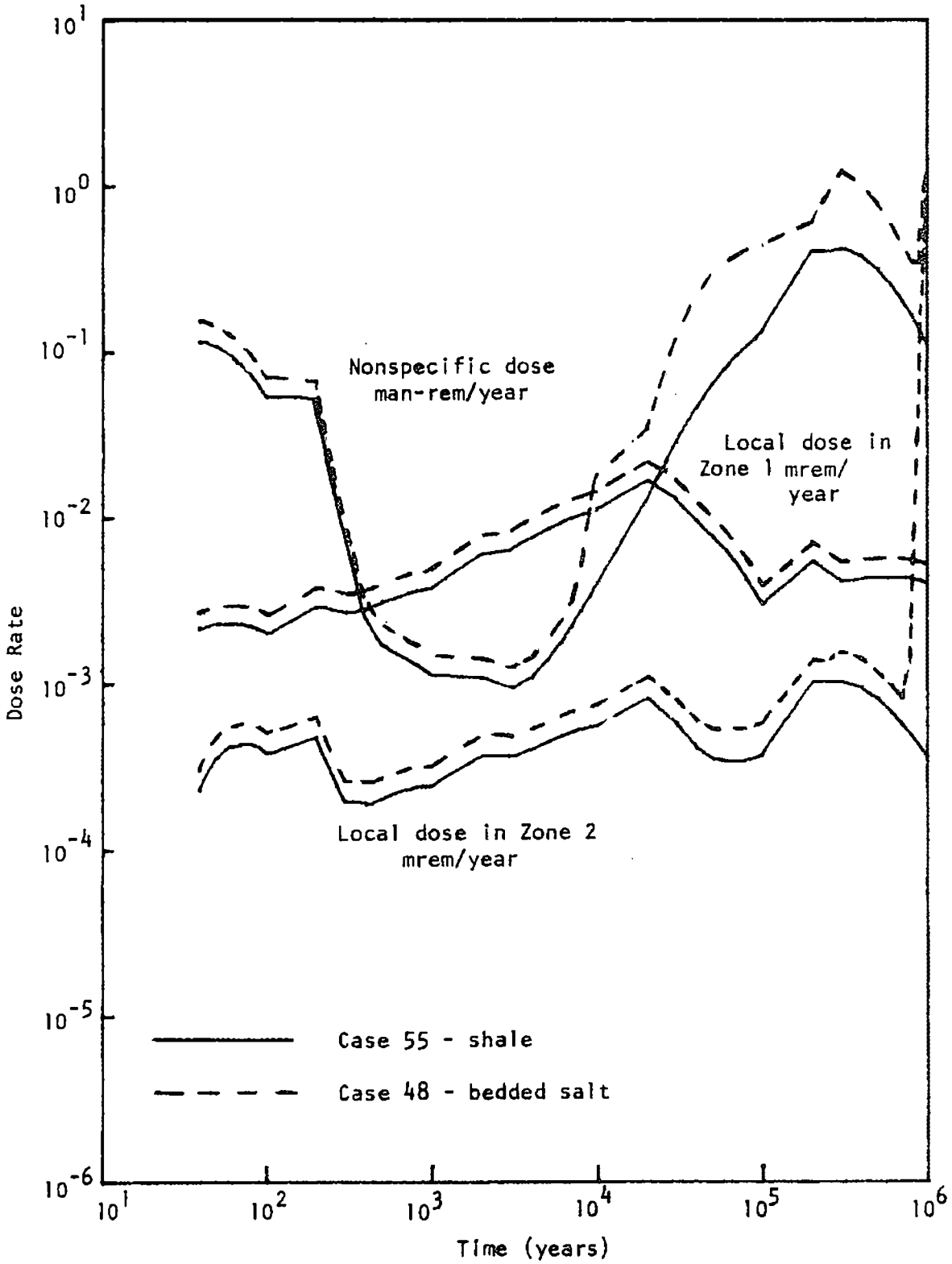


Figure. 11-2. Repository in shale compared to bedded salt: average annual local total body dose to individual in Zones 1 and 2 and nonspecific dose, total all nuclides.

here is simply to illustrate methods for changing data to apply AMRAW to another geologic setting though data acquisition for the purpose is incomplete.

CHAPTER 12

APPLICATIONS TO OTHER RADIOACTIVE AND NONRADIOACTIVE HAZARDOUS MATERIALS

The Radioactive Waste Management Systems Model and computer code AMRAW were developed for the purpose of providing tools for technology assessment of the several phases in the high-level radioactive waste management sequence. Basically, the model considers: 1) a hazardous material confined within protective barriers, 2) disruptive processes which can lead to migration, 3) movement to and through the environment to man, and 4) effects on man from exposure or intake. This suggests that the model is not limited to high-level radioactive waste but may be applicable to low or intermediate level waste, transuranic (TRU) waste, or other nonradioactive hazardous materials. A study was performed to examine the feasibility of applying AMRAW to these other materials. This involved tracing the flow of calculations to determine whether AMRAW parameters apply directly or can be adopted to apply to the other materials.

A. OTHER RADIOACTIVE MATERIALS

Radioactive waste which is other than high-level covers a wide range of materials including ion exchange resins, contaminated hardware, chemical residues, and ash residues from incineration of contaminated combustible materials. Further, these may be configured in a variety of waste forms including solidification in cement or bitumin. Disposal of this class of material in the past has been in shallow land burial sites. In the future, repository sites may range from shallow land burial to deeper geological disposal, depending upon degrees of protection required for various categories of material.

In general, AMRAW can be applied directly to these other radioactive materials. The use of each parameter is the same as for high-level waste, though there may be considerable differences in numerical values of input data. Because of the generally lower level of radioactivity prominance of short-lived nuclides and correspondingly less stringent handling, processing, and disposal requirements, the assessment process may concentrate on shorter time frames. Release scenarios appropriate to shorter time frames are emphasized. There can be some difficulty in establishing the inventory of radionuclides to be considered due to the mixture of waste components. The range of components and waste forms also presents some difficulty in estimating leaching parameters. If a wide range of leachability for components of varying nuclide content prevents use of averaged leaching properties for a given repository, AMRAW may be applied to each of two or more categories and the results superimposed.

The AMRAW code is quite flexible and can readily accept the input required to address radioactive materials derived from various sources. However, as with any new application, careful analysis of the specific problem is required in order to identify and deal properly with the prominent events and activities affecting the solution.

B. NONRADIOACTIVE HAZARDOUS MATERIALS

Hazardous materials may be divided into several general categories: 1) chemically toxic or poisonous, 2) flammable, 3) explosive, 4) biologically infectious, or 5) radioactive.

The term "hazardous waste" is defined in the Resource Conservation and Recovery Act of 1976 [PL76] as,

> "...a solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may--
>
> > "(A) cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness; or,
> >
> > "(B) pose a substantial present or potential hazard to human health, or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed..."

Further, the term "hazardous waste management" is stated to mean

> "...the systematic control of the collection, source preparation, storage, transportation, processing, treatment, recovery, and disposal of hazardous wastes."

Among other things, the Act is designed to provide technical and financial assistance for the safe disposal of discarded materials, and to regulate the management of hazardous waste. Although it specifically excludes source, special nuclear, and byproduct material as defined by the Atomic Energy Act of 1954, the parallel between these nonradioactive hazardous materials and the radioactive materials for which AMRAW was primarily designed can be seen from the above definitions. The principal differences affecting application of AMRAW to these materials are due primarily to the chemical and/or biological nature of their damage mechanisms, as opposed to radiological, and up to infinite lifetimes. Inhalation of large doses of toxic gases such as chlorine or phosgene, constitutes probably the most hazardous combination of poison and pathway, but the relatively short lifetimes of these gases in our environment place them somewhat outside the intended scope of AMRAW. In contrast elements or compounds such as barium, arsenic, cyanide and a host of other toxic materials are essentially permanent environmentally and

appear in or can be reduced to solid form. It is the management of these materials that can be best assessed with AMRAW. Wherever possible objectives should be to recycle hazardous materials or to chemically convert them to non-hazardous compounds, instead of disposing them as hazardous materials in a repository. While AMRAW may be applied to various management phases such as surface storage and transportation, the discussion which follows refers to the disposal phase. The concepts developed also apply in a general sense to the other phases.

