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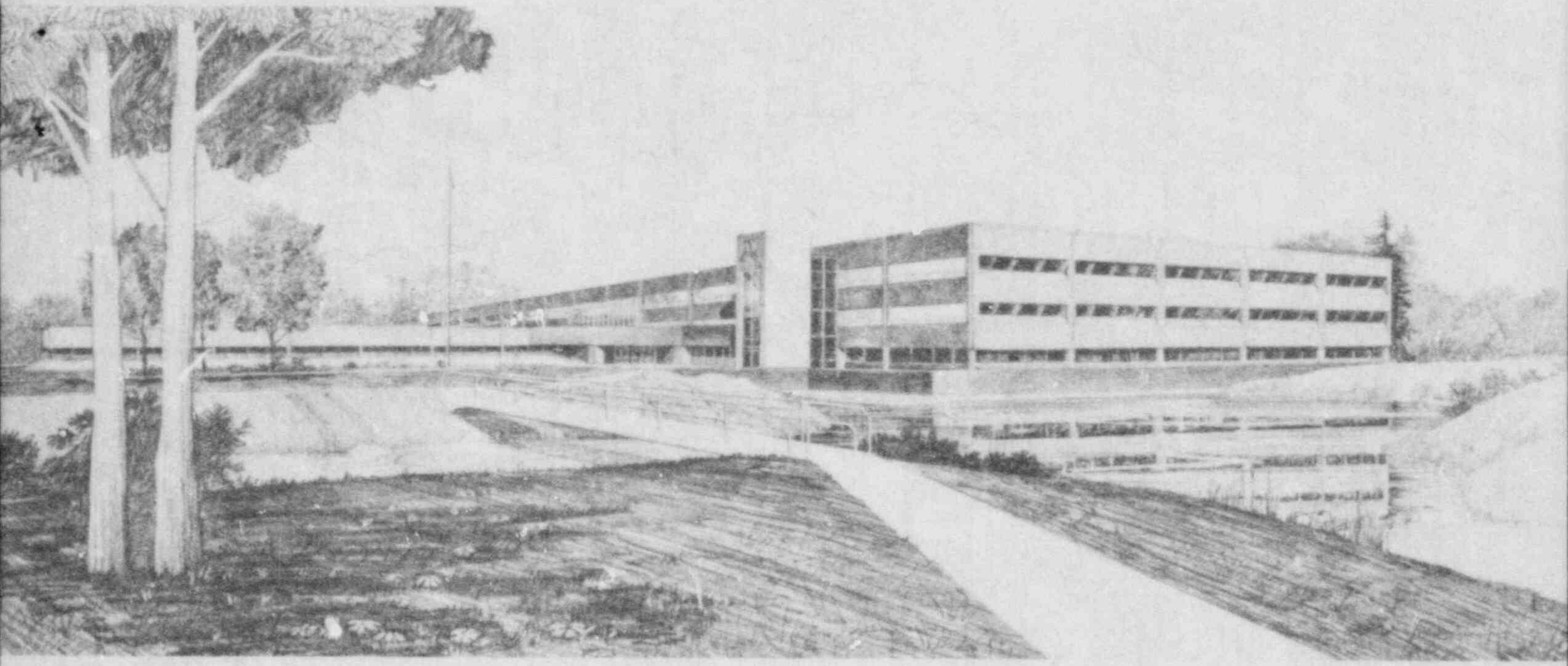

Idaho National Engineering Laboratory
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BURYIT/ANALYZ: A Computer Package for Assessment of Radiological Risk of Low-Level Radioactive Waste Land Disposal

James E. Fisher
Neil D. Cox
Corwin L. Atwood

November 1984

Prepared for the
U.S. Nuclear Regulatory Commission
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ABSTRACT

This report is a user's manual for a partially completed code for risk assessment of a low-level waste shallow-land burial site, to be used in the licensing of burial sites. This code is intended as a tool to be used for considering nuclide transport mechanisms, including atmospheric, groundwater, erosion, and infiltration to an underlying aquifer. It also calculates doses to individuals and the population through direct exposure, inhalation, and ingestion.

The methodology of the risk assessment is based primarily on the response surface method of uncertainty analysis. The parameters of a model for predicting dose commitment due to a release are treated as statistical variables in order to compute statistical distributions for various dose commitment contributions. The likelihood of a release is also accounted for by statistically evaluating the arithmetic product of the dose commitment distributions with the probability of release occurrence.

An example is given using the atmospheric transport pathway as modeled by a code called BURYIT. The framework for using other release pathways is described in this manual. Information on parameter uncertainties, reference site characteristics, and probabilities of release events is included.

FIN No. A6310—Low-Level Waste Risk Methodology Development

SUMMARY

The objective of this project is to provide the U.S. Nuclear Regulatory Commission (NRC) with a computer-implemented methodology for evaluating the public and operational risks due to radioactive releases from low-level waste. The scope of the risk methodology includes releases from a low-level burial site, a processing plant, and vehicles transporting the waste. The methodology is probabilistic in nature, allowing for the uncertainties in both the parameters of a computer model and the frequency of occurrence of release events. The methodology is intended to be used as a tool to assist in the licensing of low-level shallow-land burial sites.

The approach to the project was to base the probabilistic methodology upon a radionuclide transport modeling code developed for NRC by Science Applications, Inc. In this report, the code is called BURYIT. Numerous improvements to the code were made.

Because the atmospheric transport pathway was the first to be verified, it was the first to be treated probabilistically. Uncertainties in transport model and dose computation parameters were researched for use in the response surface method of uncertainty analysis. At the same time, an existing routine for automatically conducting response surface analysis (ANALYZ) was interfaced with BURYIT. The result is a capability to generate uncertainty distributions for various dose commitment calculations, providing that a release has occurred. With these uncertainty distributions, it is possible to state a probability level for the event that a dose commitment would exceed any specified magnitude.

The next step in the methodology was to account for the frequency, or probability, of a release event. The risk of a release scenario is defined herein as the arithmetic product of dose commitment and probability of occurrence.

Since both the dose commitment and probability are subject to uncertainty, it is necessary to treat their product statistically. The result is a capability to generate an uncertainty distribution for the risk and, consequently, to make a probability statement that concerns risk exceeding a specified level. A way to graphically compare the risks from different scenarios is also provided.

Because of a reordering of funding priorities within NRC and consequent anticipated termination of this project after FY-1984, it was decided to produce a user's manual for the risk methodology in its current state. As funding becomes available, improvements are envisioned, to allow for easier input, more realistic modeling, and more output options.

ACKNOWLEDGMENTS

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BURYIT/ANALYZ: A COMPUTER PACKAGE FOR ASSESSMENT OF RADIOLOGICAL RISK OF LOW-LEVEL WASTE SHALLOW-LAND BURIAL

1. INTRODUCTION

A computer program package is being evolved for calculating the radiological risk associated with shallow-land burial of low-level radioactive waste (LLW). The ultimate intended use of the package is as a tool for evaluating proposed or existing burial-site locations. The package includes two computer programs that are being adapted for the purpose of probabilistic risk assessment. Risk assessment requires an estimate of the consequence of a release event, providing that the event has occurred, and an estimate of the likelihood, or probability, of occurrence of the event during some time interval. The arithmetic product of the consequence and the probability of occurrence is defined herein as the risk associated with the event.

The basic calculation of the radiological hazard (or dose commitment) due to a given release event, or scenario, is accomplished by the computer code BURYIT. The code ANALYZ performs a statistical analysis of the results of BURYIT calculations for the scenario, and computes the consequence and the risk distributions in terms of the population dose commitment.

BURYIT[1] was originally a deterministic code developed to calculate population doses resulting from nuclide transport from a burial site through one or more pathways. The pathways include atmospheric or groundwater transport of nuclides, occupational exposure during packaging, shipment, burial operations, or intruder (animal or human) contamination. The content of the waste material is categorized by nuclide amount and concentration. Thus, the code has the capability to select a nuclide inventory, which is representative of the type of waste expected, to calculate the migration of the inventory through the pathway of interest, and to calculate the radiological impact to the public. A separate release scenario (= combination of pathways and release fractions) and nuclide inventory are chosen. At this time, the waste inventory categories and the release scenarios are the same as those described in Reference 1, Volume 2.

The adaptation of BURYIT to a probabilistic risk assessment code involved the installation of a computer routine that added the capability of uncertainty analysis. An uncertainty analysis technique combines uncertainties in input parameters in a prescribed fashion in order to assign statistical limits to output responses. The driver program for BURYIT sets up a perturbation pattern, or design, for varying the inputs, runs BURYIT the required number of times with the inputs perturbed according to the design, and collects the responses (doses) for each run on computer disk storage, for later use by ANALYZ.

ANALYZ was originally an uncertainty analysis code for calculating consequences of nuclear fuel thermal response during hypothetical accident scenarios.[2] It read responses from nuclear fuel pin code calculations and used response surface methodology to calculate probability limits (or consequence levels) for nuclear fuel temperatures for the given hypothetical accident. The response surface method of uncertainty analysis has three steps. First, the code perturbation responses are fitted to a second-order polynomial equation, called the response surface equation, in terms of the variable input parameters. Next, second-order error propagation is used to determine the lower four statistical moments of the response. Finally, these response moments are matched to an approximating probability density function so that the consequence of the calculated event can be determined at the specified probability value.

The adaptation of ANALYZ included minor modifications for compatibility with BURYIT responses and installation of a subprogram to perform the risk calculation.

A hypothetical risk calculation was done using the BURYIT/ANALYZ package for the atmospheric transport pathway. Fifteen variables were selected from Table 8 for demonstrating the probabilistic risk methodology.

Sections 2, 3, and 4 contain the theoretical description of the LLW risk methodology computer package. Included in Section 2 are the transport pathway models in BURYIT for the unsaturated soil column, the aquifer, the atmospheric, the soil erosion, and the direct radiation exposure pathways. Section 2 also discusses the population dose calculation subprogram. Section 3 contains an explanation of the response surface method for uncertainty analysis. Section 4 gives the details of the risk calculation. Section 5 contains a description of input requirements. Section 6 contains the results of the atmospheric pathway methodology demonstration case and also describes the outputs generated by the computer package.

2. MODELS FOR NUCLIDE TRANSPORT PATHWAYS

In this section, the principal mathematical models for consequence analysis are discussed. There are seven computer subroutines: AQUIFER, ATMOS, DIRECT, DOSET, EROSIO, UNSAT and PUNC (see Table 1). The subroutine BURYIT directs the calls to these seven subroutines as required for each release scenario; hence, reference will be made to the BURYIT program hereafter. Table 2 gives the original sources of these subroutines.

Table 1. Principal subroutines used to model shallow-land burial consequences

Subroutine	Function	Pathway
BURYIT	(Driver)	—
DOSET	Population and maximum individual doses from radionuclides released to the biosphere	—
AQUIFER	Groundwater transport in a (saturated) aquifer	1
ATMOS	Atmospheric transport in a single sector of 22.5 degrees	2
DIRECT	External gamma dose resulting from direct exposure to waste	3
—	Other scenarios, modeled as moving cloud	4
EROSIO	Nuclides blown from the disposal site by erosive wind action	5
PUNC	Dose from puncture wound	6
UNSAT	Infiltration of water through unsaturated soil to an underlying aquifer	9

There are some limitations of the BURYIT program that should be emphasized at the start of this discussion. Foremost is that only a single wind direction is modeled. This limitation affects both the ATMOS and EROSIO subroutines wherein multiple wind directions could have been allowed in principle. With a single wind direction, the population and the environs at risk are in a single sector of 22.5 degrees downwind.

Another limitation is that the infiltration of water into soil is modeled in a single vertical dimension. The groundwater may flow either upward or downward, but not laterally. The ultimate sink for downward flow is an unconfined aquifer that ultimately becomes a source of water for human consumption.

Furthermore, there is no phenomenological basis for the consequence calculation for a number of postulated release scenarios. These scenarios deal with the exposure of a single person (usually) and are called herein "Other" scenarios. More will be said about these scenarios in Section 2.1.

As a word of caution to those who must follow the details of the internal calculations, the reader is advised that the various parts of BURYIT utilize at least three different systems of units. However, efforts have been made to convert all required user-input data to the International System of Units (SI) with the only intended exception being temperature in degrees Celsius rather than Kelvin. Immediately upon being read in, the user-input is converted to the units appropriate for each algorithm, and annotations so indicate. All data files supplied with BURYIT are in SI units.

2.1 Structure of BURYIT

In order to model a particular release scenario, BURYIT calls one or more of the seven principal models according to the pathway, or pathways, included in the scenario (see Table 1). These models include the three fundamental release mechanisms for radionuclides in disposed waste (Reference 1).

2.1.1 Direct Radiation. Humans may be directly exposed to gamma radiation emanating from intact containers or from radionuclides in the waste/soil

Table 2. Sources of principal subroutines used to model shallow-land burial consequences

Subroutine	Source
BURYIT	Science Applications, Inc. (1981).[1]
AQUIFER	W. V. Demier et al., GETOUT (Version GET005), Pacific Northwest Laboratory, PNL-2970 (1979)[3]
ATMOS	J. R. Sagenderf et al., *XOQ DOQ:Computer Program for the Meteorological Evaluation of Routine Effluent Releases at Nuclear Power Stations*, NUREG/CR-2919, PNL-4380, September 1982.
DIRECT	A. Foderaro, *Photon Shielding Manual*, Pennsylvania State University, 1976;[5] T. Rockwell, III, Editor *Reactor Shield Design Manual*, TID-7004, 1956.[6]
DOSET	Science Applications, Inc., Based on NRC Regulatory Guide 1.109, 1977 and WASH-1400, 1975.
EROSIO	N. D. Woodruff and F. H. Siddoway, WEROS, U.S. Department of Agriculture, 1965.[7]
PUNC	Appendix A.
UNSAT	B. Amirijafari and B. Cheney, HYDRO, Science Applications, Inc., Technical Report submitted to EG&G Idaho, Inc., June 1979. Not published.

mixture. The dose resulting from this exposure is modeled with the subroutine DIRECT, designated in the program as Pathway 3.

2.1.2 Air. Air can transport radioactivity from exposed waste, either as vapor or as suspended solid particles. The atmospheric transport of nuclides is modeled with ATMOS (Pathway 2). The dose to humans from the intake of contaminated air and food and from cloud shine is modeled with DOSET (Pathway 4). BURYIT always calls DOSET following ATMOS in a modeling run. Therefore, the pathway-calling sequence in BURYIT is simply "2" for this scenario.

If the air-transport pathway also includes resuspended soil particles from the surface of the trenches, then the subroutine EROSIO (Pathway 5) is used to compute the airborne particulate concentration for ATMOS to use. BURYIT always calls ATMOS after EROSIO, and a call to DOSET then follows ATMOS. However, EROSIO must be preceded by the groundwater subroutine UNSAT (Pathway 9), which provides the nuclide concentration of the soil particles on the surface. The pathway-calling sequence for transport of resuspended soil particles and vapor is, therefore, "95."

2.1.3 Water. Groundwater and surface water can act as transport agents for radionuclides; however, only groundwater transport is modeled using BURYIT. The infiltration of water into the top of a column of unsaturated soil is modeled with UNSAT (Pathway 9). The water percolates into a zone containing waste and dissolves radionuclides. Subsequently, the contaminated water may either return to the soil surface or continue percolating downward until an unconfined aquifer is reached. Evaporation at the surface leaves contaminated soil particles, transport of which is modeled by EROSIO (Pathway 5). Contaminated water entering the aquifer flows some distance before reaching a point of surface discharge or a well. Saturated flow is modeled using AQUIFER (Pathway 1). DOSET, which computes the human dose due to ingestion of water, always follows AQUIFER. Thus, the pathway-calling sequence in BURYIT is "91" for infiltration to an aquifer, and is "95" for infiltration coupled with air transport of contaminated soil. The calling sequence for the two processes together is "951."

The subroutines UNSAT and AQUIFER may be used to model a contaminated well or a contaminated river, but not both at the same time. In either case, the ingestion of nuclides is overestimated because the volumetric flow of the aquifer is not taken into account. It is assumed that the nuclides leaving the disposed waste enter a water supply source, which is at a user-specified distance from the center of the site. In the case of a well, a lower bound on water usage may be set at 7700 m^3/y in order to account for low natural percolation in an arid, western site. Also, the number of people ingesting the contaminated water must depend on the type of water source being modeled.