Figure 12-1 repeated from Vol. I, is a schematic of one branch of the systems model applied, say, to a waste repository after operations are completed (terminal storage). The following paragraphs refer to this figure and consider each step through the model.

1. Inventory at Risk. The repository inventory may vary greatly, both in composition and size, for the wide range of possible applications. Waste inventories which are likely to be encountered may not be particularly large but may be highly specialized and unique.

The waste inventory input to AMRAW is a matrix in mass units, such as grams, of each element or compound of interest at each time to be calculated over the full time range studied. A compound which does not degrade with time has the same mass at all times. If it does degrade, input data reflects this by different masses at the various times following emplacement. If degradation is associated with transformation into another hazardous material, this is reflected by input data for the other material showing an increase in mass. This is analogous to radiodecay in that it is a transformation from a hazardous form to either a non-hazardous or another hazardous form. Consideration is required of potential chemical, molecular combination, phase or other changes which might be incurred by certain constituents of the waste inventory as the result of time in specific environments. These can be expressed by the input mass data for various compounds or forms. AMRAW calculates decay factors, DECFAC, using the input matrix of masses. It appears that this provision serves equally well for chemical decay of compounds or radiodecay of nuclides. If an infinite lived compound is involved, the

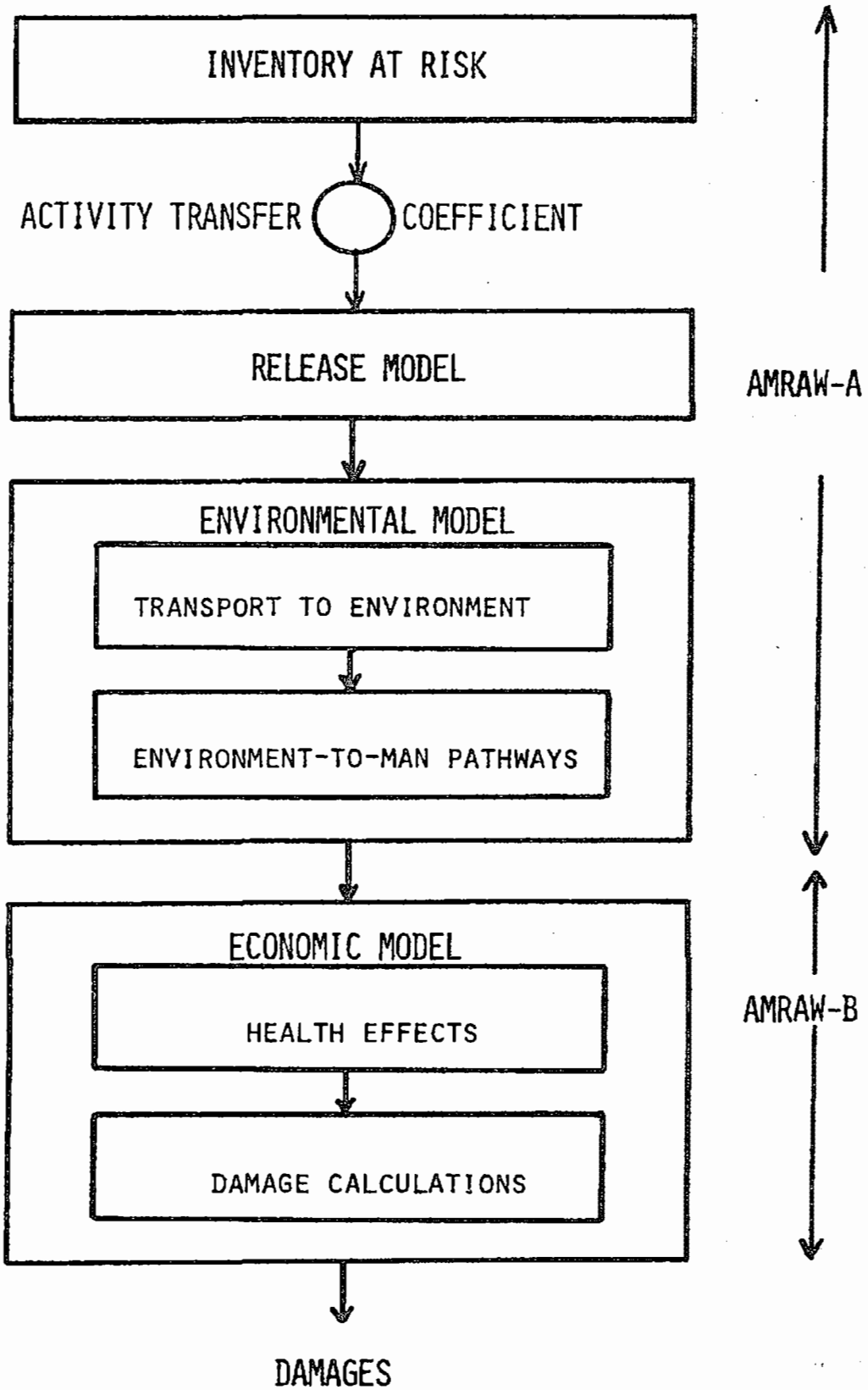


Figure 12-1. One branch of systems model.

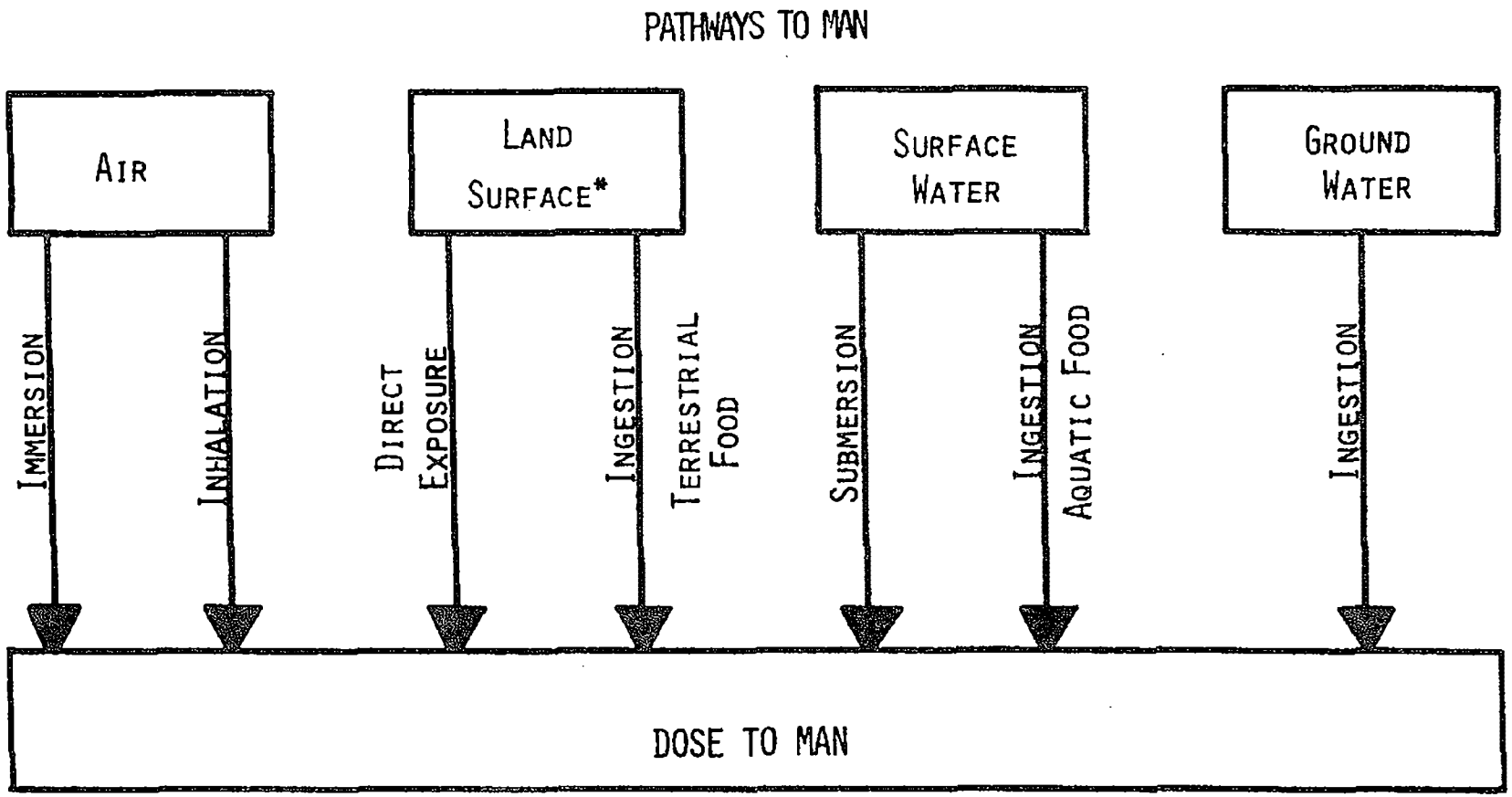
constant inventory with time simply evolves decay factors equal to unity.