2.1.4 Puncture Wound. One release scenario in BURYIT pertains to a person suffering a puncture wound caused by a contaminated sharp object. A method for estimating the dose commitment, described in Appendix A, has been derived and installed in BURYIT. The pathway-calling sequence number for this scenario is simply "6." The dose is calculated by the subroutine PUNC.

2.1.5 Other Scenarios. There are some release scenarios included within BURYIT that do not fall into the mechanisms described above. These include such events as theft of a usable item, package rupture during packaging operation, interim storage or transportation, and human or animal intrusion. A provision is made (Reference 1) for modeling these events as being, in an unexplained way, equivalent to the dose to a single human resulting from a contaminated cloud moving at a velocity not less than 2.2 m/s (5 miles/h). One supplies the dust cloud diameter and the wind velocity as input data. BURYIT then computes a pseudo-air concentration for input to DOSET which, in turn, calculates the dose to a single human. The pathway-calling sequence number for this type of scenario is simply "4."

2.2 Subroutine DIRECT

The subroutine DIRECT was written to compute the external gamma whole body dose resulting from direct exposure to undispersed waste. One of three possible geometries is selected by the user and is input from TAPE20. Distances and up to five shielding materials are also input on TAPE20. The algorithms are based primarily on formulas from References 5 and 6. One difference is that the gamma-energy treatment is performed for 10 discrete energy groups. During verification activities, it was found that DIRECT compared favorably with the computer program ISOSHLD II, except for the nuclides cobalt-60 and tritium. The results from DIRECT for these two nuclides were approximately one order of magnitude lower because DIRECT does not compute beta radiation.

2.3 DOSET and Associated Subroutines

This section applies to all pathways in which radionuclides are released to the environment. These are the pathways other than direct exposure and puncture wound.

The population and maximum individual doses are calculated in subroutine DOSET, and the results are cumulated in subroutine SUMDOS. The results are printed by OUTPUT, while PREDOS supplies concentration factors for food, milk, and meat.

The present version of DOSET utilizes two slightly different methods for computing dose commitments: (a) the original method described in Reference 1, and (b) a modified method. The original method includes dose computations for eight organs and for three age groups. The modified method uses internal dose conversion factors (DCFs) that are a weighted sum of organ DCFs, resulting in effective whole body doses. The modified method computes the dose to adults only. The results from both methods are printed in order to facilitate a comparison of the two methods. In order to bypass one method or the order, minor programming changes will be required.

2.3.1 Original DOSET. The dose is calculated for the total body and eight organs: bone, liver, kidney, gonad, lung, gastrointestinal tract, thyroid, and skin. Original DOSET involves two pathways for external exposure: nuclides in the air and nuclides on the ground. Original DOSET also involves two pathways for internal exposure: inhalation and ingestion. These latter two are age-dependent; thus, separate doses are computed for the child, teen, and adult age groups. This results in a total of eight pathway categories in Original DOSET, encompassing the organ and whole body dose commitments.

The methodology in Original DOSET is based partly on that in the NRC Regulatory Guide 1.109[8] and partly on that in WASH-1400.[9] DOSET differs in two principal respects: radionuclide release is at a uniform rate over a specified time period rather than a continuing steady-state release, and the population ingestion dose is based on the local production of contaminated foods (Reference 1, Volume 2, pp. 6-53, 54).

The Original DOSET was verified by updating the transfer constants and dose conversion factors using information more recent than that in Reference 1. In addition, manual calculations were used to verify the computational algorithms. This work is described in NUREG/CR-3210.[10]

2.3.2 Modified DOSET. There is some doubt that equal doses to organs of children and teens generate the same risks with respect to health effects as adult organ doses. As an alternative to age-specific doses, ICRP 30, Parts 1, 2, and 3[11] provides weighted or effective whole body DCFs for adults. These DCFs are based on the sum of organ doses that are weighted according to risk. This effective whole-body-dose methodology has been proposed by the NRC in a revision to 10 CFR Part 20, "Standards for Protection Against Radiation," and has been incorporated into DOSET. The DCFs are considered to be the best, currently available ones for risk assessments that stop at dose rather than estimating the health effects resulting from a unit dose. The effective whole body doses resulting from different scenarios should be easier to compare, because one dose value summarizes the dose to a number of organs.

2.4 ATMOS and Supporting Subroutines

The subroutine ATMOS and its supporting subroutines are based on recommended approximations to the time-integrated exposure resulting from airborne nuclides.[12] The underlying theory is the Gaussian plume model, wherein advantage is taken of the fact that natural diffusion in the atmosphere is modeled well by a Gaussian distribution of airborne contaminants. As stated earlier, a single wind direction is permitted in the BURYIT package, although up to 10 wind speeds may be used (Reference 1). A plume-rise model that is said to be valid only for stable atmospheric conditions is installed in the current version.[13]

A "transitional" plume-rise model is used.

plume rise

$$H(L) = SH + 1.6\,(F_b^{1/3}\,x^{2/3})/V(L)$$

$$x \le 10\,000 \text{ m}$$

final rise

$$H(L) = SH + 742.7\,(F_b^{1/3})/V(L)$$

$$x > 10\,000 \text{ m} \qquad (1)$$

where

$H(L)$ = plume height for each windspeed index (L), (m)

SH = stack height, (m)

F_b = buoyancy heat flux parameter, (m^4/s^3)

= $3.8 \cdot 10^{-5}$ SQ

SQ = heat emission rate with the plume, (cal/s) (input data must be in watts)

$V(L)$ = wind speed, (m/s)

x = distance downwind (m).

This plume-rise model approximates observations downwind to perhaps 10 000 m. The final-rise model is a constant beyond 10 000 m.

Two comments may be beneficial to the user who wishes to study the internal programming. First, the dry deposition velocities are all set to 0.01 m/s with the exception of the three noble gases Kr, Xe, and Rn, which are assigned values of zero. This is done in the absence of better information. Secondly, washout of the above three nuclides to the ground is assumed to occur during rainfall through solution. The relative effect on dose commitment induced by this assumption, as opposed to no ground deposition, has not been investigated.

2.5 UNSAT and Supporting Subroutines

UNSAT and its several supporting subroutines are used to model the infiltration of water in an unsaturated column of soil between the ground surface and an intersecting, unconfined aquifer. Low-level waste is buried in a layer of soil, the depth of which is user-specified. The underlying theory is Darcy's law with transient flow through multiple disparate soil layers and with hydraulic dispersion and ion exchange of nuclides with the soil allowed. The governing partial differential equation is given in Reference 1 (Volume 2, pp. 6-36). The finite-difference equation corresponding to the flow theory is consistent with published versions by Freeze and Cherry, Appendixes VI and VIII, p. 67.[14] The origin of the subroutine UNSAT is described in Reference 1, pp. 6-34.

A time-dependent boundary condition at the soil surface is used. Specifically, alternating wet and dry periods are allowed. Each wet period is modeled with the same constant rainfall rate, and each dry period is modeled with a constant evapotranspiration rate. Any other type of boundary condition, such as variable rainfall and evapotranspiration rates, would require modification of the program.

Each of the layers in the soil column may have distinct physical properties: hydraulic conductivity, density, thickness, and nuclide sorption characteristics. These properties are part of the input data as detailed in Section 5.2. However, hydraulic conductivity must be discussed in more detail. This property is read for the uppermost soil layer as a tabular function of the fractional water content (by volume). Upper and lower bounds on the applicability of the data are necessary and are established by water content input parameters WATL and WATH (Reference 1). (Also, a pressure head function is read in the same way.) For the second and subsequent soil layers, the hydraulic conductivity is computed by multiplying that of the first layer at the same moisture content by a constant (CONCOF) that is also supplied by the user for each soil layer. Thus, it is assumed that the characteristic hydraulic conductivity-water content curves all have the same shape and are merely shifted, according to the value of CONCOF, relative to the curve for the first soil layer.

The nuclides dissolve in the groundwater contacting the waste in the specified burial (injection) layer. The nuclide concentration in the water leaving the burial layer at each time step is assumed to be the solubility limit. A material balance on each nuclide is rationalized by computing the volume of waste in the injection layer using an emplacement efficiency factor, EMEF, defined in NUREG/CR-1759, pp. 3-8, 10,[15] and in NUREG-0782, Appendixes E and F.[16] This factor represents the ratio of volume of waste emplaced in the disposal cell to the total volume of available disposal space (soil plus waste volume). Recommended values for EMEF are 0.5 for random emplacement, and 0.75 for stacked emplacement (Reference 15).

The solubility limits of the nuclides should be elaborated on. This variable is called SOLFAC in the program and has units of curies per cubic metre of water. The user must input these values into the program in the same order as the nuclides in the waste inventory used (see Section 5.2.2.3). Suggested values for SOLFAC are listed in Table 3. Those values in groups I and II in the table are based on measurements at the Maxey Flats site (References 15 and 16). Values of the 23 nuclides in group III are guessed, pending other sources of information. Error factors (EF) are also listed such that one standard deviation uncertainty is given by (MEAN/EF; MEAN x EF). The EFs for the group I nuclides are derived from sample standard deviations. The EFs for groups II and III are subjective guesses that generally become larger as the perceived uncertainties of the estimates become larger. For instance, the group III error factors are generally orders of magnitude greater than those in group I.

The amount of each nuclide transported to the soil surface or to the underlying aquifer is computed for a unit area. In order to compute the total release of radioactivity, a separate trench area term, TRAR, is defined. This area term accounts for the desired area of infiltration and is a user-specified input having units of square metres (see Section 5.2.2.3). For example, the total radioactivity discharged to the aquifer is computed in the subroutine EXEC using TRAR. The term TRAR may represent the area of all trenches, one trench, or part of a trench as desired by the user.

2.6 Subroutine EROSIO

The EROSIO subroutine calculates the amount of radioactivity blown from the field surface of the site by the erosive action of the wind. The surface radioactivity is supplied by UNSAT, and it is assumed to be transported to the surface via evaporation of water that has contacted the waste.

Table 3. SOLFAC values

Group	Element	Geometric Mean Solubility (Ci/m^3)	Error Factor (one standard deviation)
I	From Measurements, Reference 21		
	^{3}H	0.17	10
	^{60}Co	5E-6	5
	^{90}Sr	1E-4	7
	^{137}Cs	4E-6	7
	^{238}Pu	9E-6	17
	^{239}Pu	9E-6	17
	^{241}Am	7E-7	13
	^{14}C	3E-6	6
	^{238}U	8E-9	8
II	Estimated in Reference 21 on basis of chemical similarity		
	^{99}Tc	0.02	100
	^{129}I	0.02	100
	^{55}Fe	5E-6	25
	^{59}Ni	5E-6	25
	^{63}Ni	5E-6	25
	^{94}Nb	4E-6	25
	^{135}Cs	4E-6	7
	^{235}U	8E-9	8
	^{241}Pu	9E-6	17
	^{242}Pu	9E-6	17
	^{237}Np	9E-6	300
	^{243}Cm	9E-6	300
	^{244}Cm	9E-6	300
	^{243}Am	7E-7	13
III	Guesses based on nearest neighbor in periodic table		
	^{35}S	0.02	1 000
	^{51}Cr	0.02	1 000
	^{54}Mn	0.02	1 000
	^{58}Co	5E-6	5
	^{65}Zn	5E-6	625
	^{95}Zr	4E-6	625
	^{106}Ru	0.02	1 000
	^{124}Sb	0.02	1 000
	^{125}Sb	0.02	1 000
	^{125}I	0.02	100
	^{134}Cs	4E-6	7
	^{144}Ce	8E-9	70
	^{152}Eu	9E-6	90 000
	^{154}Eu	9E-6	90 000
	^{155}Eu	9E-6	90 000
	^{226}Ra	1E-4	45
	^{230}Th	8E-9	70
	^{232}Th	8E-9	70
	^{240}Pu	9E-6	17
	^{242}Am	7E-7	13
	^{242}Cm	9E-6	300

EROSIO then supplies ATMOS with activities of the nuclides for use in calculating air and ground concentrations of radioactivity.

The basis of EROSIO is the solution of the wind erosion equation, an empirical formulation of soil loss, E, in tons per acre per annum from a given agricultural field. This equation was developed by the U.S. Department of Agriculture to predict soil loss from the great plains region of the United States.[17,7] The soil erosion is expressed in terms of five influential variables as

$$E = f(I', K', C', L', V') \qquad (2)$$

where

I' = a soil erodibility index

K' = a soil ridge roughness factor

C' = a climatic factor

L' = field length along the prevailing wind erosion direction

V' = equivalent quantity of vegetative cover.

The computed soil loss, E (in tons/acre-year), is then multiplied, in consistent units, by the duration of the wind, the contaminated area, the fraction of soil lofted, and the nuclide concentrations in the soil. The nuclide concentrations are supplied by isotope and time period. In general, the UNSAT results consist of several blocks of time. A set of EROSIO/ATMOS/DOSET calculations is performed for each block, and the wind duration factor for each sequence of calculations corresponds to the UNSAT time block. The contaminated area term is the plane surface area of the trenches. This is because the unsaturated soil column model that calculates surface nuclide concentrations is a one-dimensional model. Thus, the concentrations represent nuclide contamination for a unit surface area. The area which accounts for the total amount of surface contamination due to all the waste buried in the trenches is, therefore, that of the trench planes. The fraction of soil that is lofted, i.e., that remains suspended in the atmosphere, is largely subjective but is influenced by soil type. Estimates of the value range from a minimum of about 3% for clay particles to a maximum of about 40% for loam particles.

The computer solution to the wind erosion equation, which is done in the subroutine EROSIO, is addressed below. The solution follows the scheme outlined graphically in Reference 7.

Soil erodibility (I) is potential soil loss from a wide, unsheltered, isolated field with a bare, smooth, uncrusted surface. It is inversely related to the size of the aggregates in the surface soil and is tabulated as a function of percentage dry soil greater than 0.84 mm in diameter. Correction factors are then applied to soil erodibility to account for slope, ridge roughness, climate, dimensions and sheltering of the field, and vegetation. These correction factors are explained below.

Knoll erodibility (I_s) is the correction factor which adjusts erodibility for windward slopes less than 152 m long. This factor varies with slope and can be as large as 7 for the top of a knoll with a 10% slope. The erosion rate for long windward slopes (>152 m) is about the same as for level land. The Reference 7 data for knoll erodibility are tabulated in BURYIT for (a) the top of a knoll, and (b) for the portions of the windward slope where drag velocity and wind drag are the same as on top of the knoll (from about the upper third of the slope.)

Soil ridge roughness is a measure of the natural or artificial soil surface roughness other than caused by clods or vegetation. The roughness factor (K') is an empirical function of surface roughness (k) and varies between about 0.5 and 1. BURYIT contains tabular entries of the ridge roughness factor chart (Reference 3) for roughness values up to 0.25 m (10 in.). BURYIT also contains an equation for calculating the surface roughness based on ridge height (h) and spacing (s):

$$k = 4\ h^2/s\ .$$

The climatic factor correction includes the effects of mean annual temperature, precipitation, and prevailing wind conditions. For average annual soil loss calculations, the mean annual wind velocity data should be corrected to a standard height of 9 m. The climatic factor (C') is given by the empirical relation

$$C' = 34.483\ V^3/(P\text{-}E)^2$$

where

V = mean annual wind velocity for a particular geographic location (miles per hour)

P-E = Thornthwaite's precipitation effectiveness ratio[18]

$= 115 (P/T\text{-}10)^{10/9}$

where

P = mean annual precipitation (mm)

T = mean annual temperature (°C).

The equivalent field length correction factor (L′) accounts for the unsheltered distance across the field along the prevailing wind erosion direction. The unsheltered travel distance for each component (j) of the erosion wind rose is:

$D_j = W \sec(A_j)$

where

W = field width (m)

A_j = angle of deviation of wind rose vector from a direction perpendicular to the length of the field.

A geometric derivation of the above equation is given in Reference 1. However, in BURYIT, EROSIO considers only one wind rose direction vector, which should be in the direction of the prevailing wind. If barriers are modeled, the unsheltered travel distance is reduced by 10 times the barrier height. The result is then the equivalent field length (L) which is used to calculate L′.

The vegetative cover correction factor (V′) includes the effects of quantity, type, and orientation of the vegetation. Reference 7 data, in tabular form, are included in BURYIT for modeling the three types of vegetative cover listed below:

1. Live or dead small grain crops in seedling and stooling stage, above the surface of the ground, for crops in 7.6-cm-deep furrow (as created by a deep furrow drill) and on smooth ground.

2. Standing and flat anchored small grain stubble with any row width up to 0.25 m, including stover.

3. Standing and flat grain sorghum stubble of average stalk thickness, leafiness, and quantity of tops on the ground.

The solution of the wind erosion equation is done by a supervisory routine, COMPUT, which is called by EROSIO. EROSIO first converts the input variables (metric units) to English units and calculates the climatic factor correction. COMPUT then solves the wind erosion equation and returns the result to EROSIO, for calculation of the amount of radioactivity released to the atmosphere.

The wind erosion equation is solved in five steps. First, subroutine IPRIME determines the soil erodibility based on particle size, applies the windward knoll slope correction, and returns the result to COMPUT. The tabular lookup function for the soil erodibility and windward knoll slope tables (and ridge roughness correction and vegetative cover tables) is performed by a linear interpolation in INTER. The first intermediate result is

$E_1 = I' = I\,I_s$.

Step 2 is the calculation of the soil ridge roughness correction factor in subroutine KPRIME. The second intermediate result is

$E_2 = I'\,K'$.

The third step is the inclusion of the effects of local wind velocity and surface soil moisture, which gives

$E_3 = I'\,K'\,C'$.

The fourth step accounts for the effect of field length (L′)

$E_4 = I'\,K'\,C'\,f(L')$.

E_4 is not determined by a simple multiplication, because E_2, E_3, and E_4 are all interrelated. Subroutine LPRIME calculates equivalent field length along the prevailing wind direction (L′), and subroutine FLRM determines E_4 based on L′, E_2, and E_3. Calculation of equivalent vegetative cover is done in subroutine VEG. COMPUTE calls VEG separately to model each of the following types of vegetative cover:

1. Flat, anchored, small grain stubble

2. Live or dead small given crops in seedling and stooling stage

3. Flat grain sorghum stubble

4. Standing grain sorghum stubble.

The calls are made in the above order. It is important to specify only the desired cover type, because results of previous calls to VEG are overwritten, i.e., only the last specified type of vegetative cover is used for the correction factor. Subroutine FIN calculates the effect of the vegetative cover on soil erodibility as

$$E_5 = E = I' K' C' f(L') f(V') .$$

Again, E_5 is not obtained by simple multiplication, because of interrelations among E_4, V, and E_5. E_5 is the final, corrected soil loss result, E (ton/acre-year), which is returned to EROSIO.

After the soil loss is calculated, the value is compared to the maximum allowable erosion depth, which is set to 25.2 mm or 30 times the height of the smallest unmoved particle (0.84 mm) (References 7 and 17). The equation which considers the erosion depth expresses the result as a maximum time for erosion at the calculated rate of soil loss

$$t_{max} = \frac{(25.2)\ (\varrho)\ (1-x)}{(0.224)\ (E)}$$

where

t_{max} = time which results in an erosion depth of 25.2 mm (y)

ϱ = soil density (g/cm^3)

x = fraction of aggregates greater than 0.84 mm

0.224 = units conversion factor (g-acre-mm/tons-cm^3).

The value of soil loss used in the calculation of airborne nuclide concentration is then the larger of the time block input from UNSAT and t_{max}.

Once the corrected soil loss, E, is calculated, the next step is the computation of the radioactivity of the ith nuclide blown into the atmosphere. This may be expressed in the functional form as (in consistent units)

$$C_i = (E)(A)(t)(Y)(X_i) \qquad (3)$$

where

C_i = radioactivity to the atmosphere

E = computed total soil loss

A = contaminated area

t = duration of erosive wind

Y = percentage of soil loss into suspension

X_i = radioactivity of ith nuclide per unit weight in the surface soil.

Two points in Equation (3) should be recognized. One, the area term should apply only to that surface that is subject to evaporation of water containing dissolved nuclides. UNSAT generates the contamination level per unit area of a soil column. Thus, the area to be used should be an appropriate trench area. Second, the percentage of soil loss into suspension, Y, is included because the computed soil loss, E, accounts for saltation and creep as well as suspension. Few measurements have been made so that the value of Y is uncertain. Estimates of the value range from no more than 40% to as low as 3% (Reference 1). For example, information from Chepil (Reference 17) (as cited in *Soil Physics*[19]) is shown in Table 4, where suspension of clay particles is much less than loam particles and sand lies about in the middle.

2.7 AQUIFER and Supporting Subroutines

AQUIFER and supporting subroutines are used to model a release pathway for dissolved nuclides in water that has seeped through a waste disposal cell and entered an aquifer. The aquifer discharges at some user-specified distance into a body of water that is a supply for public consumption at a user-specified rate. The mathematical model is one-dimensional, transient flow at a constant velocity, with axial dispersion and adsorption allowed (see Reference 1, pp. 6-7). Initially, the nuclide concentration is zero everywhere. A time-dependent boundary condition is used where the seepage column intersects the aquifer. The entrance of the nuclides is modeled as a uniform release during a specific time period (a band release). The subroutine sequentially selects these time periods. Radioactive decay up to the end of the release from the soil column is accounted for in the time-dependent boundary condition.

Table 4. Relative importance of saltation surface creep, and movement in suspension in the wind-erosion process (References 13 and 19)

Soil Type	Soil Removed (%)		
	Saltation	Surface Creep	Suspension
Scepter heavy clay	72	25	3
Haverhill loam	55	7	38
Hatton fine sandy loam	55	13	32
Fine drive sand	68	16	16

The mathematical model has been solved analytically using Laplace transform techniques (Reference 3). The resulting solution was programmed and documented at Pacific Northwest Laboratory as the GET005 code. The present AQUIFER is a simplified version that does not account for daughter products and has a somewhat different input band description.

The analytical solution of the model in NUREG/CR-1963, pp. 6-8 (Reference 1), is the same as that shown by D. H. Lester et al.[20] under the same assumptions, although the latter reference should be consulted for the correct definitions of dimensionless variables. The supporting subroutines are SWD, FF10, and FERRNT. Together these subroutines compute the complimentary error function for large arguments. The result of these subroutines was validated to 13 significant figures using the intrinsic function ERFC in the Control Data Corporation Fortran library.

The radioactivity discharged from the aquifer is merged with a user-specified flow of water that is ingested by people. An implicit assumption is that the flow of water includes the total flow discharged from the aquifer.

2.8 Subroutine PUNC

The dose from a puncture wound is calculated by subroutine PUNC, using the method described in Appendix A. In the output, this dose is printed separately from any dose resulting from direct radiation or from radionuclides in the environment.

3. RESPONSE SURFACE METHOD OF UNCERTAINTY ANALYSIS

3.1 Overview

The response surface method of uncertainty analysis is a statistical approach for calculating the consequence of a postulated event, or scenario, in the presence of a large number of influential variables. The method is based on a systematic sampling of the true response surface that is then approximated by a polynomial equation in the input variables. The statistical moments of this polynomial response surface equation (RSE) are obtained using second-order error propagation. A Pearson distribution function,[21] having the same statistical moments as the RSE, is used to determine the consequence of the scenario at a specified probability value. The response surface method is outlined in the following steps and explained in the discussion below.

1. Identify the influential input variables, and obtain the mean value, the standard error, and the probability density function (PDF) for each variable.

2. Choose a statistical experimental design and assign each input variable to a column of the design matrix.

3. Perform the calculations using BURYIT. Make one run for each row of the design matrix, with the input variables perturbed according to their assigned factor levels for the row. The result of these calculations are the samples of the true response surface.

4. Fit a second-order polynomial RSE to the dose commitment response surface samples. Check the RSE for adequacy of fit and alter if needed.

5. Estimate the statistical moments of the RSE using second-order error propagation.

6. Match a probability density function (PDF) to the statistical moments of the RSE. The consequence of the scenario is then defined herein as the dose commitment which corresponds to a specified probability value (usually the 5% upper tail probability value) of the PDF.

The identification of influential input variables sometimes involves a preliminary sensitivity study. The purpose of the preliminary sensitivity study is to pare the number of variable input parameters to those which actually influence the response surface. For each candidate variable, the mean or nominal value and the probability density should be known. The study is done with each of the candidate variables perturbed to its limiting value. These limiting values are usually taken to be three standard deviations above and below the mean ($\mu \pm 3\sigma$); however, for some bounded distributions, notably the uniform probability density function, the extreme values occur at less than $\pm 3\sigma$ from the mean. Two runs are done for each candidate, one for each limiting value. These runs are called the star points of the design. The responses for each run can be saved on computer disk storage for later use in estimating the quadratic terms of the RSE.

When the influential input variables have been identified, a statistical experimental design is chosen. A statistical experimental design is a pattern for perturbing the variable parameters, also called the factors of the design. An efficient design provides the information necessary to estimate the coefficients of all important terms of the RSE in as few computer runs as possible. Designs are classified according to the degree of confounding, or confusion of factors, caused by the pattern for perturbing the factors. The categories are actually in ascending order based on the resolution of terms of the RSE. Of interest are the following categories (Reference 6):

1. Resolution III designs: linear terms are free from confounding with other linear terms; but, are confounded with two-factor interactions and two-factor interactions with each other.

2. Resolution IV designs: linear terms are free from confounding with each other and with two-factor terms (also called interaction terms); but, two-factor terms are confounded with each other.

3. Resolution V designs: linear terms and two-factor terms are free from confounding with other linear or two-factor terms; but, two-factor terms are confounded with three-factor terms.

Resolution IV designs are well suited for calculation of second-order polynomial RSEs, because of the relative abundance of the linear and two-factor terms appearing in the actual equations. In general, each variable identified in the sensitivity analysis will have an associated linear term in the RSE. In addition, a few two-factor terms will appear, but usually the number is less than the number of linear terms. Resolution IV designs are efficient when the number of two-factor terms is not greater than the number of factors associated with a saturated design, i.e., a design containing the maximum number of factors for its size. The following discussion will clarify this concept.

Two types of designs are available in the BURYIT/ANALYZ package: fractional factorial and Plackett-Burman designs. Both types are of Resolution III in their basic forms. However, a Resolution IV design can be obtained for either by adding the foldover, which is simply the negative of the original design. This of course doubles the number of runs and, equivalently, the number of degrees of freedom available to estimate coefficients. The basic fractional factorial designs require the number of runs to be an integer power of two ($n = 2k$), while the Plackett-Burman designs only require the number of runs to be an integer multiple of four ($n = 4k$). For both types, the maximum number of factors is n-1. Thus, Plackett-Burman designs in certain circumstances are more efficient. Plackett-Burman designs of 20 and 24 runs are particularly useful in this respect. The disadvantage of the Plackett-Burman designs is the complexity of the confounding patterns. Algorithms are available for calculating confounding patterns for both fractional factorial and Plackett-Burman designs, but only the fractional factorial confounding pattern algorithm is installed in BURYIT/ANALYZ (Appendix B).

To illustrate confounding in fractional factorial designs, consider a 15-factor, foldover design. Figure 1 is a 15-factor, fractional factorial design including foldover and star point runs. The basic design requires 16 runs and 16 more are required for the foldover. The coefficients that can be estimated are: one constant term (also known as the grand mean), 15 linear terms (one for each factor), and 15 two-factor terms. The constant and the linear terms are free from confounding with two-factor interactions. However, there are 105 possible combinations of 15 factors taken two at a time, so the two-factor terms are in 15 groups each containing 7 confounded terms. Table 5 shows the confounding pattern for a 15-factor, fractional factorial design with its foldover. Because of this confounding, the order of the input factors should be chosen so that each two-factor term suspected of being significant is in a group with only insignificant terms. If advance knowledge of significant two-factor terms is either not available or proves inadequate, a second calculation of the response polynomial can be made using a different sequence of input factors. Comparison of the coefficients of the two-factor terms of the two response polynomials should assist the isolation of significant two-factor terms.

BURYIT includes a driver program which automatically varies the input factors according to the design, makes the calculations for the response surface samples, and collects the results on computer disk storage. If a sensitivity analysis was done (Step 1), the results can be appended to the results of the linear analysis (Runs 1-32 of Figure 1). Thus, the sensitivity analysis results are the star points of the design (Runs 33-62), which are used for estimating the quadratic terms of the RSE.

The response surface samples are fitted to a second-order polynomial equation to fit the true response surface. If the equation fits well, the residuals, the errors in predicting the individual samples, are small and should appear to be random deviations. An equation is underfit if not enough terms are included to adequately model the response surface. Conversely, an equation is overfit if it contains so many terms that it tries to match the "random" residuals of the response. A good strategy[22] will guard against both underfit and overfit. ANYOLS,[23] the code within ANALYZ that calculates the response surface equation, contains four regression strategies.

The first strategy uses the F-test (Reference 22) to determine which terms to include in the equation. The F-statistic is calculated for each term, to test whether the corresponding coefficient is zero. A large value of the F-statistic indicates that the coefficient is probably nonzero, and provides justification for including that term in the equation. To guard against overfit, terms in the model are reexamined at each step, and any with small F-statistics are removed from the model.

Another strategy uses the C_p statistic[24,22] to estimate the mean squared error (MSE) of the fitting equation. C_p measures the sum of the squared

RUNS	FACTORS 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
2	-1.	1.	1.	1.	-1.	-1.	-1.	1.	1.	1.	-1.	-1.	-1.	1.	-1.
3	1.	-1.	1.	1.	-1.	1.	1.	-1.	-1.	1.	-1.	-1.	1.	-1.	-1.
4	-1.	-1.	1.	1.	1.	-1.	-1.	-1.	-1.	1.	1.	1.	-1.	-1.	1.
5	1.	1.	-1.	1.	1.	-1.	1.	-1.	1.	-1.	-1.	1.	-1.	-1.	-1.
6	-1.	1.	-1.	1.	-1.	1.	-1.	-1.	1.	-1.	1.	-1.	1.	-1.	1.
7	1.	-1.	-1.	1.	-1.	-1.	1.	1.	-1.	-1.	1.	-1.	-1.	1.	1.
8	-1.	-1.	-1.	1.	1.	1.	-1.	1.	-1.	-1.	-1.	1.	1.	1.	-1.
9	1.	1.	1.	-1.	1.	1.	-1.	1.	-1.	-1.	1.	-1.	-1.	-1.	-1.
10	-1.	1.	1.	-1.	-1.	-1.	1.	1.	-1.	-1.	-1.	1.	1.	-1.	1.
11	1.	-1.	1.	-1.	-1.	1.	-1.	-1.	1.	-1.	-1.	1.	-1.	1.	1.
12	-1.	-1.	1.	-1.	1.	-1.	1.	-1.	1.	-1.	1.	-1.	1.	1.	-1.
13	1.	1.	-1.	-1.	1.	-1.	-1.	-1.	-1.	1.	-1.	-1.	1.	1.	1.
14	-1.	1.	-1.	-1.	-1.	1.	1.	-1.	-1.	1.	1.	1.	-1.	1.	-1.
15	1.	-1.	-1.	-1.	-1.	-1.	-1.	1.	1.	1.	1.	1.	1.	-1.	-1.
16	-1.	-1.	-1.	-1.	1.	1.	1.	1.	1.	1.	-1.	-1.	-1.	-1.	1.
17	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.	-1.
18	1.	-1.	-1.	-1.	1.	1.	1.	-1.	-1.	-1.	1.	1.	1.	-1.	1.
19	-1.	1.	-1.	-1.	1.	-1.	-1.	1.	1.	-1.	1.	1.	-1.	1.	1.
20	1.	1.	-1.	-1.	-1.	1.	1.	1.	1.	-1.	-1.	-1.	1.	1.	-1.
21	-1.	-1.	1.	-1.	-1.	1.	-1.	1.	-1.	1.	1.	-1.	1.	1.	-1.
22	1.	-1.	1.	-1.	1.	-1.	1.	1.	-1.	1.	-1.	1.	-1.	1.	-1.
23	-1.	1.	1.	-1.	1.	1.	-1.	-1.	1.	1.	-1.	1.	1.	-1.	-1.
24	1.	1.	1.	-1.	-1.	-1.	1.	-1.	1.	1.	1.	-1.	-1.	-1.	1.
25	-1.	-1.	-1.	1.	-1.	-1.	1.	-1.	1.	1.	-1.	1.	1.	1.	1.
26	1.	-1.	-1.	1.	1.	1.	-1.	-1.	1.	1.	1.	-1.	-1.	1.	-1.
27	-1.	1.	-1.	1.	1.	-1.	1.	1.	-1.	1.	1.	-1.	1.	-1.	-1.
28	1.	1.	-1.	1.	-1.	1.	-1.	1.	-1.	1.	-1.	1.	-1.	-1.	1.
29	-1.	-1.	1.	1.	-1.	1.	1.	1.	1.	-1.	1.	1.	-1.	-1.	-1.
30	1.	-1.	1.	1.	1.	-1.	-1.	1.	1.	-1.	-1.	-1.	1.	-1.	1.
31	-1.	1.	1.	1.	1.	1.	1.	-1.	-1.	-1.	-1.	-1.	-1.	1.	1.
32	1.	1.	1.	1.	-1.	-1.	-1.	-1.	-1.	-1.	1.	1.	1.	1.	-1.
33	3.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
34	-3.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
35	0.	3.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
36	0.	-3.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
37	0.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
38	0.	0.	-1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
39	0.	0.	0.	3.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	-3.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
41	0.	0.	0.	0.	3.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
42	0.	0.	0.	0.	-3.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
43	0.	0.	0.	0.	0.	3.	0.	0.	0.	0.	0.	0.	0.	0.	0.
44	0.	0.	0.	0.	0.	-3.	0.	0.	0.	0.	0.	0.	0.	0.	0.
45	0.	0.	0.	0.	0.	0.	3.	0.	0.	0.	0.	0.	0.	0.	0.
46	0.	0.	0.	0.	0.	0.	-3.	0.	0.	0.	0.	0.	0.	0.	0.
47	0.	0.	0.	0.	0.	0.	0.	3.	0.	0.	0.	0.	0.	0.	0.
48	0.	0.	0.	0.	0.	0.	0.	-3.	0.	0.	0.	0.	0.	0.	0.
49	0.	0.	0.	0.	0.	0.	0.	0.	3.	0.	0.	0.	0.	0.	0.
50	0.	0.	0.	0.	0.	0.	0.	0.	-3.	0.	0.	0.	0.	0.	0.
51	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.	0.	0.	0.	0.	0.
52	0.	0.	0.	0.	0.	0.	0.	0.	0.	-3.	0.	0.	0.	0.	0.
53	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.	0.	0.	0.	0.
54	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	-3.	0.	0.	0.	0.
55	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.	0.	0.	0.
56	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	-3.	0.	0.	0.
57	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.	0.	0.
58	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	-3.	0.	0.
59	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.	0.
60	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	-3.	0.
61	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	3.
62	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	-3.
63	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