2. Activity Transfer Coefficient. For radioactive waste, this is the specific activity, Ci/g, and this converts mass in the inventory to activity in Curies. For nonradioactive materials, the calculations may be retained in mass units by input of 1.0 for this parameter for each compound considered. If a toxicity index comes into usage and it is desired to carry the calculations in terms of such units, the activity transfer coefficient can be employed to make the conversion.

3. Release Model. Release Model calculations are performed in the same manner as for radioactive materials and differ from the other applications mainly in input parameters associated with the elements and compounds forming the waste, and the scenarios pertinent to probably shorter time frames and perhaps less effective geologic barriers. The release model calculates the fraction of inventory released during a given time period either on a probabilistic or discrete event basis, as designated by input parameters. It makes no difference whether this refers to an inventory in grams, Curies, or some other unit. It is within this model that a sub-program calculates leached quantities. There may be difficulty in determining appropriate diffusivity coefficients, $\mathcal{D}_e$, and dissolution rate constants, k, for the variety of compounds and waste forms.

4. Transport to Environment. This first part of the Environment Model can operate the same for nonradioactive materials as for radioactive materials. Retardation in ground water transport depends upon the distribution coefficient, K_d. There may be difficulty in obtaining values of K_d to use for the variety of chemical forms encountered.

5. Environment-to-Man Pathways. This last part of the Environmental Model is where differences of emphasis appear between radioactive and nonradioactive applications. Figure 12-2, repeated from Vol. I, illustrates the main environment-to-man pathways. Predominant casual pathways for nonradioactive materials are ingestion, and, to a lesser extent, inhalation of resuspended or transformed materials. Immersion, submersion, and direct exposure, which would correspond to direct contact pathways such as skin contact with caustic chemicals, are of less significance because of dilution in the analysis of effects caused by



*For Land Surface, the net total accumulated concentration applies to the Direct Exposure pathway, and current deposition concentration applies to the Terrestrial Food pathway.

Figure 12-2. Main environment-to-man pathways.

later, non-occupational exposure.

The environmental input receptor concentrations, which are calculated in preceding stages, are transformed to human dose commitment through the transfer coefficient, C, which is formed as follows,

$$C = BIOFAC \times VOLINT \times DOSFAC \ . \qquad (12\text{-}1)$$

The factor, BIOFAC, expresses the concentration or integrated concentration in food and drink per unit concentration in the associated environment, and input values may be obtained in the same manner as for radionuclides. Difficulty could arise, however, where particular elements or compounds of interest are not currently included in output by codes such as TERMOD [Kℓ76] or FOOD [Ba76] or where no stable element transfer factors or bioaccumulation factors have been generated.

The second factor, VOLINT, expresses the consumption, exposure or food production rate for each zone or subpath, and values may also be produced in the same manner as for radioactive nuclides. Immersion and direct exposure values should be carried through this factor, in the event they are required for some specialized calculation or sensitivity analyses.

The last term, DOSFAC, is the dose commitment conversion factor for each combination of element or compound, organ, and exposure mode. For intake of radionuclides, DOSFAC expresses mrem of dose equivalent per μCi of activity intake. This is the single factor for which no simple analogous approach currently exists for toxic materials. However, if the values in the DOSFAC matrix are simply input as 1.0, the output from the Environmental Model will be calculated intake. For example, if masses of toxic materials in grams are carried through the model (inventory in grams and "specific activity" = 1.0), setting DOSFAC = 1.0 results in intake in μg being calculated, or a "dose rate" of μg/y. This form can be useful for comparisons or a judgement review to determine whether excessive values for public safety are indicated. Setting DOSFAC = 0.0 may be input for immersion in air or water and direct exposure to land surface, to confine the problem to one concerned with the ingestion and inhalation pathways. Before proceeding with the Economic Model, additional discussion follows concerning the difficulty

of relating intake of toxic materials to effects.

Certain characteristics of toxic effects will affect adaptation of AMRAW at this stage. First, the radiological application develops nuclide concentrations in various organs, including total body, from which estimated damages or damage rates are obtained directly based on nuclide characteristics. Only the concentrations are pathway dependent. In describing the effects of poisons on humans, however, the detailed body organ receptor stage is replaced by cataloging data based largely on mode of entry. For example, the inhalation hazard categorization and toxic effects are treated in terms of LC_{50} or lethal concentrations in the input environment; the ingestion hazard is treated in terms of LD_{50} or concentration in the recipient, a scheme more closely approaching the radiological method. This is illustrated in Table 12-1 taken from EPA publication SW-508 [EPA76a] which contains an accepted breakout of hazard categories together with criteria applicable to different hazard grade levels used in a scheme developed by the National Academy of Sciences for the U. S. Coast Guard. Difficulty in effecting the AMRAW interface is further aggravated by deficiencies in available toxicology information [EPA76b]. For the most part, descriptions and documentation of toxicity are published for elemental parent substances and very little information is available for many new compounds. Also, most documentation deals with responses to acute doses in relatively high concentrations, as is pertinent to occupational or laboratory interest, and very little information is available that is relevant to the relatively small quantities or concentrations expected in repositories or landfills. As a result, biological half-lives, and the immediate, latent, cumulative, and genetic effects of small repeated doses are germaine but are not yet fully available and assembled for convenient use in analyses such as AMRAW.

Another feature noted from Table 12-1 is the inclusion of hazard effect categories other than those effecting man directly; viz., fire, aquatic toxicity, and reactions. The original framework of AMRAW [Lo74a] contained a branch for "Environmental Effects" to cover effects not directly man related, but to reduce complexity in subsequent development of AMRAW, this feature was eliminated.

Table 12-1. Summary of Hazard Evaluation Criteria[a]

	GRADE	Hazard Categories: I Fire	II Health: Skin and Eyes	III Health: Vapor Inhalation	IV Health: Gas Inhalation	V Health: Repeated Inhalation	VI Water Pollution: Human Toxicity	VII Water Pollution: Aquatic Toxicity	VIII Reaction: Water Reaction	IX Reaction: Self-Reaction
Essentially Nonhazardous Wastes	0	Non-combustible	All not described below	All not described below	Not Applicable	OSHA ≥ 1000 ppm	LD_{50} > 5000 mg/kg	TL_m > 1000 mg/ℓ	Insignif. Hazard	No appreciable self-reaction
Priority II Moderately Hazardous Wastes	1	FPcc > 140°F (60°C)	Corrosive to eyes	Depressants, asphyxiants	All not described below	OSHA 100-1000 ppm	LD_{50} 500-5000 mg/kg	TL_m 100-1000 mg/ℓ	e.g., Cl_2	May polymerize with low heat evolution
	2	FPcc 100°F-140°F (37.8°-60°C)	Corrosive to skin	LC_{50} 200-2000 ppm	LC_{50} 200-2000 ppm	OSHA 10-100 ppm	LD_{50} 50-500 mg/kg	TL_m 10-100 mg/ℓ	e.g., NH_3	Contamination may cause polymerization; no inhibitor required
Priority I* Highly Hazardous Wastes	3	(37.8°C) FPcc < 100°F BP > 100°F (37.8°C)	LD_{50} 20-200 mg/kg 24-hr. skin contact	LC_{50} 50-200 ppm or 0.5-2 mg/ℓ	LC_{50} 50-200 ppm	OSHA 1-10 ppm	LD_{50} 5-50 mg/kg	TL_m 1-10 mg/ℓ	e.g., Dioxum	May polymerize; requires stabilizer
	4	(37.8°C) FPcc < 100°F BP < 100°F (37.8°C)	LD_{50} ≤ 20 mg 24-hr. skin contact	LC_{50} ≤ 50 ppm or ≤ 0.5 mg/ℓ	LC_{50} ≤ 50 ppm	OSHA < 1 ppm	LD_{50} < 5 mg/kg	TL_m < 1 mg/ℓ	e.g., SO_3	Self-reaction may cause explosion or detonation

*Priorities are discussed in Subsection 3.1.3

Note: Bio-concentratable materials are raised to next higher hazard classification. Suspected carcinogens are rated as Grade 4.