ALPHA = 3.0000

Figure 1. Design matrix for a 2**(15-10) fractional factorial including foldover and quadratic runs.

Table 5. Confounding pattern for two-factor interactions for 15-factor, fractional factorial design

1-2	1-3	1-4	1-5	1-6
3-11	2-11	2-12	3-8	2-8
4-12	4-13	3-13	4-9	4-10
6-8	5-8	5-9	6-11	5-11
7-9	7-10	6-10	7-12	7-13
10-15	9-15	8-15	10-14	9-14
13-14	12-14	11-14	13-15	12-15
1-7	1-8	1-9	1-10	1-11
2-9	2-6	2-7	2-15	2-3
3-10	3-5	3-15	3-7	4-14
5-12	4-15	4-5	4-6	5-6
6-13	7-14	6-14	5-14	7-15
8-14	9-13	8-13	8-12	9-10
11-15	10-12	10-11	9-11	12-13
1-12	1-13	1-14	1-15	2-5
2-4	2-14	2-13	2-10	3-6
3-14	3-4	3-12	3-9	4-7
5-7	5-15	4-11	4-8	8-11
6-15	6-7	5-10	5-13	9-12
8-10	8-9	6-9	6-12	10-13
11-13	11-12	7-8	7-11	14-15

biases (due to lack of fit) in the response equation at all sample points. This method depends on a good estimate of σ_b^2 (variance due to "random" residuals in the sample data), and is, therefore, less desirable than S^2 minimization or PRESS.

A third strategy for selecting terms to be included in the equation is minimization of S^2, the mean residual sum of squares. The S^2 is the estimate of σ_b^2 with the minimum variance if the residuals are truly random.

$$S^2 = RSS/(N-P)$$

where

RSS = the residual sum of squares, the sum of the squares of the residuals of the fitted polynomial at all sample points

N = the number of sample points

P = the number of terms in the equation.

Since adding terms to the polynomial decreases RSS and increases P, the minimum value of S^2 will occur at a small value of RSS, but before too many terms are included in the equation. Thus, the S^2 minimization strategy guards against both overfit and underfit (Reference 23).

The fourth strategy is Prediction Error Sum of Squares (PRESS).[25] In this method, all response samples, but one, are included in the fit, and the error in calculating the remaining point is measured. The sum of squares of these prediction errors, summed over all the sample points, is PRESS. Selection of terms for inclusion in the polynomial equation is based on minimizing PRESS. This strategy guards against both overfit and underfit and is the default-stepwise-regression method for ANALYZ.

Second-order error propagation is used to estimate the lower four moments of the response density under the assumption that the uncertainty variables are statistically independent. The computer program SOERP[26] solves equations for the raw moments (moments-about-the-origin) of the response distribution. These equations are based on a multivariable Taylor series expansion that is truncated after second-order terms and are, therefore, second-order error propagation equations. They use all moments of the input variables up to and including the eighth and produce estimates of the lower four moments of the fitted response surface equation. SOERP is incorporated as a subcode in ANALYZ.

The statistical moments of the response, calculated using SOERP, are then used to obtain a probability density function (PDF) which approximates the actual BURYIT dose commitment response density. The code PDFPLOT,[27] within ANALYZ, matches the lower four response moments to those of a member of the Pearson family of distribution curves. The approximate response PDF is then used to estimate the consequence of the calculated scenario at the specified probability value of interest. Often the consequence is defined in terms of the spread of dose commitment that includes 90% of the response sample population. The bounds on the consequences of the calculated scenario thus correspond to the 5% lower and upper tail probability values, respectively. For dose commitment, the 5% upper tail probability value, which translates as the upper consequence bound, is the one of interest.

The relationship between the mean value and the spread of dose commitment response are such that some portion of the approximate response density could lie to the left of the origin. This situation occurred, in fact, in the methodology demonstration case (Section 6). To preclude the representation of negative dose commitments as physically meaningful, a one-sided truncation was included in the calculation of the Pearson density approximation. The truncation population is formed by removing the portion of the density which lies to the left of the origin (defined as the point of truncation) and then including the removed fraction in the remaining density, to the right of the truncation point. The one-sided truncation incorporated into the PDFPLOT subcode is given by the following transformation.[28,29]

If x is a random variable with density f(x) and cumulative distribution F(x), then the density of x truncated on the left at point a is given by

$$g(x) = \frac{f(x)}{1 - F(a)} I_{(a)}(x)$$

where

$I_{(a)}(x)$ is the indicator function;

$I = 1$ for $a \leq x$

$I = 0$ otherwise

$a \geq 0.$

The cumulative distribution of x truncated on the left at point a is:

$$G(x) = \frac{F(x) - F(a)}{1 - F(a)} I_{(a)}(x) \quad .$$

The above transformation gives a conservative representation of the specified probability values (SPVs) that are used to estimate the dose commitment consequence. Quite simply, $G(x) \leq F(x)$, and thus, $x_G \geq x_F$ for $G = F$. That is, the dose commitment x corresponding to a SPV defined by cumulative distribution G is never smaller than the x which corresponds to the same SPV defined by F.

Note that the truncation is performed on the values generated by the Pearson distribution. The truncation does not affect the response moments calculated by SOERP. Thus, the risk calculation (described in Section 4) uses the actual moments calculated for the dose commitment response and not the truncated density. Truncation of the risk density, if necessary, is performed separately and follows the risk calculation.

Alternatively, the user has the option of fitting the logarithm of the response rather than the response itself. The fitting coefficients are computed by ANYOLS and passed to SOERP, which computes the first four moments and passes them to PDFPLOT. PDFPLOT then finds the corresponding Pearson distribution for log (response). This does not need to be truncated, because a logarithm can be positive or negative. Finally, PDFPLOT mathematically transforms the variable and plots the distribution for the original response. In situations when the final dose is roughly proportional to the important factors, using logs only avoids the truncation problem, but may also provide a substantially improved fit in ANYOLS.

3.2 Sensitivity of Dose Commitment Computations

Once the response surface equation (RSE) has been obtained, the parametric sensitivity of the dose commitment computations may be studied. The term *parametric sensitivity* refers to the rate of change of a response with respect to an uncertainty factor, usually a parameter.

Two kinds of sensitivity coefficients are in common usage. For convenience here, these will be called the absolute sensitivity coefficient and the relative sensitivity coefficient. The absolute sensitivity coefficient refers to the change in response in its original units with respect to either a change in the parameter in its original units or a change in the parameter normalized with respect to its uncertainty standard deviation. The relative sensitivity coefficient refers to the fractional change of the response relative to its nominal value with respect to the fractional change of the parameter relative to its nominal value.

From the discussion in Section 3.1, it should be apparent that the linear coefficients in the response surface equation are the absolute sensitivity coefficients for the parameters. In mathematical terms, a linear term in a Taylor series expansion is the first partial derivative evaluated at the nominal (expansion) point

$$\left.\frac{\partial R}{\partial p}\right|_{nom}$$

where

R = response

p = parameter.

This is precisely the definition of an absolute sensitivity coefficient. In the case of simple models, such coefficients may be computed directly. With more complex models and when a Resolution IV experimental design is used in evaluating the response surface coefficient, the linear terms are obtained without confounding among themselves. In the methodology described herein, the absolute sensitivity coefficient is often expressed as rate of response change with respect to a parameter change of one standard deviation. Thus, if the parameter is normalized as $u = p/\sigma$, the absolute sensitivity coefficient will come out as

$$\left.\frac{\partial R}{\partial u}\right|_{nom} .$$

Such coefficients are produced by SOERP and are designated as LB( )s. The absolute sensitivity coefficients are useful for mapping the behavior of the response in the vicinity of the nominal point. In addition, the second-order terms of the RSE may be used to assess the magnitude and direction of deviations from linearity.

The relative sensitivity coefficients may also be derived from the linear terms of the RSE. If R_o and P_o are the values of the response and a parameter at the nominal point, the relative sensitivity coefficient is

$$\left(\frac{p}{R}\right)_o \left.\frac{\partial R}{\partial p}\right|_{nom} = \left(\frac{p}{\partial R}\right)_o \left.\frac{\partial R}{\partial u}\right|_{nom}$$

In other words, this sensitivity coefficient is the linear term in the RSE multiplied by the ratio $(p/R)_o$. The relative sensitivity coefficients are useful to those analysts who prefer to use percentage numbers to describe the perturbation behavior of the response.

Thus, the response surface uncertainty analysis methodology focuses on the calculation and use of the response surface equation. This second-order polynomial approximates the surface of the BURYIT code response over a small range of input parameter variation. The RSE forms the basis for the response density, which is a statistical representation of the likelihood of occurrence of a dose commitment, given a scenario and the statistical properties of the uncertainty variables. Section 4 describes the calculation of the risk of the dose commitment, given the consequence and the statistical properties of scenario occurrence probability.

4. CALCULATION OF RISK

The risk associated with an event, or scenario, is defined herein to be the product of the consequence of the event, providing that the event has occurred, and the probability of occurrence of the event within some convenient time period. That is,

$$(\text{RISK})_i = (\text{Consequence})_i \cdot (\text{Probability})_i \quad . \qquad (4)$$

The time period pertaining to the occurrence probability is often taken as one year; but, whatever time period is selected must be considered in the interpretation of computational results. The above definition of risk due to a particular scenario, i, arises as a term in the (probabilistic) expected consequence at a site

$$E(\text{Consequence}) = \sum_{i=1}^{n} (\text{Probability})_i \cdot (\text{Consequence})_i = \sum_{i=1}^{n} (\text{Risk})_i , \qquad (5)$$

where the scenarios (events) are independent and mutually exclusive. Thus, each risk term represents a contribution to the expected consequence.

As discussed earlier, the true consequence of a particular release scenario, (e.g., the ith) is not known exactly, but rather is represented by a probability density function. At the same time, the true probability that a release scenario will take place is not known exactly and must be represented by a probability density function. As a result of these uncertainties, the risk associated with the ith release scenario must be represented by a probability density function, as must the ith consequence. The estimation of a probability density function for each risk term is discussed next. This is followed by a description of the estimation of the probability density function of the expected consequence, i.e., the sum of the risks.

A direct application of the response surface method is used to determine the risk density, given the variable input parameters of scenario consequence and probability and their respective densities. Here the response surface equation is obtained from the definition of risk in Equation (4). To obtain the coefficients of the RSE, Equation (4) is expanded in a Taylor series about the mean values of the respective input variables. In the notation of Reference 26,

$$Z(x_1, x_2) = Z(\nu_{11}, \nu_{21}) + \frac{\partial h}{\partial x_1}(x_1 - \nu_{11}) + \frac{\partial h}{\partial x_2}(x_2 - \nu_{21}) + \frac{\partial^2 h}{\partial x_1 \partial x_2}(x_1 - \nu_{11})(x_1 - \nu_{21}), \qquad (6)$$

where

$Z = h(x_1, x_2) = x_1 \cdot x_2$

ν_{11} = expected value (mean value) of the variable x_1.

ν_{21} = expected value (mean value) of the variable x_2.

The derivatives are

$$\frac{\partial h}{\partial x_1} = x_2, \ \frac{\partial h}{\partial x_2} = x_1, \text{ and } \frac{\partial^2 h}{\partial x_1 \partial x_2} = 1 \quad .$$

Thus, the exact response surface equation consists of a constant (intercept) term, two linear terms, and one two-factor term.

$$Z = b_0 + b_1(x_1 - \nu_{11}) + b_2(x_2 - \nu_{21}) + b_{12}(x_1 - \nu_{11})(x_2 - \nu_{21}) \quad . \qquad (7)$$

The coefficients of the RSE are:

$b_0 = Z(\nu_{11}, \nu_{21})$ (intercept coefficient)

$b_1 = \nu_{21}$ and $b_2 = \nu_{11}$ (linear coefficients)

$b_{12} = 1$(two-factor or cross-product coefficient).

Equation (7) is the RSE which is supplied to SOERP for calculating the risk dose commitment response moments, assuming statistically independent variables.

The absence of quadratic terms in Equation (7) is fortunate. It was stated earlier that the equations solved by SOERP equations required the first eight central moments of the variable input parameters. Only the first four moments of scenario consequence dose commitment are available from SOERP. All the terms in the SOERP equations requiring input parameter moments 5 through 8 contain quadratic coefficients as well. All these terms vanish for the calculation of the risk moments. Thus, the first four moments of dose commitment are sufficient for the calculation.

In addition to the first four moments of the dose commitment, the risk calculation requires the first four moments of the scenario occurrence probability PDF. Scenario occurrence probability is modeled as a log-normal variate. Log-normal distributions are commonly described in terms of a median value and an error factor. The median value, m, is given by

$$m = \exp[\mu_n],$$

where μ_n is the mean of the underlying normal distribution of logarithms. The error factor, EF, often includes 90% of the population described by the distribution, and is given by

$$EF = \exp[1.645\ \sigma_n],$$

where σ_n is the standard deviation of the underlying normal distribution of logarithms, and 1.645 is the 0.90 fractile of the two-sided, standard normal distribution. The mean and variance of the distribution of scenario occurrence probability are given in terms of the mean and variance of the underlying normal distribution of logarithms (Reference 29):

$$\mu_1 = \exp\left(\mu_n + \frac{\sigma_n^2}{2}\right)$$

and

$$\sigma^2 = \exp\left(2\ \mu_n + \sigma_n^2\right)\exp\left[\left(\sigma_n^2\right) - 1\right].$$

Of course it is more useful to have the mean and variance of the distribution of scenario occurrence probability in terms of the given information. Thus,

$$\mu_1 = \exp\left[\ln m + \frac{1}{2}\left(\frac{\ln EF}{1.645}\right)^2\right],$$

and

$$\sigma^2 = \exp\left[2 \ln m + \left(\frac{\ln EF}{1.645}\right)^2\right]\left[\exp\left(\frac{\ln EF}{1.645}\right)^2 - 1\right].$$

The raw moments (moments-about-the-origin) are given by (Reference 29).

$$\nu_r = \exp\left[r\ \mu_n + \frac{1}{2} r^2\ \sigma_n^2\right]$$

where r denotes the order of the moment. SOERP requires the central moments of the variable input parameters. The first four central moments of a distribution are related to the raw moments as follows:

$$\mu_1 = 0$$

$$\mu_2 = \nu_2 - \nu_1^2 \equiv \sigma^2$$

$$\mu_3 = \nu_3 - 3\ \nu_2\ \nu_1 + 2\ \nu_1^3$$

$$\mu_4 = \nu_4 - 4\ \nu_3\ \nu_1 + 6\ \nu_2\ \nu_1^2 - 3\ \nu_1^4.$$

Thus, given the statistical properties of the dose commitment and probability, along with the response surface equation which describes the risk in terms of the two inputs, SOERP estimates the lower four statistical moments of the risk. As in Section 3, these response moments are then used to obtain a PDF which approximates the actual risk density. PDFPLOT is used again to match the response moments to those of a Pearson distribution. The location of the 5% upper tail probability value of the Pearson distribution again corresponds to the dose commitment of interest. Therefore, the risk associated with a given scenario is the dose commitment value which includes 90% of the area under the risk density curve. As in the previous section, a one-sided truncation is performed, if necessary, to avoid representation of negative dose values as physically significant.

If the log of the dose was originally fitted, computations similar to the above are used to get the moments, and then the PDF, of log (risk). This is then used to get the PDF for the risk itself.

Response surface methodology is, therefore, applied twice in the assessment of risk associated with a postulated event for a LLW disposal site. The first application involves the least-squares fitting of a RSE to the responses of BURYIT. The density associated with this RSE is used to define the consequence of the scenario. The second application combines the consequence density with the density of the likelihood (probability) of the event to form a second response, the density of which is defined to be the risk of the scenario. The risk bounds calculated for the total population dose or the maximum individual dose for several scenarios may be plotted in bar graph form for comparison.

The estimation of the density of the expected consequence (sum of scenario risks) is now discussed, even though currently this is not included in the program package. In accord with Equation (4), linear error propagation is used assuming that the scenario risks are statistically independent. It is also implicitly assumed that the consequence under no release is exactly zero. The means and first four central moments of the density for expected consequence are determined by the means and central moments of the risks, μ_{ij}. Again, as in Sections 3 and 4, these moments may be fed to the subroutine PDFPLOT in order to obtain a density function for expected consequence (i.e., total risk). Just as before, upper and lower probability bounds on total risk may be computed.

5. INPUT AND OUTPUT

5.1 Analysis Flexibility

This section contains a brief discussion of the flexibility of the BURYIT/ANALYZ package, followed by a description of the input requirements. A flexible computer code or package is one which has the capability to perform only a portion of the entire sequence of calculations, so the results of the selected portion may be observed separately. Insight gained from the results of the selected calculation may then be used to modify the code inputs in order to obtain a more representative model for use in the remainder of the calculation sequence. An inflexible code, by contrast, may require execution of the entire sequence of calculations for each set of inputs. Inflexibility can result in wasted calculations and unnecessary computer costs. A flexible code is desirable for uncertainty analysis calculations, primarily because input parameter uncertainties may be imprecisely known, and advance knowledge of the effects of the uncertainties on the code responses may be sketchy. Flexibility options were incorporated in the BURYIT/ANALYZ package, as follows.

The BURYIT uncertainty analysis option includes the capability to do selected portions of an uncertainty analysis. The uncertainty analysis calculation, done by BURYIT, includes steps 1 through 3 of the response surface method, which was discussed in Section 3. The input variables are perturbed according to an experimental design, and the responses from each run of the design are collected on computer disk storage. Steps 4 through 6 of the response surface method involve obtaining the response surface polynomial equation and determining its statistical properties. ANALYZ performs these steps. The BURYIT flexibility options are:

1. Calculation of the experimental design and confounding pattern

2. Option 1 plus calculation of the scenario with all inputs set to nominal values

3. Option 1 plus calculation of the quadratic runs (star points) of the design

4. Complete uncertainty analysis calculation

5. Uncertainty analysis calculation of linear runs of the design, appending the results of quadratic runs previously obtained using Option 3.

Option 1 is useful for obtaining the confounding pattern for a fractional factorial design, and for determining the order of the input variables in the design. Option 2 can be used for checking for input correctness and determining whether the calculated dose commitment is a reasonable nominal value. Option 3 is used for a sensitivity study. The quadratic runs are made with each input variable perturbed singly to the practical limits of its density function (usually 3σ on either side of the nominal value). The results can be used to identify variables having little or no effect on the response. Option 5 is used in conjunction with Option 3, and includes the capability to call responses of selected variables from the results of the sensitivity study.

BURYIT was originally written as a deterministic program, i.e., with no variable input parameters. In this form, one or several scenarios can be calculated in the same run. This mode of calculation was retained in the present version and can be specified by merely omitting the uncertainty analysis control variable. The original version permitted interactive as well as batch operation. However, due to cost considerations and computer storage requirements associated with interactive execution of BURYIT, no effort was made to retain this capability. Thus, BURYIT in its present form is for batch use only. The capability for calculating several scenarios in the same run was retained subject to the original restriction that all scenarios which call the unsaturated soil column model (UNSAT) use the same nuclide inventory. This stipulation is necessary because the nuclide retardation factors, used in the calculation of nuclide transport through the soil layers, depend on both the type of soil in each layer and the nuclide involved. Thus, the retardation factors, corresponding to the nuclide source list for the inventory specified for the scenario, are supplied in the geology data input. Therefore, the nuclide inventory must be correct for the geology data file being used.

ANALYZ includes features to improve its flexibility as well. The options available are the following:

1. Calculation of the statistical moments of scenario consequence, based on the response samples obtained using BURYIT and the densities of the input variables

2. Calculation of the statistical moments of scenario occurrence probability

3. Calculation of the statistical moments of scenario risk. This includes the calculations in Options 1 and 2, and the calculation of the product of the two results.

In all three options, the calculated moments are matched to a Pearson distribution in order to estimate the result (dose commitment or occurrence probability) which corresponds to a specified probability value. Additionally, the subcode PDFPLOT may be accessed directly in order to obtain an approximate probability density for a set of user-supplied statistical moments.

5.2 Input Requirements

Three types of input must be furnished to the BURYIT/ANALYZ package. They are: (a) the radiological data base, (b) the environmental characteristics of the location being modeled, and (c) the control information necessary to do the uncertainty analysis and the risk calculation. Items a and b are nearly the same as described in NUREG/CR-1963, Volume 1 (Reference 1). Changes to these items reflect the model improvements and corrections to coding errors as described in Section 2. Item c represents implementation of the response surface methodology for doing the uncertainty analysis and the risk calculation, described in Sections 3 and 4, respectively. Because of the amount and variety of input required, the information is divided among several disk files, each of which supplies a specific type of information. A summary of these files is contained in Table 6 and a detailed description of the function of each file is in the following paragraphs. The files which form the data base will not normally be changed by the user. Appendix C contains the scenario control file. Instructions for modeling the environmental characteristics of the site location under analysis were published by Science Applications, Inc., (Reference 1). However, for integrity of this document, a complete list of input instructions is included herein, which includes modeling changes and corrections that have been made to

Table 6. Disk file allocation for BURYIT/ANALYZ

File Name	Function
TAPE1	Nuclide data
TAPE2	Nuclide list
TAPE3	Intercom terminal
TAPE4	Uncertainty analysis responses
TAPE5[a,b]	Input-uncertainty analysis
TAPE6	Printed output
TAPE7	Scenario control and scenario descriptions
TAPE8[b]	Erosion data
TAPE9[b]	Atmospheric data
TAPE10[b]	Geology and rainfall data
TAPE11[b]	Aquifer data
TAPE12	Nuclide inventories
TAPE14[b]	Input control and title
TAPE15[b]	Agriculture and population data
TAPE20[b]	Shine exposure data
TAPE21	Internal BURYIT file for storage of intermediate dose results
TAPE44	Sensitivity analysis input to BURYIT
TAPE45	Sensitivity analysis results
TAPE97	Scenario occurrence probability, input to ANALYZ.
TAPE98	Input scenario risk file containing the results of risk calculations for previously done scenarios
TAPE99	Output scenario risk file containing TAPE98 results plus results of current risk calculation
META	DISSPLA plot file

a. User-created file, input to ANALYZ

b. User-created file, input to BURYIT.

BURYIT. Also contained in the following discussion are the instructions for using the uncertainty analysis and risk calculation options.

5.2.1 Computer Storage Files for BURYIT/ANALYZ. TAPE1 is the nuclide data file, and is supplied with the BURYIT/ANALYZ package as part of the data base. The file contains dose equivalence factors, gamma exposure constants, and radioactive decay constants for each nuclide. The information for the nuclide data base was compiled by Science Application, Inc., and is documented in Reference 1.

TAPE2 is the nuclide index file, used for locating entries in TAPE1. It contains the nuclide names in the same sequence as the nuclide property entries in TAPE1.

TAPE3 is the intercom input file for BURYIT. It is used to specify the desired scenarios and to supply minimal information to the code if BURYIT is executed interactively. Although interactive capability is presently considered inactive, the installed coding pertinent to this feature was retained. The inputs supplied by the intercom terminal are included in the TAPE14 input for a batch job and are listed there.

TAPE4 is the uncertainty analysis response file, written by BURYIT for input to ANALYZ. In addition to the responses of the BURYIT runs, TAPE4 contains the control information for calculating the experimental design, the first eight central moments of the input variables, and plot title information.

TAPE5 is the primary input file. It contains the job control language and the uncertainty analysis control information. A detailed description of TAPE5 information is contained in the input requirements section, below.

TAPE6 is the printed output file. The contents depend on the options specified, of course, but include echoes of input files, the results of BURYIT dose calculations, and uncertainty analysis results.

TAPE7 is the scenario control file. It contains, for each scenario, the control word that specifies the scenario description, the waste inventory, the pathway sequence, and the fraction of the waste specified to follow each pathway. It also contains the narratives describing the scenarios. Appendix C contains a listing of the contents of TAPE7.

TAPE8 (erosion data), TAPE9 (atmospheric data), TAPE10 (geology and rainfall data), TAPE11 (aquifer data), TAPE15 (agriculture and population data), and TAPE20 (shine exposure data) are specific to the site being modeled and are described in the input requirements section, below.

TAPE12 is the nuclide (waste) inventory file. It contains lists of isotopes and their amounts for six classifications of waste. These waste classifications are designated WS-1 through WS-6 and represent the following types of waste:

1. WS-1 is highly activated light water reactor (LWR) components and is assumed to be stainless steel with cobalt-60 as the primary isotope.

2. WS-2 is LWR operational waste, assumed to be primarily comprised of low-level activity items such as filters, filter backwork, filtered phase separator decant liquid, evaporator bottoms, demineralizer wastes, laundry wastes, and general trash. This class contains 33 radionuclides.

3. WS-3 is LWR decommissioning waste, consisting primarily of cobalt-60, nickel-63, and iron-55.

4. WS-4 is assumed to result from decontamination of decommissioned facilities. It is similar in composition to LWR operational wastes but has a much higher specific activity. This class contains 33 radionuclides.

5. WS-5 consists of nonfuel cycle (institutional) waste and contains four radionuclides.

6. WS-6 is the waste inventory assumed to represent an average composition in a burial trench. The original WS-6 inventory supplied with BURYIT was based on information supplied by R. D. Smith.[30] This class contains 44 radionuclides.

Appendix D lists the contents of the waste inventory file. The first line for each waste inventory contains the name of the inventory, the number of nuclides present, and the average density (kg/m^3). The density is used for puncture-wound scenarios. The remaining lines for the inventory consist of a nuclide name and concentration (Ci/m^3), one line per nuclide.

TAPE14 is the calculation control file for BURYIT. It contains the logic switches for specifying either a maximum individual dose or cumulative population dose, an intercom or batch job, and the amount of printed output to be produced. It also contains the title card, and, for a batch job, the scenario number and pathway-dependent information. For an interactive job, the scenario number and pathway-dependent input are supplied from the terminal (TAPE3). TAPE14 contents are completely described in the input requirements section, below.

TAPE21 is an internal scratch file, used by BURYIT to store intermediate results of the dose calculation.

TAPE44 and TAPE45 are used for storage and manipulation of BURYIT responses for sensitivity analysis runs. The responses are written to TAPE45 during the sensitivity analysis and read from TAPE44 during a subsequent uncertainty analysis. The quadratic runs which were done during the sensitivity analysis are not repeated. Instead, the results are read from TAPE44 and appended to the linear run responses which are written to TAPE4.

TAPE97 is the scenario probability file used by ANALYZ. The probabilities of occurrence for the scenarios are assumed to be log-normal variates, which are commonly described by a median value and an error factor. TAPE97 contains a median value and a 90% error factor for each scenario. Appendix E discusses these values and their derivation.

TAPE98 and TAPE99 are the scenario risk files used by ANALYZ. TAPE98 contains the results of the risk calculations (Equation 4) for previously done scenarios. TAPE99 contains the TAPE98 results, plus the result of the current scenario risk calculation.

The above files all fall within three categories. They are part of the data base furnished with BURYIT/ANALYZ, are internal files used for storage of intermediate results or for passing results between BURYIT and ANALYZ, or are output files containing the results of the calculations. In all cases, these files are normally not within the direct control of the user. The following files form the specific model for which the calculations are performed and are all user-supplied. Detailed instructions for creating the user-supplied inputs for BURYIT/ANALYZ are given in the following paragraphs.

5.2.2 Input Instructions

5.2.2.1 BURYIT Control and Title. TAPE14 contains control and title information for BURYIT. The control variables specify interactive or batch mode, amount of printed output, and whether a maximum individual dose is calculated. Other input is specific to batch mode; interactive users supply this information from the terminal (TAPE3) in response to prompts by BURYIT.

Card 1: IBATCH, IPRINT

FREE FORMAT

IBATCH = 0, interactive job (interactive option is presently inactive)

IBATCH = 1, batch job

IPRINT = 0, printed output consists of input file echoes and results summary

= 1, printed output contains input file echoes, formatted input printout, intermediate results from UNSAT, AQUIFER, and/or EROSIO, and results summary

= 2, printed output consists of the above plus detailed intermediate results from UNSAT.

Card 2: (ITITLE(I), I=1,8)

FORMAT(8A10)

ITITLE problem title which appears on printed output file and plots.

Cards 3-8 are for batch input only. Interactive users supply the following inputs in response to code prompts:

Card 3: ISCEN scenario code

FORMAT(A4).

Card 4: INVET waste inventory code

FORMAT(A9).

Cards 5-8 are pathway-dependent and are determined by the scenario requested. Appendix C contains a listing of the scenario control file (TAPE7), which includes the list of pathways specified for each scenario. Each pathway for the scenario must include the appropriate cards, as follows:

Paths 3-4

Card 5: CUMT, RF, EMEF, TIMWET, TIMCYC

FREE FORMAT

CUMT exposure time (h)

RF annual rainfall for ATMOS and EROSIO (m/y)

EMEF emplacement efficiency for UNSAT (waste volume/total volume)

TIMWET time for the rain cycle (h), for ATMOS and UNSAT

TIMCYC total time in one cycle of rain and dry (h)

Card 6: VOL volume of package (m^3)

FREE FORMAT

Card 7: UD, DI

FREE FORMAT

UD wind velocity for equivalent contaminated cloud exposure model (m/s). Minimum value is 2.24 m/s (5 miles/h)

DI dust cloud diameter (m)

Paths 3-6

Card 5: CUMT, RF, EMEF, TIMWET, TIMCYC as above

Card 6: VOL as above

Card 7: PDEPOS mass deposited in puncture wound (μg)

Paths 3-2, 3, 2

Card 5: CUMT, RF, EMEF, TIMWET, TIMCYC as above

Card 6: VOL as above

Paths 3-2-951, 2-951, 3-951, 2-91, 3-91

Card 5:	CUMT, RF, EMEF, TIMWET, TIMCYC		as above
Card 6:	VOL		as above
Card 7:	CUMT, RF, EMEF		
	CUMT	time span for unsaturated soil column calculation (y)	
	RF, EMEF, TIMWET, TIMCYC		as above

Paths 951, 91

Card 5:	CUMT, RF, EMEF, TIMWET, TIMCYC		
	CUMT	time span for unsaturated soil column calculation (y)	
	RF, EMEF, TIMWET, TIMCYC		as above

Path 4

Card 6:	CUMT, RF, EMEF, TIMWET, TIMCYC		
	CUMT	exposure time (h)	
	RF, EMEF, TIMWET, TIMCYC		as above
Card 7:	UD, DI		as above

Path 3-4-951

Cards 5-7:	as for Path 3-4		
Card 8:	CUMT, RF, EMEF, TIMWET, TIMCYC		
	CUMT	time span for unsaturated soil column calculation (y)	
	RF, EMEF, TIMWET, TIMCYC		as above

The following files contain information specific to the site being modeled. The SI (international metric) system of units is used with the exception of the mean annual temperature (MAT) where degrees Celsius should be used.