[a]Taken from EPA publication SW-508 [EPA76a].

6. Economic Model. The Economic Model comprises AMRAW-B and draws as its major input the "dose rate" output from AMRAW-A. The first part of this model is Health Effects. For radioactive materials, this part of the model applies incidence rates of various health effects (various cancers, particularly) to corresponding organ dose rates to obtain deaths from health effects. This assumes a linear response of effects to dose. For nonradioactive hazardous materials, simple correlations apparently do not yet exist. If a threshold response is more realistic, test statements can be added to AMRAW-B to determine whether a calculated intake rate exceeds a threshold for a given effect, whether morbidity or death. Again, the combination of the DOSFAC factor in AMRAW-A and the incidence rates of health effects factor in AMRAW-B comprise the area where more information about toxic materials is needed. Knowledge of radioactivity and its effects is more advanced than for other materials. The final part of the Economic Model, Damage Calculations, can proceed as with assessment of radioactive waste management phases. The evaluation of health effects depends upon whether morbidity or death is being considered.

7. Additional Discussion. From this brief survey of nonradioactive hazardous waste management it appears that terminal disposal philosophy for these materials is strongly based on rapid environmental decay and expected waste dilution on the intermediate time scales of concern. The sensitivity and meaning of the Environmental Decay Constant, EDC, used in AMRAW may require further study for this type of application. Throughout AMRAW, editorial changes are required such as modification of FORMAT write statements to reflect the type of assessment and the nature of input data and output.

Also, in contemplating the application of AMRAW to nonradioactive wastes, note should be taken of the wide variety of waste inventory compositions which can be encountered, the relatively small, decentralized nature of operations and disposal of the materials--usually co-located with the generating plant, and of the somewhat independent manner in which industry has necessarily operated in this field, conforming to state or local guidelines where they exist, or resorting to its own judgement. One intent of the Resource Conservation and Recovery Act of 1976 is to

bring order and a common frame of reference to these activities, and it is possible that methodology such as is offered in AMRAW can be useful in solving many aspects of this problem.

APPENDIX O

SAMPLE AMRAW REPOSITORY OPERATIONS DOSE CALCULATION OUTPUT

Sample output for the preliminary demonstration of AMRAW to the repository operations phase, Case No. 56, all probabilistic releases, broken down by environmental receptors.

Table O-1

Average Annual Local Dose to Individual, MAN2LF for JF = 1 to 4, MAN2L for Total, mrem/y, Total for All Nuclides, Zones 1 and 2.

Table O-2

Average Annual Nonspecific Dose to Population, MAN2NF for JF = 1 to 4, MAN2N for Total, man-rem/y, Total for All Nuclides.

Table O-1.

** AVERAGE ANNUAL LOCAL DOSE TO INDIVIDUAL, MAN2LF FOR JF=1 TO 4, MAN2L FOR TOTAL, IN MILLIREMS/YEAR

TOTAL FOR ALL NUCLIDES — TOT BODY

ZONE= 1

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER	TOTAL
0.	0.0	0.0	0.0	0.0	0.0
5.	2.73E-01	1.66E-03	0.0	0.0	2.74E-01
10.	1.22E 00	9.23E-03	0.0	0.0	1.23E 00
15.	2.47E 00	2.28E-02	0.0	0.0	2.49E 00
20.	3.46E 00	3.84E-02	0.0	0.0	3.50E 00
25.	3.84E 00	5.09E-02	0.0	0.0	3.89E 00
30.	3.41E 00	5.60E-02	0.0	0.0	3.46E 00
40.	1.80E 00	4.60E-02	0.0	0.0	1.85E 00
50.	1.36E 00	3.60E-02	0.0	0.0	1.40E 00
60.	1.06E 00	2.92E-02	0.0	0.0	1.09E 00
70.	8.41E-01	2.43E-02	0.0	0.0	8.66E-01
80.	6.78E-01	2.06E-02	0.0	0.0	6.98E-01
90.	5.57E-01	1.80E-02	0.0	0.0	5.75E-01
100.	4.69E-01	1.61E-02	0.0	0.0	4.85E-01
200.	3.22E-01	1.30E-02	0.0	0.0	3.35E-01
300.	1.89E-01	1.03E-02	0.0	0.0	2.00E-01
400.	1.55E-01	9.48E-03	0.0	0.0	1.64E-01
500.	1.35E-01	8.91E-03	0.0	0.0	1.44E-01
600.	1.20E-01	8.41E-03	0.0	0.0	1.29E-01
700.	1.09E-01	7.94E-03	0.0	0.0	1.17E-01
800.	9.67E-02	7.50E-03	0.0	0.0	1.06E-01
900.	9.00E-02	7.10E-03	0.0	0.0	9.71E-02
1000.	8.25E-02	6.75E-03	0.0	0.0	8.92E-02
2000.	6.39E-02	5.75E-03	0.0	0.0	6.96E-02
3000.	4.50E-02	4.59E-03	0.0	0.0	4.96E-02
4000.	3.87E-02	3.98E-03	0.0	0.0	4.27E-02
5000.	3.45E-02	3.51E-03	0.0	0.0	3.80E-02
6000.	3.10E-02	3.11E-03	0.0	0.0	3.41E-02
7000.	2.81E-02	2.76E-03	0.0	0.0	3.08E-02
8000.	2.55E-02	2.47E-03	0.0	0.0	2.80E-02
9000.	2.33E-02	2.22E-03	0.0	0.0	2.55E-02
10000.	2.13E-02	2.00E-03	0.0	0.0	2.33E-02
20000.	1.41E-02	1.22E-03	0.0	0.0	1.53E-02
30000.	6.27E-03	4.14E-04	0.0	0.0	6.68E-03
40000.	3.08E-03	1.26E-04	0.0	0.0	3.20E-03
50000.	1.72E-03	3.95E-05	0.0	0.0	1.76E-03
60000.	1.03E-03	1.49E-05	0.0	0.0	1.05E-03
70000.	6.36E-04	7.25E-06	0.0	0.0	6.43E-04
80000.	3.94E-04	4.41E-06	0.0	0.0	3.99E-04
90000.	2.47E-04	3.09E-06	0.0	0.0	2.50E-04
100000.	1.57E-04	2.32E-06	0.0	0.0	1.60E-04
200000.	3.04E-05	6.79E-07	0.0	0.0	3.11E-05
300000.	2.14E-06	7.38E-08	0.0	0.0	2.22E-06
400000.	2.21E-07	7.76E-09	0.0	0.0	2.29E-07
500000.	2.22E-08	7.88E-10	0.0	0.0	2.30E-08
600000.	2.19E-09	7.86E-11	0.0	0.0	2.26E-09
700000.	2.13E-10	7.75E-12	0.0	0.0	2.21E-10
800000.	2.06E-11	7.58E-13	0.0	0.0	2.13E-11
900000.	1.98E-12	7.38E-14	0.0	0.0	2.05E-12
1000000.	1.90E-13	7.17E-15	0.0	0.0	1.97E-13