5.2.2.2 Aquifer Data. The aquifer data are input from TAPE11 using a free formatted read statement.

Aquifer Card: XZ, EI, VZ, FLOWR, (RNWV(I), I = 1, NUMNUC)

XZ	length of aquifer (m)
EI	axial dispersion coefficient (m^2/s)
VZ	velocity of aquifer flow (m/s)
FLOWR	water flow rate (L/y)

RNWV inverse equilibrium constant for each nuclide

NUMNUC number of nuclides in the inventory specified for the scenario. NUMNUC is supplied from TAPE12, however.

5.2.2.3 Geology and Rainfall Data. The information pertinent to the unsaturated soil column model is input from TAPE10. All the inputs are in free format.

Card 1: JK, ND, IN

JK number of soil layers

ND number of entries in the hydraulic conductivity and pressure head tables

IN number of the soil layer initially containing the waste.

Card 2: DELW water content increment for the pressure head and hydraulic conductivity tables. Fractional water content is the independent variable for the two soil property tables, which are input on Cards 5 and 6, respectively. The fractional water content table is generated internally in UNSAT. The first entry is 0; subsequent entries are equally spaced with increment DELW. The total number of entries is ND.

Card 3: RAIN, DRY

RAIN rainfall rate during wet period (m/s)

DRY evapotranspiration during dry period (m/s); DRY < 0

Card 4: (DD(I), I = 1, JK+1)

DD locations of soil layer boundaries (m), DD(1) = 0

Card 5: (P(I), I = 1, ND) pressure head (m). Pressure head is input as a tabular function of fractional water content. Fractional water content entries are generated internally within UNSAT, start with zero, and are equally spaced with increment DELW. Unfortunately, a minimum water content value exists at which the pressure head curve becomes asymptotic. This water content corresponds to the amount of moisture which is bound to the internal surfaces of the soil or rock complex due to the forces of molecular attraction (bound water). Pressure head loses physical significance below this asymptote; thus, tabular entries in this region of low water content represent artificial circumstances. The next to last entry in the pressure head table should correspond to saturation water content (zero pressure head). The final entry should have a positive value for P.

Card 6: (E(I), I = 1, ND) Hydraulic conductivity (m/s), input as a tabular function of fractional water content. Hydraulic conductivity, like pressure head, is asymptotic at some positive value of water content, and tabular entries in the region below the asymptote are without physical basis.

Card 7: (W(I), I = 1, KK) Initial water content at each soil layer boundary, fraction by volume.

Card 8: HDRY, HWET, WATL, WATH

HDRY pressure head (m) which corresponds to minimum water content

HWET pressure head (m) which corresponds to saturation water content, normally zero.

WATL minimum water content (bound water), volume fraction.

WATH maximum water content at soil saturation, volume fraction.

Cards 9-11 contain information specific to the soil layers. Input consists of JK sets of these three cards; however, some sets may be skipped. The sets are input in ascending layer order; skipped layers are assigned the characteristics of the next specified layer. Layer JK cannot be skipped.

Card 9: LYR layer number

Card 10: (XD(I, LYR), I = 1, NUMNUC) distribution coefficients (mL/g) for each nuclide in the inventory list.

Card 11: CONCOF (LYR), DNSTY (LYR)

CONCOF conductivity factors for correction of hydraulic conductivity (Card 6) to the soil characteristics of a layer (dimensionless). CONCOF (1) is internally set to 1.

DNSTY density of soil layer (kg/m^3).

Card 12: (SOLFAC(I), I = 1, NUMNUC) nuclide solubilities (Ci/m^3) for each nuclide in the inventory list (See Table 3).

Card 13: TRAR trench area subject to infiltration (m^2).

5.2.2.4 Erosion Data. The information required for the solution of the wind erosion equation is input from TAPE8. The entire group of cards is entered using free format.

Card 1: IK1, PAG84, IK3, MAT, ANGL, ANGWND, HTBR, FW, FL, R, CK5, CK8, CK11, CK13, SAIR

IK1 soil erodibility calculation control variable

= 1, calculate soil erodibility I′ for flat land

> 1, calculate I′ and apply windward knoll slope correction to result as follows:

= 2, correction is based on potential soil loss from top of knoll

= 3, correction is based on potential soil loss from that portion of windward slope where drag velocity and windward drag are the same as on top of the knoll (from about the upper third of the knoll)

PAG84 percentage of soil in the top layer of the burial site that is greater than 0.84 mm diameter ($1 \leq PAG84 \leq 80$)

IK3 soil ridge roughness correction control variable

= 1, ridge roughness is specified, and determines the ridge roughness factor K′.

= 2, ridge height and spacing are specified. Calculate ridge roughness, then use roughness to determine K'.

= 3, K' = 0.5 (minimum value for ridge roughness factor)

= 4, K' = 1.0 (maximum value for ridge roughness factor)

MAT	mean annual temperature (°C). MAT is a floating point variable
ANGL	lower compass direction that parallels the long axis of the field (0° is North, 90° is East, 0 to 179).
ANGWND	compass direction from which wind is blowing (0° is North, 90° is East, 0 to 359).
HTBR	barrier height (m)
FW	field width (m) $0 < FW < 1524$ m
FL	field length (m)
R	vegetative cover (kg/m^2). Limits on R depend on cover type and are given in Table 7.
CK5	> 0, specifies anchored small grain stubble
CK8	> 0, specifies small grain crops in seedling and stooling stage
CK11	> 0, specifies flat grain sorghum stubble
CK13	> 0, specifies standing grain sorghum stubble
SAIR	percentage of eroded soil which remains suspended (lofted soil).

The following cards are optional, and supply additional parameters as required by Card 1.

Card 2: Include if IK1 > 1

KLSP knoll slope in percent ($0 \leq KLSP \leq 10$). KLSP is a floating point variable

Card 3: Include if IK3 = 1

RDGRGH soil ridge roughness (m). $0 \leq RDGRGH \leq 0.254$

Card 4: Include if IK3 = 2

RDGHT soil ridge height (m)

RDGSP soil ridge spacing (m)

Card 5: Include if CK5 > 0

CK6 = 0, specifies standing small grain stubble

= 1, specifies flat small grain stubble

Table 7. Maximum input values for equivalent vegetative cover, R (kg/m²)

Vegetation Type	R (maximum)
Small grain crops, seedling, and stooling	
In furrow	1.3
On smooth ground	1.6
Anchored small grain stubble	
Standing	3.1
Flat	1.6
Grain sorghum stubble	
Flat	1.4
Standing, 0.2 m (8 in.)	1.9
Standing, 0.3 m (12 in.)	2.4
Standing, 0.4 m (16 in.)	3.0
Standing, 0.5 m (20 in.)	3.6

Card 6: Include if CK8 > 0

CK9 = 0, small grain crops on smooth ground

CK9 = 1, small grain crops in furrows

Card 7: Include if CK13 > 0

HT height of standing grain sorghum stubble (m) ($0 < HT \leq 0.5$ m)

5.2.2.5 Atmospheric Data. The atmospheric data are input from TAPE9. Included are stack (or release) height and energy release rate, for use in the Gaussian plume-rise model, and the wind frequency array, for use in the Gaussian plume-rise model and in the soil-erosion model. The wind frequency array consists of a wind speed vector (m/s) and up to seven stability classes. Each frequency vector corresponds to the fraction of the total time that the atmospheric conditions fit a particular stability category. Each entry within the frequency vector corresponds to a value of wind speed and represents a fraction of the total time within the stability category at the corresponding wind speed. The total of the fractions of all the frequency vectors should be unity.

Card 1: SH, SQ

FREE FORMAT

SH release or stack height (m)

SQ stack energy release rate (W)

Card 2: NU, KS, NS

FREE FORMAT

NU — number of entries in wind speed vector (maximum of 10)

KS — optionally specify one wind speed for the ATMOS calculation

= 0, use entire wind speed vector

> 0, use wind speed entry KS, and use a wind frequency of 1 for that entry

NS — number of stability categories (maximum of 7)

Card 3: U(I), I = 1, NU

FREE FORMAT

U — wind speed vector (m/s). Note: If an uncertainty or sensitivity analysis is to be performed with K levels of wind (K = 3 or 5), then Card 3 must be input here K times. See the discussion of the wind frequency array in Section 5.2.3.

Card 4: (F(I,J), I = 1, NU), J = 1, NS

FREE FORMAT

F — wind speed-stability class frequency array. Input consists of NS lines, NU entries per line. Note: As with Card 3, the array called "Card 4" must be input K times here if an uncertainty or sensitivity analysis is performed with K levels of wind.

5.2.2.6 Agriculture and Population Data. The agriculture and population data are input from TAPE15.

Card 1: NR — number of radial increments (maximum of 20)

FREE FORMAT

Card 2: RM(I), I = 1, NR

FREE FORMAT

RM — distance from the disposal trench to the center of the radial increment (m)

Card 3: BEEF, COWS, (FAGE(I), I = 1, 3), FCA, NCPY, PRODUC

FREE FORMAT

BEEF — number of beef cattle per square kilometer for all radial increments

COWS — number of milk cows per square kilometer for all radial increments

FAGE — age group fraction breakdown by child, teen, and adult, respectively, for all radial increments

FVA — fraction of the total involved area available to plant leafy vegetables

NCPY number of crops per year

PRODUC food crop production (kg/y-km^2)

Card 4: IPOP(I), I = 1, NR

FREE FORMAT

IPOP population in each radial increment

5.2.2.7 Direct Exposure Data. The direct exposure data are input from TAPE20.

Card 1: IST, RANGE, NSH, (MATRL(I), I = 1, NSH)

FREE FORMAT

IST direct source type as specified below

= 1, point source

= 2, line source

= 3, volume source

RANGE distance from the direct source (m)

NSH number of shielding materials around source container (minimum = 0, maximum = 5)

MATRL composition of shielding materials

= 1, aluminum

= 2, iron

= 3, lead

= 4, ordinary concrete

= 5, water

Card 2: THK(I), I = 1, NSH

FREE FORMAT

THK thickness of shielding material I (m)

Card 3: A

FREE FORMAT

If IST = 3, A = radius of the volume source = half length of the volume source (m)

If IST = 2, A = half the length of the line source (m)

If IST = 1, this card may be omitted.

5.2.2.8 Scenario Requirements Summary. Table I-1 in Appendix I contains a list of scenarios available for BURYIT analysis. Included in the table are a description of the scenario, the waste inventory assumed for the site, and a list of the files required for the calculation.

5.2.3 Uncertainty Analysis Input. The uncertainty analysis input to BURYIT is on file INPUT. It includes the control variable that calls the uncertainty analysis option and the variables which specify the design, the input parameters and their uncertainties, and the responses.

Card 1: IUNCRT, MAXI, IDERIV

FREE FORMAT

IUNCRT = 0, no uncertainty analysis performed
= 1, uncertainty analysis performed

MAXI = 0, cumulative population dose calculated
= 1, maximum individual dose calculated

IDERIV = 0, no derivatives calculated
= 1, derivatives calculated for certain responses and input parameters.

If no cards reside on file INPUT, all three variables are set to zero. If the uncertainty analysis option is chosen, and if MAXI = 1, BURYIT is executed first under the nominal conditions to determine which individual receives the maximum dose. This same individual is then used for all the remaining runs, even though another individual may receive a larger dose on some of these runs. If the uncertainty analysis option is specified, then the uncertainty analysis variables are input using a Namelist READ statement, now described.

Each line of namelist input begins in Column 2. The namelist name, IN, is on the first line and is preceded by a $. The last line of namelist input is $END.

$IN

IFLAG flag for check runs

= 0, calculate the design and confounding pattern (default)

= 1, add the nominal BURYIT run

= 2, do the uncertainty analysis specified by LTYPE and ISTART.

LTYPE type of analysis desired

= 1, linear (default)

= 2, linear plus foldover

= 3, linear plus quadratic

= 4, linear plus foldover plus quadratic

= 5, linear plus quadratic, user-specified quadratic factor level

= 6, linear plus foldover plus quadratic, user-specified quadratic factor level

LPB statistical experimental design flag

= 0, fractional factorial design (default)

= 1, Plackett-Burman design

LFAC(N) list of factors from Table 8 to be included in the design. Order is important because it determines the placement of the factors in the confounding pattern.

LRES(N) List of responses from Table 9. LRES(1) means either the

MRES(N) cumulative population dose or the maximum individual dose, depending on the value of MAXI in the BURYIT control input (see Section 5.2.2).

FACTOR(J) Flag to specify additive or multiplicative uncertainties for input factor J as listed in Table 8, i.e., J = 1, ... , 100.

= 0, additive

= 1, multiplicative

C(I,J) Uncertainty associated with factor J. Presently the I index is used if factor J has different uncertainties for each age group; i.e., I = 1 (child), 2 (teen), 3 (adult). I could also be used for other applications. Otherwise use I = 1.

If the uncertainty is additive, i.e., FACTOR(J) = 0, then for most applications C(I,J) should equal one standard deviation. The program multiplies C(I,J) by ± 1 or ± P, and adds this perturbation to the nominal value (mean), to produce a perturbed value for the factor. When LTYPE ≤ 4, the program calculates P. When LTYPE = 5 or 6, the user specifies P, for example as 2 or 3.

If the uncertainty is multiplicative, i.e., FACTOR(J) = 1, then C(I,J) is the multiplier analogous to adding one or P standard deviations in the additive case. The program multiplies or divides the nominal value (median) by C(I,J) or $[C(I,J)]^P$, to produce a perturbed value for the factor. The perturbed value then has the same sign as the nominal value.

Note: When the uncertainties are additive, ANALYZ fits the response as a linear or quadratic function of the factors. When any uncertainty is multiplicative, ANALYZ implicitly uses the logarithm of that factor, rather than the factor itself.

NOLD(J) A list of factors used in a previous sensitivity analysis, the responses for which are input on TAPE44. Some or all of the sensitivity study responses are assumed to be the quadratic factor level responses for the present uncertainty analysis. NOLD is used in conjunction with ISTART (below) and LFAC.

AMU(I,J) First eight central moments (I = 1,8) for Factor J. Default central moments are for a normal distribution.

ISTART Sensitivity analysis flag

= 0, Perform a complete uncertainty analysis as specified by LTYPE

Table 8. **BURYIT uncertainty factor call list**

LFAC	Factor
Meteorological Factors	
1	Amount of time specified for rainfall for UNSAT
2	Annual rainfall for ATMOS and EROSIO
3	Weather frequency array
4	Plume width crossrange standard error
5	Plume width vertical standard error
6	Nuclide deposition velocity
7	Stack (release) height
8	Stack energy release rate
9	Rainfall rate during wet period for UNSAT
10	Gaussian plume model lack of fit
11-29	Not assigned
Consumption Factors	
30	Breathing rate for child/teen/adult
31	Drinking water use per person, child/teen/adult
32	Fruit, vegetable, grain, and root crop consumption (maximum exposed individual) child/teen/adult
33	Leafy vegetable consumption (maximum exposed individual) child/teen/adult
34	Milk consumption (maximum exposed individual) child/teen/adult
35	Meat consumption (maximum exposed individual) child/teen/adult
36	Grain, root crop, etc., consumption (average individual) child/teen/adult
37	Milk consumption (average individual) child/teen/adult
38	Meat consumption (average individual) child/teen/adult
39	Vegetable consumption (average individual) child/teen/adult
40-49	Not assigned

Table 8. (continued)

LFAC	Factor
Agricultural Factors	
50	Leafy vegetable crop density
51	Areal grass density
52	Grass consumption rate by steer
53	Beef dressout fraction
54	Beef slaughter fraction
55	Cow weight (kg)
56	Milk production per cow (L/y)
57	Soil pool areal density (kg/m^2)
58	Crop deposition fraction (except iodine)
59-69	Not assigned
Operations Factors	
70	Total nuclide inventory (Ci/m^3), Σ ORI
71	Release fraction for Path 1
72	Release fraction for Path 2
73	Release fraction for Path 3
74	Release fraction for Path 4
75	Total human population
76	Direct exposure time (CUMT for DIRECT)
77	Distance from direct source (RANGE)
78	Thickness of Shield 1
79	Thickness of Shield 2
80	Thickness of Shield 3
81	Thickness of Shield 4
82	Thickness of Shield 5
83	Thickness of Shield 6
84	Waste deposited in puncture wound
85-100	Not assigned

Table 9. BURYIT uncertainty analysis response calls

LRES	1	2	3	4	5	6	7
MRES	Total Dose	Direct or Puncture Dose	Dose by Nuclide	Dose by Distance	Dose by Pathway	Dose by Organ	Dose by Age Group
0	TOTAL						
1	None	Direct	Order in TAPE12	Order in TAPE15	Cloud shine	Whole body	Child
2		Puncture wound			Ground shine	Bone	Teen
3					Inhalation	Liver	Adult
4					Resuspended particle inhalation	Kidney	
5					Water ingestion	Gonad	
6					Leafy vegetation	Lung	
7					Root crop, etc.	GI	
8					Milk	Thyroid	
9					Beef	Skin	
10							
11							
.							
.							
.							

= 1, Determine the experimental design specified by LTYPE, but do only the quadratic runs (sensitivity analysis runs) and write the responses to TAPE45

= 2, Calculate the design specified by LTYPE, but use the responses from the sensitivity analysis runs for the quadratic portion of the design. Attach the sensitivity analysis responses as TAPE44, call in the desired responses with NOLD(J), where J is the sensitivity analysis factor sequence number, and NOLD(J) is listed in the order of the present (complete uncertainty analysis) factors LFAC(J) as given in Table 8. The following example demonstrates the use of NOLD(J):

Example: A previous sensitivity analysis used:

```
$IN
.
.
.
LFAC(1) = 27, 7, 9, 1, 2, 8, 20, 12,
ISTART = 1,
.
.
.
$END
```

The present uncertainty analysis is to use factors 7, 8, 9, 27, 2, 12:

```
$IN
.
.
.
LFAC(1) = 7, 8, 9, 27, 2, 12,
NOLD(1) = 2, 6, 3, 1, 5, 8,
ISTART = 2,
.
.
.
$END
```

IPRINT — Flag for printing additional design information, including design generators and one and two factor aliases (applicable to fractional factorial designs only)

= 0, no (default)

= 1, yes

$END — last line of namelist input.

If LTYPE > 4, user specifies quadratic factor levels, one entry per factor, immediately following $END, FORMAT(10F5.0).

If the wind-frequency array is specified as a variable input factor (LFAC(J) = 3), the associated uncertainty is not straightforward. Instead, the wind frequency varies in a complex fashion as atmospheric conditions become more or less stable. To accommodate the representation of uncertainty in such variables, a routine was incorporated into BURYIT which reads several sets of values for the entire array, and assigns the set to the array which represents the appropriate factor level for the present run. The sets of values are input in the following order:

1. nominal case
2. linear ($+1\sigma$) factor level
3. linear (-1σ) factor level
4. positive quadratic factor level (P)

5. Negative quadratic factor level.

The wind-frequency factor involves the perturbation of both the wind speed vector (U) and the wind frequency array (F). For LTYPE $\leq$ 2, Card 3 (Section 5.2.2.5) consists of three lines to input nominal and linear factor levels, and for LTYPE $\geq$ 3, Card 3 consists of five lines to specify U for nominal, linear, and quadratic factor levels. In a similar manner, Card 4 of Section 5.2.2.5 (the F array) consists of either 3 or 5 sets of NS lines per set, to specify the wind frequency vectors for NS stability categories for nominal and linear factor levels (and quadratic factor levels for LTYPE $\geq$ 3).

If the user desires variable input factors not presently included in Table 8, then installation is fairly simple. Assign an unused index number (up to 100) to the new variable input factor, and update the code at the appropriate location with

```
CALL DIALOT(ALP, JNDEX, INDEX, FDIALA, FDIALM)
VARIABLE = (VARIABLE + FDIALA) * FDIALM
```

where

ALP = current factor level

JNDEX = 1 for simple variable input factors. For factors which have different values and/or uncertainties according to age group or other characteristics, JNDEX is an index variable which is used to assign the appropriate uncertainty according to the index of the characteristic. For assigning uncertainties by age group, the updated coding becomes:

```
DO 30 JNDEX = 1, 3
CALL DIALOT(ALP, JNDEX, INDEX, FDIALA, FDIALM)
30 VARIABLE(JNDEX) = (VARIABLE(JNDEX) + FDIALA) * FDIALM
```

for VARIABLE(1) = child value
VARIABLE(2) = teen value
VARIABLE(3) = adult value

INDEX = assigned index number for the new variable input parameter

FDIALA = additive uncertainty amount

FDIALM = multiplicative uncertainty factor

VARIABLE = new variable input parameter to be used in uncertainty analysis.

5.2.4 ANALYZ Input. The main control variable for ANALYZ is on file INPUT. It determines the remainder of the input requirements, as follows:

Card 1: MBRANCH ANALYZ option control variable

FORMAT(I5)

MBRANCH = 1, Perform uncertainty analysis using the responses from BURYIT. The required inputs are:

1. TAPE4, which was written by BURYIT, and contains the uncertainty analysis control variables and the BURYIT responses

2. ANALYZ uncertainty analysis control variables on file INPUT in Namelist PL(details below).

MBRANCH = 2, Perform uncertainty analysis using responses from BURYIT, then do risk calculation for "cumulative population dose" or "maximum individual dose" response, as specified in BURYIT input. The required inputs are:

1. TAPE4 (as above)

2. Namelist PL on file INPUT (as above)

3. Scenario probability file (TAPE97)

4. TAPE98, which contains the results of risk calculations for previously done scenarios (optional).

In this case, TAPE99 should be saved, to use as TAPE98 in the next run.

MBRANCH = 3, Plot probability density function and cumulative probability distribution for likelihood (or probability of occurrence) for specified scenario. Required inputs are:

1. Scenario probability file (TAPE97)

2. Plot titles and scenario number on file INPUT (details below).

MBRANCH = 4, Plot probability density function and cumulative probability distribution for a user-input density. Required input consists of plot titles and the lower four statistical moments of the desired density which are on INPUT (details below).

Card 2: LTNAME(I), I = 1, 11. Input if MBRANCH $\geq$ 3.

FORMAT(8A10)

Plot title for PDF and CDF plots of scenario occurrence probability (MBRANCH = 3) or user-input density (MBRANCH = 4). For ANALYZ calculations using the responses from BURYIT, the plot titles are written by BURYIT onto TAPE4.

Card 3: LYNAME(I), I = 1,4. Input if MBRANCH $\geq$ 3.

FORMAT(8A10)

X-axis title for PDF and CDF plots. Cards 2 and 3 are either both included or both omitted.

Card 4: AMEAN, SIGMA2, RTBT1, BETA2, LPRINT. Input if MBRANCH = 4.

FORMAT(4E15.5, I5)

AMEAN	mean of user-input density
SIGMA2	variance
RTBT1	skewness coefficient, β_1
BETA2	kurtosis coefficient, e.g., 3 for the Gaussian distribution.
LPRINT	print control variable
	≠ 0, print complement of the cumulative distribution (CCD)
	= 0, bypass CCD printout.

Card 5: ISCEN Input if MBRANCH = 3.

FORMAT(A4)

Scenario code specified for plot of occurrence probability PDF and CDF.

Card 6: Namelist PL optional input, MBRANCH ≤ 2. This input block specifies the uncertainty analysis options for ANALYZ. Each line of namelist input begins in Column 2. The namelist name PL is on the first line and is preceded by $.

$PL

LISTR(I) List of responses for which uncertainty analysis is to be performed. Responses are specified by their numbers in the order in which they are designed in LRES and MRES (Section 5.2.3). If the risk calculation is requested. LISTR must include the "cumulative population dose" or "maximum individual dose', as appropriate (LRES(I) =). A maximum of 100 responses may be requested by LISTR.

LTRAN(I) Option to transform the independent variables (factors) by taking the exponential, logarithm, inverse, square, or square root prior to performing the regression analysis in ANYOLS. The option was not installed in the original version of ANALYZ and has not been incorporated into the present version.

LOGFIT If LOGFIT = 0, the response is fitted to a linear or quadratic function of the factors.

If LOGFIT = 0, the natural logarithm of the response is used instead. The default is LOGFIT = 0. It is useful to set LOGFIT = 0 when the uncertainties on the factors are multiplicative and the response is approximately proportional to the product of the factors. In this case, the multiplicative uncertainties cause ANALYZ to use the logs of the factors rather than the factors themselves; and, the log of the response is approximately proportional to the sum of the logs of the factors so a good fit can be obtained. The distribution finally plotted is for the original response, not for its logarithm.

LPRINT Printout option for ANYOLS regressions, according to the following schedule:

		TRIAL REGRESSION	
		No Output	Summary
	No Output	00	01
FINAL	Summary	10	10
MODEL	Summary plus regression coefficients	20	21

IPLT Plot control variable

= 0, No plots (default)

= 1, Up to six plots for current scenario of options requested by MBRANCH:

a. Residuals of response surface equation

b. Fitted values versus data

c. Probability density function (PDF) of response surface

d. Cumulative distribution function (CDF) of response surface

e. PDF of scenario risk

f. CDF of scenario risk

= 10. Bar graph of scenario risk, at probability value specified by NSPV. If risk file (TAPE98) is present, include previous scenario risk values in bar graph.

= 11. Same as IPLT = 1 plus IPLT = 10.

NSPV Control the probability level of the risk plotted in the bar graph, when IPLT ≥ 10. The probabilities corresponding for values of NSPV are:

NSPV	Probability	Upper Tail
1	0.01	0.99
2	0.025	0.975
3	0.05	0.95
4	0.10	0.90
5	0.50	0.50
6	0.90	0.10
7	0.95	0.05
8	0.975	0.025
9	0.99	0.01

The default is NSPV = 7, corresponding to a 95% upper bound on the risk.

KKRIT Stepwise regression strategy option

= 1, F-statistic

= 2, S^2 minimization

$END Last line of Namelist PL.

Card 7: STAR(I), I = 1, NFAC. Input, LTYPE ≥ 5.

FORMAT(10F5.0)

Specify factor levels for the quadratic runs (star points) of the design.

6. UNCERTAINTY ANALYSIS EXAMPLE—ATMOSPHERIC PATHWAY

In this section, an example of a probabilistic risk assessment is presented in order to illustrate the breadth of analysis possible with the current status of BURYIT/ANALYZ. ANALYZ presently works on the atmospheric release pathway; that is, the subroutines ATMOS and DOSET, Pathway 2-4. The example uncertainty analysis deals with a hypothetical release at a waste processing or packaging facility and the resulting population dose commitment, release scenario P-4 with inventory WS-4. In what follows, the inputs for the BURYIT portion of the package will be discussed first. Then, the necessary inputs for the ANALYZ portion of the package will be discussed. (Note that Table 8 was rearranged subsequently to its present form.) Finally, the results of the uncertainty and risk analyses will be presented. The reader is cautioned that *some of the BURYIT input was selected deliberately to magnify the computed release; therefore, there is no similitude to any real facility.* The only purpose of this section is to demonstrate the capability for probabilistic risk assessment.

6.1 BURYIT Input

The release scenario, Code P-4 (Volume 1, Reference 1, pp. 4-22 and 7-18) was selected to represent the Pathway 2-4 with waste inventory WS-4. The scenario description is:

> "Container with volatile substance is ruptured during packaging. Volatile substance escapes to atmosphere."

The waste inventory is described as "LWR operational waste—high concentration" and has 33 nuclides with a total activity concentration of 32 Ci/m^3. The scenario release fraction is 1.0; the volume of the package is 3 m^3; and the release time is 200 hours. The cumulative population dose is calculated.

As discussed in section 5.2.2.1, input Card 6 for Path 2 also requires, in addition to the release time (CUMT), the annual rainfall in m/y (RF), emplacement efficiency (EMEF), time for the rain cycle in hours (TIMWET), and total time in one cycle of rain and dry periods in hours (TIMCYC). The seven input cards entered on TAPE14 are thus:

Card No.	Entry
1	1 2
2	*Atmospheric Path Uncertainty Analysis, Hanford Site: Maximum Individual Dose* (Hanford Site refers roughly to population, rainfall, and wind-frequency array.)
3	0
4	P-4
5	WS-4
6	200 0.2 0.5 480 8760
7	3.

In addition to the above cards, site-specific information must be available on TAPE9 and TAPE15. The former must contain stack height, energy release rate, and the wind speed-stability class array. The latter tape must contain agricultural and population data.

For this example problem, the stack (release) height is taken as 5 m; and the stack energy release rate is taken as 29 288 000 W (7 000 000 cal/s). Thus, it is assumed that the vaporizing material is somehow conveyed to an incinerator or furnace for combustion; however, the energy release rate is clearly excessive for a realistic waste processing facility. Card No. 1 on TAPE9 appears as:

5 29.288E+06.

In the example problem, six wind speed groups and seven stability classes are entered. The complete array is used for the calculations. Card No. 10 on TAPE9 appears as:

6 0 7.

Card No. 3 must contain the wind speed groups in meters per second; for the example problem:

0.67 2.46 4.47 6.93 9.61 12.29.

Card No. 4 must contain the frequency for each of the six speed groups by wind stability class. Thus, for the example problem, the nominal array is:

STABILITY CLASS						
A	.017	.036	.021	.014	.007	.005
B	.017	.036	.021	.014	.007	.005
C	.017	.036	.021	.014	.007	.005
D	.049	.029	.023	.019	.012	.009
E	.021	.023	.032	.045	.025	.013
F	.021	.023	.032	.045	.025	.013
G	.051	.070	.077	.041	.004	.000

TAPE15 contains site-specific agricultural and population data as described in section 5.2.2.6. Table 10 is a reproduction of the echo of these data for the example problem. Note that the population is concentrated mainly in the third and fourth of five radial incremental distances from the facility.

6.2 ANALYZ Input

This probabilistic risk assessment example was run using 15 uncertainty factors from Table 8 and 52 responses from Table 9. The discussion of the results will be limited to only one of the responses. The type of uncertainty analysis for BURYIT is the linear plus foldover plus quadratic, user-specified quadratic factor level; that is, LTYPE = 6. The uncertainty variable with user-specified quadratic factor level is Wind Speed-Frequency Array, LFAC(J) = 3. As discussed previously in section 5.2.3, a subroutine in BURYIT processes several complete sets of values for the purpose of uncertainty analysis.

ANALYZ sets up a statistical experimental design for the 15 factors. In this example, the design is the fractional factorial (LPB = 0) that was shown previously in Figure 1. The perturbations of the numerical values of the factors away from the nominal value are expressed as number of standard deviations of the factor's distribution; i.e., the perturbations are ± 1 or ± 3 standard deviations. As shown in Figure 1, 62 perturbation runs of BURYIT are called by ANALYZ.

Figure 2 is a reproduction of the Namelist IN printed by the computer package. The first entries are FACTOR(J). It may be seen that of the 30 factors from Table 8, 19 have multiplicative uncertainties (FACTOR(J) = 1), while the remainder have additive uncertainties (FACTOR(J) = 0). With multiplicative uncertainty, the logarithm (to the base e) is treated as a random variable. There is room for 100 entries in this array. (The order of factors does not agree with that in Table 8, because Table 8 has been rearranged by the type of factor since the example was run.)

The next entries are the C(I,J). These represent one standard deviation (standard error) of the distribution of each uncertainty factor. Provision is made for three age groups; thus, there is room for 300 entries. In the case of multiplicative uncertainties, a multiplication factor for the nominal value is used to yield the value at one standard deviation. For this example case, 13 of the 19 multiplicative uncertainties are assigned multiplication factors of 1.1 (10% uncertainty). This was an arbitrary choice made only for expediting the demonstration. All other uncertainties were estimated from the literature, as given in Appendix F.