ZONE= 2

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER	TOTAL
0.	0.0	0.0	0.0	0.0	0.0
5.	9.88E-04	3.39E-06	4.68E-03	0.0	5.67E-03
10.	4.29E-03	1.86E-05	1.47E-02	0.0	1.90E-02
15.	8.35E-03	4.57E-05	2.80E-02	0.0	3.70E-02
20.	1.11E-02	7.62E-05	4.39E-02	0.0	5.51E-02
25.	1.16E-02	1.00E-04	5.75E-02	0.0	6.92E-02
30.	9.32E-03	1.10E-04	6.38E-02	0.0	7.32E-02
40.	3.54E-03	9.03E-05	5.27E-02	0.0	5.63E-02
50.	2.68E-03	7.07E-05	4.10E-02	0.0	4.38E-02
60.	2.09E-03	5.73E-05	3.23E-02	0.0	3.45E-02
70.	1.65E-03	4.76E-05	2.55E-02	0.0	2.72E-02
80.	1.33E-03	4.05E-05	2.01E-02	0.0	2.14E-02
90.	1.09E-03	3.53E-05	1.58E-02	0.0	1.69E-02
100.	9.21E-04	3.16E-05	1.25E-02	0.0	1.34E-02
200.	6.32E-04	2.56E-05	6.47E-03	0.0	7.13E-03
300.	3.72E-04	2.02E-05	1.52E-03	0.0	1.91E-03
400.	3.04E-04	1.86E-05	1.02E-03	0.0	1.35E-03
500.	2.65E-04	1.75E-05	8.89E-04	0.0	1.17E-03
600.	2.37E-04	1.65E-05	7.96E-04	0.0	1.05E-03
700.	2.14E-04	1.56E-05	7.15E-04	0.0	9.45E-04
800.	1.94E-04	1.47E-05	6.41E-04	0.0	8.50E-04
900.	1.77E-04	1.40E-05	5.74E-04	0.0	7.65E-04
1000.	1.62E-04	1.33E-05	5.16E-04	0.0	6.92E-04
2000.	1.26E-04	1.13E-05	3.73E-04	0.0	5.10E-04
3000.	8.85E-05	9.01E-06	2.32E-04	4.08E-23	3.29E-04
4000.	7.60E-05	7.83E-06	1.91E-04	1.46E-13	2.75E-04
5000.	6.77E-05	6.89E-06	1.66E-04	3.81E-09	2.41E-04
6000.	6.10E-05	6.10E-06	1.50E-04	2.83E-07	2.17E-04
7000.	5.52E-05	5.43E-06	1.43E-04	9.95E-07	2.04E-04
8000.	5.02E-05	4.85E-06	1.38E-04	9.44E-07	1.93E-04
9000.	4.59E-05	4.36E-06	1.28E-04	2.47E-07	1.78E-04
10000.	4.19E-05	3.94E-06	1.17E-04	1.87E-08	1.63E-04
20000.	2.77E-05	2.41E-06	7.88E-05	1.02E-11	1.09E-04
30000.	1.23E-05	8.13E-07	3.75E-05	4.12E-36	5.06E-05
40000.	6.05E-06	2.47E-07	2.09E-03	0.0	2.72E-05
50000.	3.39E-06	7.76E-08	1.40E-05	0.0	1.75E-05
60000.	2.03E-06	2.93E-08	1.05E-05	1.25E-31	1.26E-05
70000.	1.25E-06	1.42E-08	8.22E-06	1.71E-25	9.48E-06
80000.	7.76E-07	8.67E-09	6.50E-06	2.25E-21	7.28E-06
90000.	4.85E-07	6.07E-09	5.15E-06	1.36E-18	5.64E-06
100000.	3.09E-07	4.57E-09	4.09E-06	9.77E-17	4.40E-06
200000.	5.97E-08	1.33E-09	1.11E-06	6.65E-14	1.18E-06
300000.	4.21E-09	1.45E-10	9.86E-08	5.75E-20	1.03E-07
400000.	4.34E-10	1.52E-11	8.00E-09	1.42E-28	8.53E-09
500000.	4.36E-11	1.55E-12	6.44E-10	1.70E-20	6.89E-10
600000.	4.28E-12	1.54E-13	7.58E-11	2.67E-14	8.03E-11
700000.	4.17E-13	1.52E-14	1.96E-07	2.10E-10	1.96E-07
800000.	4.03E-14	1.49E-15	5.83E-05	6.26E-08	5.83E-05
900000.	3.88E-15	1.45E-16	2.02E-03	2.17E-06	2.02E-03
1000000.	3.72E-16	1.41E-17	1.58E-02	1.68E-05	1.58E-02

Table O-2.

** AVERAGE ANNUAL NONSPECIFIC DOSE TO POPULATION, MAN2NF FOR JF=1 TO 4,

TOTAL FOR ALL NUCLIDES MAN2N FOR TOTAL, IN MANREMS/YEAR TOT BODY

TIME	JF=1 AIR	JF=2 GROUND SURFACE	JF=3 SURFACE WATER	JF=4 GROUND WATER	TOTAL
0.	0.0	0.0	0.0	0.0	0.0
5.	0.0	5.39E 00	5.91E-01	0.0	5.98E 00
10.	0.0	1.20E 01	1.66E 00	0.0	1.37E 01
15.	0.0	1.76E 01	2.98E 00	0.0	2.06E 01
20.	0.0	2.09E 01	4.37E 00	0.0	2.53E 01
25.	0.0	2.12E 01	5.64E 00	0.0	2.69E 01
30.	0.0	1.47E 01	6.17E 00	0.0	2.09E 01
40.	0.0	0.0	4.92E 00	0.0	4.92E 00
50.	0.0	0.0	3.79E 00	0.0	3.79E 00
60.	0.0	0.0	2.99E 00	0.0	2.99E 00
70.	0.0	0.0	2.36E 00	0.0	2.36E 00
80.	0.0	0.0	1.86E 00	0.0	1.86E 00
90.	0.0	0.0	1.46E 00	0.0	1.46E 00
100.	0.0	0.0	1.14E 00	0.0	1.14E 00
200.	0.0	0.0	5.01E-01	0.0	5.01E-01
300.	0.0	0.0	4.71E-02	0.0	4.71E-02
400.	0.0	0.0	6.27E-03	0.0	6.27E-03
500.	0.0	0.0	2.02E-03	0.0	2.02E-03
600.	0.0	0.0	1.40E-03	0.0	1.40E-03
700.	0.0	0.0	1.21E-03	0.0	1.21E-03
800.	0.0	0.0	1.09E-03	0.0	1.09E-03
900.	0.0	0.0	9.78E-04	0.0	9.78E-04
1000.	0.0	0.0	8.85E-04	0.0	8.85E-04
2000.	0.0	0.0	6.74E-04	0.0	6.74E-04
3000.	0.0	0.0	4.98E-04	9.63E-20	4.98E-04
4000.	0.0	0.0	5.01E-04	3.45E-10	5.01E-04
5000.	0.0	0.0	6.21E-04	9.00E-06	6.30E-04
6000.	0.0	0.0	6.89E-03	6.68E-04	7.55E-03
7000.	0.0	0.0	2.86E-02	2.35E-03	3.10E-02
8000.	0.0	0.0	4.87E-02	2.23E-03	5.09E-02
9000.	0.0	0.0	5.29E-02	5.83E-04	5.35E-02
10000.	0.0	0.0	5.20E-02	4.42E-05	5.21E-02
20000.	0.0	0.0	4.83E-02	2.50E-05	4.83E-02
30000.	0.0	0.0	3.76E-02	5.47E-12	3.76E-02
40000.	0.0	0.0	2.84E-02	7.63E-34	2.84E-02
50000.	0.0	0.0	2.18E-02	0.0	2.18E-02
60000.	0.0	0.0	1.69E-02	2.29E-29	1.69E-02
70000.	0.0	0.0	1.31E-02	3.13E-23	1.31E-02
80000.	0.0	0.0	1.02E-02	4.11E-19	1.02E-02
90000.	0.0	0.0	7.91E-03	2.50E-16	7.91E-03
100000.	0.0	0.0	6.15E-03	1.79E-14	6.15E-03
200000.	0.0	0.0	1.54E-03	1.22E-11	1.54E-03
300000.	0.0	0.0	1.19E-04	1.51E-16	1.19E-04
400000.	0.0	0.0	8.89E-06	2.32E-16	8.89E-06
500000.	0.0	0.0	6.55E-07	1.35E-19	6.55E-07
600000.	0.0	0.0	4.84E-08	3.15E-14	4.84E-08
700000.	0.0	0.0	2.34E-07	2.48E-10	2.35E-07
800000.	0.0	0.0	6.88E-05	7.39E-08	6.88E-05
900000.	0.0	0.0	2.39E-03	2.56E-06	2.39E-03
1000000.	0.0	0.0	1.87E-02	1.98E-05	1.87E-02

APPENDIX P

DESCRIPTION OF DENVER BASIN
(ASSEMBLED BY P. A. LONGMIRE)

GEOGRAPHIC FEATURES OF THE DENVER BASIN

The Denver Basin is one of the largest basins in the Rocky Mountain area. It extends over 60,000 square miles across northeastern Colorado, western Nebraska, and southeastern Wyoming. It is typically asymmetric with its axis parallel with and close to the Front Range of central Colorado; its deepest portion lies near Denver where there are more than 13,000 feet of sediments.

Bounding the Basin on the west are the Front and Laramie Ranges of Colorado and Wyoming. Other tectonic features surrounding the Basin include the Hartville uplift on the northwest, the Black Hills on the north, the Chadron-Cambridge Arch on the northeast, the Las Animas arch on the southeast and on the south and southwest, the Sierra Grande and Apishipa uplifts.

Strata in and around the Basin indicate that the area was predominantly a marine shelf during the early Paleozoic. Uplift during the middle Paleozoic locally exposed older sedimentary rocks to extensive erosion.

GEOLOGIC HISTORY OF THE DENVER BASIN

The seas transgressed in the Early Pennsylvanian and eroded the Mississippian systems from the south. Fine to medium clastics and dense thin-bedded carbonates were deposited in these seas. The first major uplift of the Ancestral Rockies occurred in the Lower Pennsylvanian Period. This uplift reached its peak during Lower Middle Pennsylvanian. Clastic material from the uplifted mountains intertongues with marine sediments of the expanding Des Moines sea. Marine transgression continued through the Upper Middle Pennsylvanian Period. Regression continued during the Permian and a suite of rocks was deposited which range from normal marine through evaporite to continental.

Upper Permian and Triassic rocks supplied sediments to a shallow hypersaline sea. Non-deposition persisted from Late Triassic to Middle Jurassic time. During the Middle and Late Jurassic, seas encroached from the northwest. At the close of the Jurassic, the seas regressed and a broad Flood plain was developed.

The present basin form began to emerge as Early Cretaceous seas advanced from the north and south [Bt37]. Earlier sediments were reworked and the Jurassic-Cretaceous boundary was obscured. As the sea regressed, Fluviatile material from the east and northeast developed a complex delta system which intertongued with marine sediments basin ward. Another delta extended into the area from the southwest and merged with an eastern delta. A second cycle of transgression and regression developed similar depositional patterns. During Late Cretaceous, a major transgression joined the northern and southern seas into a large seaway across the down warping basin. Laramide tectonic activity reached its peak during the Eocene. It was during the Laramide that the Front Range was uplifted and the Basin acquired its present configuration.

PIERRE FORMATION

The Pierre shale of Late Cretaceous Age represents extensive marine deposition on the broad eastern shelf of the Cretaceous Geosyncline [Gr49]. It is composed of thick sequences of gray and black shales and shaly sandstones of the Upper Upper Cretaceous. In northeastern Colorado, the formation has been subdivided into four zones, or members: the Sharon Springs, Rusty, Hygiene and Transition members, in ascending order. The Sharon Springs member is characterized by lack of fossils, and the Rusty member by red-brown Limonitic ($FeO \cdot OH$) concretions. The Hygiene member consists of sandy shales and sandstones which make up the transition of the Pierre to the overlying Fox Hills formation.

STRATIGRAPHY AND SEDIMENTATION OF THE PIERRE FORMATION

The sandstone zones of the Pierre Formation are composed of alternating soft to hard, buff and gray sandstones and gray sandy shales. The sandstones are dominantly fine-grained, ranging from fine to medium. The grains show, for the most part, fair sorting of quartz grains, abundant chert and matrix, and relatively few unstable minerals, with the

exception of a few cases in which the clay matrix seems to have been washed out and is largely replaced by calcite.

A marine environment of deposition of the sandstones is indicated by both megafossils and macrofossils, and by the intimate interbedding of individual sandstone beds with marine shales. With the exception of the few cross-bedded members, which are mostly discontinuous. The Pierre Sandstones contain a rather abundant clay matrix. This immature condition of sorting would seem to indicate rather rapid mass transportation and deposition. Mild pulsating uplifts in the general area of the northern Front Range, accompanying the deposition of some of the sandstones, are suggested by foraminiferal evidence (Scott, Cabban 1959, reported by Weimer [Wm59]).

The Pierre sandstones represent the eastern most deposits of the Mesa Verde group in Colorado, in as much as they are similar lithologically and occur in approximately the same stratigraphic position. The Hygiene group of the Pierre shale of northeastern Colorado is divisible into a lower shale unit, a middle sandy unit, and an upper shale unit. The middle sandy unit has been referred to as the "Hygiene sandstone."

STRATIGRAPHY OF THE HYGIENE SANDSTONE MEMBER

Fenneman (1905), as reported by Weimer [Wm59], named this member for sandstone beds that outcrop about a third of the way from the base of the Pierre shale a mile and a half west of the town of Hygiene in northeastern Boulder County, Colorado. The Hygiene member consists of a basal 240 foot thick light olive-gray to yellowish-gray silty limestone concentrations in the upper part, a medial 38-foot dark-gray clayey shale with orange-brown iron-stained limestone concretions, and an upper 126 foot-thick ridge forming dusky-yellow thick-bedded friable medium-grained sandstone. Three miles north of Kassler, the Hygiene member is 1,420 feet above the base of the Pierre, it is 600 feet thick and consists of dusky yellow-soft shaly sandstone that contains, at the lower part and the top, masses as much as 12 feet in diameter of gray rough hard crystalline limestone. Beds and concretions of orange-brown ironstone are present in the upper half. Marine invertebrate megafossils are common in the Hygiene member in the Kassler-Boulder area.

The Hygiene is separated from the younger Terry sandstone member by as much as 387 feet of olive-gray sandy shale (Mather, Gilluly and Lusk, 1928, per Weimer [Wm59]).

TERRY SANDSTONE MEMBER

Ball [Baℓ24] named this member for sandstone beds exposed at Terry Lake two miles north of Fort Collins, Colorado. Olive-gray massive fine-grained sandstone makes up the member at the type locality. Highly fossiliferous-calcareous sandstone concretions 6 to 18 inches in diameter are common. The thickness of the member in the Fort Collins area ranges from 10 to 20 feet. The Terry is separated from the younger Rock Ridge sandstone member by 511 to 604 feet of sandy and non-sandy shale. This shale unit in the Eldorado Springs-Morrison area contains a thin glauconic sandstone about 900 feet above the top of the Hygiene member. Large brown calcerous sandstone concretions in this bed contain numerous fossils.

ROCK RIDGE SANDSTONE MEMBER

This member was named by Ball [Baℓ24] and consists of olive-gray fine grained massive sandstones. It contains large calcerous sandstone concretions that weather dark brown and is 97 feet thick. The Rocky Ridge is separated from the higher Larimer sandstone member by 163 feet to 187 feet of soft yellowish-gray sandstone and sandy shale with gray sandstone concretions.

LARIMER SANDSTONE MEMBER

This member is composed of olive-gray fine grained massive sandstone with brown calcerous sandy concretions. The member consists of two to four thin ledge-forming brown sandstone beds separated by thicker units of softer and lighter colored sandstone. The Larimer contains a large and varied invertebrate fauna. The Larimer is separated from the younger Richard Sandstone Member by 171 feet of sandy shale.

RICHARD SANDSTONE MEMBER

Olive-gray massive fine-grained sandstone is characteristic of the Richard sandstone. Large orange-brown calcareous sandstone concretions are common. The thickness is about 60 feet at Richard Lake, three miles northeast of Fort Collins.

IGNEOUS ACTIVITY IN THE DENVER BASIN

Igneous activity in the Denver Basin has played a minor role in its evolution. It is possible, however, that some volcanic processes took place within the Basin during the uplift of the Front Range during the time span of Cretaceous to Eocene. However, few surface expressions of volcanic structures are known in the Basin. Therefore, it can be generally stated that prolific volcanism is absent in the Denver Basin.

APPENDIX Q

COMMENTS ON DIFFUSIVITIES AND K_d VALUES BASED ON DATA FROM THE OKLO NATURAL REACTOR (D. G. BROOKINS)

DIFFUSIVITIES

The effective diffusivity, $\mathcal{D}_e$, in units of cm^2/d, used for calculation of leach rates of nuclides from a borosilicate glass waste form were estimated (see Vol. I) with the use of the Stokes-Einstein relation [Bi60]

$$\mathcal{D}_e = KT \frac{1}{6\pi\mu R_k} \qquad \text{(Q-1)}$$

where K is the Stokes-Einstein constant equal to 1.38×10^{-16} $g\text{-}cm^2/sec^2$ molecule °K; μ is the solvent viscosity at absolute temperature T °K (2.35×10^{-3} g/cm sec at 523 °K for water); and R_k is the radius of the diffusing particle in cm. As applied in leach rate calculations, a corresponding dissolution rate constant, in units of d^{-1}, was also obtained which relates $\mathcal{D}_e$ and experimentally measured leach data. The values obtained for $\mathcal{D}_e$ are listed in Column 1 of Table Q-1.

Values range from 2.0×10^{-8} (^{135}Cs and ^{137}Cs) to 3.3×10^{-10} (Pu isotopes). Use of these diffusivities may be justified only for those species likely to be present as free ions (or possibly as simple complex ions) in normal ground water. If one assumes that ground water from the Jurassic Westwater Canyon Sandstone is typical, then the data of Phoenix [Ph59] allows calculation of I = 0.06; this is possibly in support of use of a simple diffusion equation as above where activity coefficients of species being transported are assumed close to 1 (i.e., approximately ideal solution).

An attempt is made here to comment on the use of such diffusivities for the species tabulated (Table Q-1) based on the available data for the Oklo Natural Reactor [IAEA75]. In brief, the parts of the uranium ore at the Oklo deposit that sustained a critical fission reaction of some 500,000 y duration at about 1.8 billion years ago are confined to

Table Q-1. Estimates of Diffusivities

Nuclide	Diffusivity, cm^2/d	
	Column 1[a]	Column 2[b]
^{14}C	9.6×10^{-10}	10^{-16}
^{90}Sr	1.6×10^{-8}	10^{-21}
^{90}Y	1.6×10^{-8}	10^{-23}
^{93}Zr	6.3×10^{-10}	10^{-23}
^{93}Nb	6.9×10^{-10}	10^{-23}
^{99}Tc	1.2×10^{-9}	10^{-18}
^{129}I	9.5×10^{-10}	10^{-10}
^{135}Cs	2.0×10^{-8}	10^{-21}
^{137}Cs	2.0×10^{-8}	10^{-21}
^{210}Pb	9.4×10^{-10}	10^{-18}
^{225}Ra	7.7×10^{-10}	10^{-21}
^{226}Ra	7.7×10^{-10}	10^{-21}
^{229}Th	6.6×10^{-10}	10^{-23}
^{230}Th	6.6×10^{-10}	10^{-23}
^{237}Np	7.5×10^{-10}	10^{-23}
^{239}Np	7.5×10^{-10}	10^{-23}
$^{238,239,240,241}Pu$	3.3×10^{-10}	10^{-23}
$^{241,242,243}Am$	8.1×10^{-10}	10^{-23}

[a]Estimated by Stokes-Einstein relation.

[b]Estimated by Brookins from Oklo data.

very high grade (to 70% U by weight) ore in veins of 1 to 2 m thickness. Most of the fission and other products listed in Table Q-1 were produced during the reactors' lifetime; exceptions are ^{14}C, $^{242}Am(?)$ and $^{243}Am(?)$ isotopes.

The high grade ore at Oklo is a mixture of sooty pitchblende and well crystallized uraninite; the former may have the approximate formula $UO_{2.6}$ (due to some oxidation of U^{4+} to U^{6+} requiring excess oxygen) and the latter near-stoichiometric UO_2. Although very high temperature may have been locally obtained in the reactor ore, the maximum temperature and pressure close to the reactor zones were on the order of 100°C and 0.5 to 1 Kb(?).

The behavior of radioactive nuclides within host pitchblende* (* here used to include uraninite as well for simplicity) can be thought of as being controlled as follows. Fissiogenic or nuclides produced by neutron capture (i.e., Pu, Np, Am) will or will not be retained in the pitchblende as a function essentially of crystal chemistry and of host grain stability. A typical "grain" of pitchblende at Oklo is usually cracked with sulfide veins as infillings and the edges of the grains are commonly corroded.

The actinide elements Th, U and transuranics Np, Pu, Am are all found under reducing conditions as +4 ions which exhibit a high degree of solid solution with each other. Similarly, other ions with radii of approximately one angstrom and z = +3, +4 and electronegativities similar to U will be relatively stable in sites in the pitchblende. Hence, the rare earth elements (REE) are almost 100% retained within the pitchblende. Elements with higher electronegativites (i.e., chalcophile elements) may be enriched in the sulfide veinlets. Only those elements with very different charges and non-chalcophile tendencies will be expected to be highly metastable in the host pitchblende. Thus, alkali, alkaline earth and halide elements would be classified as metastable.

One must keep in mind that a direct comparison of the results of the study of the Oklo Phenomenon [IAEA75] with the experimental studies leading to the diffusivities in Column 1 of Table Q-1 is probably not justified. The experimental data are obtained under controlled conditions and, more importantly, usually under oxygenated systems. The

nuclear reactions at Oklo, on the other hand, occurred under very reducing conditions, perhaps with $P_{O_2} = 10^{-50}$ or so. Under these very reducing conditions high valence elements which commonly form very soluble metal oxanions (or other complexes) may behave in a completely different fashion. Thus, Tc and Ru would be predicted from Eh-pH diagrams to be stable at Oklo as TcS_2 or RuS_2 in the reduced S (i.e., S^{2-}) field and as TcO_2 or RuO_2 in the oxidized S (S^{6+}) field; that the Oklo ores fall near the Eh-pH boundary between reduced and oxidized sulfur is demonstrated by the presence of both primary pyrite (FeS_2) and hematite (Fe_2O_3). At Eh values expected in atmospheric-saturated waters, P_{O_2} is close to 0.2 atm. and Tc and Ru are present as highly soluble TcO_4^- and RuO_4^- ions.

The diffusion of any of the fissiogenic nuclides at Oklo can be thought to be controlled by at least three steps: (1) solid state diffusion (by exchange, vacancy, interstitial or interstitialcy mechanisms), (2) surface diffusion, and (3) grain boundary diffusion; any or all of which must occur before a species would be free to be transported by diffusion in an aqueous solution. Thus, a fissiogenic nuclei, M, may move by (1) to an intergranular site (3) before dissolution occurs. This sequence of events may be further complicated by armoring and/or fixation on gangue clay minerals. Hence, an atom of Pb, for example, would have to move from an original site in the host pitchblende to the surface of the grain or to an inter-granular site where it would likely be incorporated into sulfide minerals. From the host sulfide it must again diffuse to the surface where, in order for dissolution to occur, entrapment in some MCO_3 (or similar) grain must be avoided and the exchangeable sites on clay minerals filled with high cec atoms. If these conditions are met, then the Pb atom is free to be transported as Pb^{2+} or possibly as $PbCl_x^{n-}$. Chloride complexes at Oklo are not, however, thought to have played a major role.

A very limiting factor at Oklo, and one which is applicable to any equivalent set of Eh-pH conditions, is that for diffusion in an aqueous medium to occur, the element must not be incorporated into a compound stable at those conditions. If such a compound does exist, whether a CaF_2 (i.e., uraninite) structure, sulfide, or other, the proper diffusivity

to use is that involving the solid state.

For the nuclides tabulated in Table Q-1, only ^{90}Sr, ^{129}I, and ^{135}Cs ^{137}Cs are likely to have diffusivities as high as 10^{-8} to 10^{-10} cm^2/d. Even for these nuclides, diffusion studies by Foland, [Fo74] indicate approximate diffusivities for Rb, Sr (and, by inference, Cs) of 10^{-16} to 10^{-18} cm^2/sec in silicates. Further, data are available [Bo75] suggesting retention of ^{135}Cs and ^{137}Cs for at least 23 million years (m.y.); e.g., about ten times the half life of ^{135}Cs.

Chalcophile elements such as Pb, Bi, Cd, Mo, In, Sb, Te, Ag, Pd are present in sulfides where typical diffusivities range from 10^{-11} cm^2/s to much lower values, i.e., 10^{-15} cm^2/s [Bc74]; and these values may be 2 to 4 orders of magnitude greater than corresponding diffusivities in oxides. After possible sulfide grain destruction by local oxidation, then species such as Mo and Cd as MoO_4^{2-} and Cd^{2+} respectively, may posses diffusivities on the order of $1 - 2 \times 10^{-5}$ cm^2/s, which is in agreement with the 10^{-9} cm^2/d diffusivities listed in Table Q-1.

Radium, as either ^{225}Ra or ^{226}Ra, presents a special case. While oxidation is not a problem with Ra, its solubility is. The gangue at Oklo contains appreciable sulfate minerals, much of it as barite. Since the solubility product of $RaSo_4$ is less than that for $BaSO_4$, then any barite present would efficiently scavenge any Ra^{2+} in solution. Thus, while a diffusivity of 717×10^{-10} cm^2/d is probably not unrealistic for the time span between loss of Ra from host pitchblende and incorporation into sulfates (or adsorbed on clay minerals for that matter), this time span is, in geologic time sense, infinitesimally small. Ra scavenging is so effective, for example, that in areas of the Colorado Plateau, a Ra-rich barite is dubbed "radiobarite;" further, Ra is scavenged during uranium milling by treating the waste water with BaF_2:$BaSO_4$ which effectively removes Ra as $(Ba,Ra)SO_4$.

The case for carbon as ^{14}C cannot be directly addressed with regard to Oklo. There is no reason to expect that any carbon species should have been removed from the reactor zones, however, due to the presence of large amounts of carbonate minerals (i.e., dolomite, calcite, lesser amounts of siderite, magnesite) in the gangue. Further, from stable isotope studies [Sh74], meteoric waters commonly allow for widespread

exchange of oxygen but not for carbon under reducing conditions. Thus, an argument can be made for ^{14}C retention under the Eh-pH conditions at Oklo in any other shale site as well.

The above comments suggest that in most cases the diffusivities for the species listed in Table Q-1 used by themselves for migration calculations are too high by many orders of magnitude. Only under oxygen saturated conditions would diffusivities on the order or 10^{-8} to 10^{-10} cm^2/d be met; for ^{129}I and possibly for ^{135}Cs, ^{137}Cs and ^{90}Sr, the diffusivities of Table Q-1 might also be applicable--but only under the unlikely conditions of absence of carbonates and/or clay minerals. The lithophile elements, Y, Zr, Nb, Th, Np, Pu, Am will possess diffusivities on the order of 10^{-20} (or less) cm^2/s in oxide or hydroxide or silicate phases and thus, be unlikely to migrate. The chalcophile elements, Tc, Pc will possess higher diffusivities due to greater ease for diffusion in sulfides relative to oxides or silicates, but even these values will be on the order of 10^{-15} cm^2/s. When converted to units of cm^2/d, then the above $\mathcal{D}$ values decrease by at least 10^{-3}. The more realistic $\mathcal{D}$ values estimated here are listed as column 2 in Table Q-1.

It should be noted that while the discovery of a natural fission reaction at Oklo is unique, the host rocks are very common. Collectively, the data argue for the feasibility for shale as a waste repository under reducing conditions similar to those at Oklo.

K_d VALUES

The K_d values (Table Q-2), like the diffusivities (Table Q-1), are subject to large uncertainties due to the assumptions of (1) soil type, (2) oxidation potential, and (3) pH. Extrapolation from the Oklo environment (see earlier discussion) to the "U. S. Western Soil" and for experimental data taken under high Eh, acid pH conditions are not applicable to Oklo. However, if one uses the Column 1, Table Q-2, K_d value for Th isotopes as a reference, then the Oklo "K_d's" can be estimated. This has been done using the Eh-pH arguments, geochemical considerations [Hf74], and geologic constraints discussed earlier and in IAEA proceedings [IAEA75].

Table Q-2. Estimated K_d Values

Nuclide	K_d, cm^3/g	
	Column 1[a]	Column 2[b]
^{14}C	2	200
^{90}Sr	20	200
^{90}Y	2000	10000
^{93}Zr	2000	10000
^{93}Nb	2000	10000
^{99}Tc	0	1000
^{129}I	0	0(?)
$^{135,137}Cs$	200	200
^{210}Pb	4000	5000
$^{225,226}Ra$	100	5000
$^{229,230}Th$	15000	15000
$^{237,239}Np$	15	10000
$^{238,239,240,241}Pu$	2000	15000
$^{241,242,243}Am$	2000	15000

[a]Estimated for "Western Desert Soil."

[b]Estimated by Brookins from Oklo data.

The species assigned K_d values of 15000 cm^3/g (Th, Pu, Am) are those exhibiting wide stability fields for solid species under the Eh-pH conditions for Oklo. For those in the 10000 range (Zr, Y, Nb, Np) either lower pH or higher Eh might allow an aqueous species to be encountered; this probability is considered less than 1/3 and hence the value shown is chosen. Similarly, those in the 5000 range (Pb, Ra) are stable in sulfide or sulfate species which are more disseminated than the Zr, Y, Nb, Np possible species. Tc is assigned a value of 1000 because of weakly chalcophile tendencies and some evidence for local redistribution at Oklo. Yet it is retained. Species in the 200 range include C, Sr, Cs which (for Cs and Sr at least) have migrated although probably on a local scale. Mixing with gangue to an uncertain degree is noted. Fixation of Cs and Sr on clay minerals has been demonstrated. Only for iodine is a value of 0 assigned as daughter Xe may be totally missing from Oklo samples (note: this point is not resolved, however).

The same final comment as for diffusivities can be made when comparing the K_d values of Columns 1 and 2. The Oklo uranium deposit occurs in a rather poor quality, yet not a typical, shale. Retention of the nuclides for which K_d values have been assigned is based on predictions from Eh-pH diagrams coupled with geochemical-geologic constraints, including knowledge of mineralogy. For shales at a depth of 500 meters or so in the pH range of 7 to 8.5 and in which buffering by argillaceous (and sulfate-bearing) carbonates in the presence of sulfides, the K_d values of Column 2, normalized to Th - 15000, may be more applicable than those of Column 1.

GLOSSARY

damages — the value of adverse or unwanted effects measured in economic units, usually dollars. Total damages are a summation over causes and time; marginal damages are total damages divided by a reference production quantity.

diapir — a mobile core such as salt which moves upward injecting into the more brittle overlying rock.

diatreme — a volcanic vent or pipe, typically less than 1000 m in diameter, drilled through enclosing rocks by the explosive energy of gas-charged magmas (mobile, possibly molten, rock material).

distribution coefficient (K_d) — a sorption parameter relating amount of material sorbed on solid material and amount remaining in solution.

dose — "committed dose equivalent" is sometimes referred to here as simply "dose." Dose equivalent is the product of the absorbed dose from radioactivity and the quality factor, loosely called biological dose, expressed in units of rem or millirem (mrem). Committed dose is the sum of future dose accrual (generally over 50 y) resulting from a radioactivity intake. Dose expressed in man-rems is the sum of dose to individuals in a given population.

dose rate — the rate at which dose (committed dose equivalent) accrues following an intake or during exposure to an external source. Where an intake rate is also involved, reference is made here to "dose committment rate" (committed dose equivalent rate).

health effect — an unwanted health effect such as leukemia, a cancer, or serious genetic effect, equatable to a death for damage estimation purposes.

leach incident — a combination of events that introduces circulating ground water to the waste inventory and starts dissolving waste components. Time delays for the leach process and migration via ground water flow retard the environmental effects.

local dose — committed dose equivalent to individuals located in a given geographic zone, in mrem.

nonspecific dose	committed dose equivalent to an undefined population from consumption of largely exported agricultural products, in man-rem.
nuclide	a nuclear species characterized by the number of neutrons and protons in the nucleus. Used here at times in lieu of the more descriptive term: radionuclide.
offset faulting	movement producing relative displacement of adjacent rock masses along a fracture and resulting in a separation or gap.
probabilistic	based on probability, which is the number of times something will probably occur in a given amount of time. The probabilistic mode refers to operations with probabilities included in the calculations.
radionuclide	a nuclide which is unstable or radioactive.
release	a breach of containment which allows radioactive material to migrate through the geosphere. A release may or may not be directly to the biosphere.
resuspension	the process of material deposited onto land surface being picked up by wind action and resuspended.
risk	The product of probability of occurrence of an event and the consequences of an occurrence. As used in economics, risk refers to the chance of damage or loss.
sorption	an overall term referring to retention of a species on a solid by any of several processes such as absorption, adsorption, and ion exchange.
volcanic, volcanism	adjective and noun, respectively, pertaining to natural processes resulting in the formation of volcanoes or lava flows.
volcanic explosion	a violent explosive form of volcano ejecting material into the atmosphere.
volcanogenic transport	non-explosive carrying of material by any of three mechanisms: magma transport, volatile transport, or hydrothermal transport.

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