The next two names in the list, LRES(N) and MRES(N), together designate the 52 responses, of which 33 are doses from specific nuclides. A response surface equation (RSE) is obtained for each of the responses. The RSE permits a sensitivity analysis; i.e., the rate of change of a response because of a change in factor level. A combined uncertainty analysis and probabilistic risk computation may be performed (based on the RSE) for any of the responses designated in the PL namelist in the name LISTR(I).

The next two names are LTYPE and LPB. Both of these were commented upon earlier in this section.

The next name, AMU(I,J) pertains to the first eight central moments of the statistical distribution for the uncertainty variables. The default values are those for the Gaussian distribution, and these appear 100 times in Figure 2.

The next four names in Namelist IN are IPRINT, NOLD, IFLAG, and ISTART. Only IFLAG has a nonzero value, IFLAG = 2. The meaning of these names should be clear from the earlier namelist discussion.

The uncertainty analysis and probabilistic risk calculation options are specified in Namelist PL. Figure 3 shows the PL printout for the example. The name LISTR designates the responses to be treated, in this case, numbers 36, 37, 39, 28, and 1.

Table 10. Input data on TAPE15

```
         0         1         2         3         4         5         6         7         8
         12345678901234567890123456789012345678901234567890123456789012345678901234567890

 THIS IS AN ECHO OF TAPE 15

   1        5
   2        8045.     24135.    40225.     56315.    72405.
   3         8.        2. .20 .14 .66  .1    2  200000.
   4              0         4      34594      46481       941

         0         1         2         3         4         5         6         7         8
         12345678901234567890123456789012345678901234567890123456789012345678901234567890

AGRICULTURE AND POPULATION DATA FROM TAPE15
   5 RADIAL INCREMENTS SPECIFIED
  8045.00     METERS,   24135.0     METERS,   40225.0    METERS,   56315.0    METERS,   72405.0    METERS,
POPULATION
         0                  4                 34594                 46481                 941

AGE GROUP FRACTIONS
CHILD =  .200 TEEN =  .140 ADULT =  .660

 8.00000      BEEF CATTLE PER KM**2

 2.00000      MILK COWS PER KM**2

 .1000 OF TOTAL AREA AVAILABLE FOR LEAFY VEGETABLES

     2 CROPS PER YEAR

FOOD CROP PRODUCTION IS  200000.     KG/KM**2-YR
```

```
$IN
FACTOR = .1E+01, .1E+01, 0.0, .1E+01, .1E+01, .1E+01, 0.0, .1E+01, .1E+01,   0.0, 0.0, .1E+01, .1E+01, 0.0, .1E+01,
         .1E+01, 0.0, .1E+01, .1E+01, .1E+01, .1E+01, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, .1E+01, .1E+01, .1E+01, .1E+01, 0.0,
         0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,   0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
         0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,   0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
         0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,   0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
         0.0, 0.0, 0.0, 0.0, 0.0, 0.0,

C      = .11E+01, 0.0, 0.0, .11E+01, 0.0, 0.0, 0.0, 0.0, 0.0, .11E+01, 0.0,   0.0, .11E+01, 0.0, 0.0, .11E+01, 0.0,
         0.0, .16E+01, 0.0, 0.0, .11E+01, 0.0, 0.0, .11E+01, 0.0, 0.0,   .193E+04, .315E+04, .207E+04, .6E+02,
         .45E+02, .85E+02, .11E+01, .11E+01, .11E+01, .11E+01, .11E+01,   .11E+01, .4E+02, .7E+02, .4E+02, .11E+01,
         .11E+01, .11E+01, .11E+01, .11E+01, .11E+01, .4E+02, .7E+02, .4E+02,   .11E+01, .11E+01, .11E+01, .11E+01,
         .11E+01, .11E+01, .16E+01, 0.0, 0.0, .18E+01, 0.0, 0.0, .1E+02, 0.0,   0.0, .1E-01, 0.0, 0.0, .3E-01, 0.0,
         0.0, .265E+02, 0.0, 0.0, .53E+03, 0.0, 0.0, .112E+01, 0.0, 0.0,   .128E+01, 0.0, 0.0, .13E+01, 0.0, 0.0,
         .16E+01, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,   0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
         0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,   0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
         0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,   0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
         0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,   0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
         0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,   0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
         0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,   0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
         0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,   0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
         0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,   0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
         0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,   0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
         0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,   0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
         0.0, 0.0, 0.0, 0.0,

LPES   = 1, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3,   3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 4, 5,
         5, 5, 5, 5, 5, 5, 5, 6, 6, 5, 6, 6, 6, 6, 6, 6, 0, 0, 0, 0, 0, 0, 0, 0,   0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
         0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,   0, 0, 0, 0, 0,

MRES   = 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19,   20, 21, 22, 23, 24, 25, 26, 27, 28, 29,
         30, 31, 32, 33, 2, 1, 2, 3, 4, 6, 7, 8, 9, 1, 2, 3, 4, 5, 6, 7, 8, 9,   0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
         0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,   0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,

LFAC   = 1, 2, 3, 7, 8, 10, 16, 17, 18, 19, 20, 21, 22, 28, 29, 0, 0, 0, 0, 0,   0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
         0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,   0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
         0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,   0, 0, 0, 0, 0, 0, 0, 0,

LTYPE  = 6,

LPR    = 0,
```

Figure 2. Namelist IN.

```
AMU    = 0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
         0.0, .1E+01, 0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03, 0.0, .1E+01,   0.0, .3E+01, 0.0, .15E+02, 0.0, .105E+03,
IPRINT = 0,
NOLD   = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,   0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
         0, 0, 0, 0,
IFLAG  = 2,
ISTART = 0,
$END
```

Figure 2. (continued).

```
$PL
LISTR    = 36, 37, 39, 28, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0,
LTRAN    = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
           0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
LPRINT   = 10,
KKPIT    = 4,
PREF     = .5E-01, .95E+00, 0.0, 0.0,
NSPV     = 7,
IPLT     = 11,
$END
```

Figure 3. Namelist PL.

These numbers correspond to the order specified by the names LRES(N) and MRES(N) in Namelist IN. In particular, the responses are dose from cloud shine, dose from ground shine, resuspended particle inhalation dose, dose from nuclide plutonium-242, and cumulative population dose.

Continuing with Namelist PL, LTRAN is not used. LPRINT = 0 means that no printout is desired from the regression subroutine ANYOLS. KKRIT = 4 means that PRESS is the regression strategy option. Finally, the probability bounds for the uncertainty and risk distribution functions for all responses are specified by PREF(I); in this case, 0.05 and 0.95.

6.3 Example Problem Results

6.3.1 Nominal Dose Computational Results. The nominal dose calculation is that using the "best-estimate" values of the parameters; i.e., the mean value when uncertainty is additive and the median value when the uncertainty is multiplicative. This is the "best estimate" of the population dose given the occurrence of the release of 96 Ci of inventory WS-4 (Appendix D). The computed results for the example problem are shown in Figure 4. (The effective whole body dose results were omitted to save space.) The cumulative population dose, which is also the population whole body dose, is 6930 person-rem with the largest contribution occurring in a radial increment centered at 40 225 m from the point of release. A brief computation shows that 98% of the dose results from the three nuclides cesium-137, cesium-134, and plutonium-242. Furthermore, 97% of the dose is transported through the two pathways, resuspended particle inhalation and leafy vegetable inhalation.

6.3.2 Sensitivity Results. Lists of factor names and response names are printed by both the BURYIT and ANALYZ subroutines (see Figure 5). Following the Namelist PL, which is printed by ANALYZ, the experimental design matrix appears. This is the same as Figure 1 in this case.

Following the design matrix, the confounding array appears. This provides the same information as Table 5, but in a different form. The confounding array is reproduced in Figure 6. The numbers across the top and down the side of the array represent the numbers of the factors in the same order as printed out in the list of factor names (see previous paragraph). The entries in the confounding array represent the groups wherein the second-order interactions are confounded (aliased). For example, the (1, 2) interaction is in group nine. Thus, the (1, 2) interaction coefficient cannot be estimated separately from any other interaction in group nine using only the present design matrix. (Additional perturbation runs or fewer factors would be necessary to do so.) This is the reason for the importance of the order in which the factors are entered by LFAC(N). As shown later, it is often possible to know that certain interaction terms must be zero because of the model structure.

The results printed next, but not reproduced here, include the levels of the factors in each perturbation run and the computed response. Then follows a tabulation of the actual response, the regression equation response (YHAT), and their difference (residual), also not reproduced here. The residuals are important for determining whether the response surface equation is adequately fitted. Plots of the residuals or YHAT versus response may also be obtained, e.g., as in Figures 7 and 8.

A tabulation of the coefficients of the response surface equation follows in the ANALYZ printout. For example, Table 11 contains response surface coefficients for dose from cloud shine where the nominal (unperturbed) value is 8.34E-03 rem. This table shows linear coefficients of five factors. These are the absolute sensitivity coefficients, normalized with respect to standard deviation, for the factors: stack energy release rate [LB(2)], weather-frequency array [LB(3)], stack release height [LB(4)], fruit, vegetables, and grain consumption rate [LB(7)], and the lack-of-fit of the Gaussian plume model [LB(15)]. Such coefficients should always be subjected to critical examinations.

Factors 2, 3, 4, and 15 are "atmospheric" factors and clearly should affect the computed value of dose from cloud shine; and a study of the BURYIT model confirms this. On the other hand, Factor 7 is a "consumption" factor and does not enter the BURYIT model for cloud shine at all. This may be confirmed by the identical computed responses in perturbation Runs 47 and 48 where Factor 7 is set to ± 3 (standard deviations) and all other factors are at the nominal levels (the two star points). Thus, the Factor 7 coefficient is spurious, and the reason for this is lack-of-fit by the quadratic RSE. Using either the defining relations printed by subroutine DESIGN or Table 5, it can be shown

DOSE OUTPUT (PERSON-REM)
FOR ALL PATHS
ATMOSPHERIC PATH P R A TEST CASE, HANFORD SITE: CUMULATIVE POPUL. DOSE

OUTPUT BASED ON DOSE TO ORGAN FOR EACH AGE GROUP

CUMULATIVE POPULATION DOSE	6.93E+03
DIRECT EXPOSURE DOSE	0.

TOTAL POPULATION DOSE BREAKDOWN BY RADIONUCLIDE, DISTANCE CELL, DOSE PATHWAY, BODY ORGAN AND POPULATION AGE GROUP.

RADIONUCLIDE

CR51	1.03E-01	CO58	2.65E+01
FE55	7.28E+00	ZN65	6.11E+00
ZR95	1.32E-01	RU106	2.78E-01
SB124	9.95E-01	SB125	7.72E-01
EU152	1.84E-04	EU154	2.96E-02
EU155	1.74E-03	SR90	2.61E+01
CS137	1.75E+03	MN54	1.08E+01
CS134	1.64E+03	H3	4.55E-01
C14	3.82E-01	NI59	3.93E-02
TC99	1.60E-03	I129	3.14E-02
CS135	9.04E-03	NP237	2.21E+01
PU238	1.61E-01	PU239	5.75E-01
PU240	4.23E-01	PU241	1.27E+00
PU242	3.43E+03	AM241	2.10E+00
AM242M	6.39E-01	AM243	2.33E-01
CM242	1.96E-02	CM243	1.11E-01
CM244	5.14E-01		

DISTANCE(M)

8045.	6.84E+02	24135.	6.85E+02
40225.	2.45E+03	56315.	2.39E+03
72405.	7.18E+02		

PATH

CLOUD SHINE	8.36E-04	GROUND SHINE	3.83E+01
DIRECT INHALATION	1.32E+00	RESUS. INHALATION	3.45E+03
WATER INGESTION	0.	LEAFY VEG INGESTION	3.29E+03
ROOT INGESTION	1.99E+01	MILK INGESTION	1.02E+02
BEEF INGESTION	2.33E+01		

ORGAN

WHOLE BODY	6.93E+03	BONE	1.42E+05
LIVER	2.49E+04	KIDNEY	1.64E+04
GONAD	7.22E+03	LUNG	1.10E+04
G.I.TRACT	6.21E+02	THYROID	5.75E+01
SKIN	4.23E+01		

AGE GROUP

CHILD	1.11E+03	TEEN	8.66E+02
ADULT	4.95E+03		

Figure 4. Example problem results.

```
15 INPUT FACTORS

FACTOR( 1)= AMOUNT OF TIME SPECIFIED FOR RAINFALL
FACTOR( 2)= STACK ENERGY RELEASE RATE
FACTOR( 3)= WEATHER FREQUENCY ARRAY
FACTOR( 4)= STACK RELEASE HEIGHT
FACTOR( 5)= ANNUAL RAINFALL FOR ATMOS AND EROSIO
FACTOR( 6)= BREATHING RATE FOR CHILD/ TEEN/ ADULT
FACTOR( 7)= FRUIT, VEG., GRAIN (MAX. EXPOSED INDIV)
FACTOR( 8)= LEAFY VEG.CONSUMP. (MAX. EXPOSED INDIV)
FACTOR( 9)= MILK CONSUMPTION (MAX. EXPOSED INDIV)
FACTOR(10)= MEAT CONSUMPTION (MAX. EXPOSED INDIV)
FACTOR(11)= LEAFY VEGETABLE CROPDENSITY
FACTOR(12)= AREAL GRASS DENSITY
FACTOR(13)= GRASS CONSUMPTION RATE BY STEER
FACTOR(14)= CROP DEPOSITION FRACTION (EXCEPT IODINE)
FACTOR(15)= GAUSSIAN PLUME MODEL LACK-OF-FIT

52 RESPONSES

RESPONSE( 1)= CUMULATIVE POPULATION DOSE
RESPONSE( 2)= DOSE FROM RADIONUCLIDE CR51
RESPONSE( 3)= DOSE FROM RADIONUCLIDE CO58
RESPONSE( 4)= DOSE FROM RADIONUCLIDE FE55
RESPONSE( 5)= DOSE FROM RADIONUCLIDE ZN65
RESPONSE( 6)= DOSE FROM RADIONUCLIDE ZR95
RESPONSE( 7)= DOSE FROM RADIONUCLIDE RU106
RESPONSE( 8)= DOSE FROM RADIONUCLIDE SB124
RESPONSE( 9)= DOSE FROM RADIONUCLIDE SB125
RESPONSE(10)= DOSE FROM RADIONUCLIDE EU152
RESPONSE(11)= DOSE FROM RADIONUCLIDE EU154
RESPONSE(12)= DOSE FROM RADIONUCLIDE EU155
RESPONSE(13)= DOSE FROM RADIONUCLIDE SR90
RESPONSE(14)= DOSE FROM RADIONUCLIDE CS137
RESPONSE(15)= DOSE FROM RADIONUCLIDE MN54
RESPONSE(16)= DOSE FROM RADIONUCLIDE CS134
RESPONSE(17)= DOSE FROM RADIONUCLIDE H3
RESPONSE(18)= DOSE FROM RADIONUCLIDE C14
RESPONSE(19)= DOSE FROM RADIONUCLIDE NI59
RESPONSE(20)= DOSE FROM RADIONUCLIDE TC99
RESPONSE(21)= DOSE FROM RADIONUCLIDE I129
RESPONSE(22)= DOSE FROM RADIONUCLIDE CS135
RESPONSE(23)= DOSE FROM RADIONUCLIDE NP237
RESPONSE(24)= DOSE FROM RADIONUCLIDE PU238
RESPONSE(25)= DOSE FROM RADIONUCLIDE PU239
RESPONSE(26)= DOSE FROM RADIONUCLIDE PU240
RESPONSE(27)= DOSE FROM RADIONUCLIDE PU241
RESPONSE(28)= DOSE FROM RADIONUCLIDE PU242
RESPONSE(29)= DOSE FROM RADIONUCLIDE AM241
RESPONSE(30)= DOSE FROM RADIONUCLIDE AM242M
RESPONSE(31)= DOSE FROM RADIONUCLIDE AM243
RESPONSE(32)= DOSE FROM RADIONUCLIDE CM242
RESPONSE(33)= DOSE FROM RADIONUCLIDE CM243
RESPONSE(34)= DOSE FROM RADIONUCLIDE CM244
RESPONSE(35)= DOSE AT 2.4 E+04 METERS
RESPONSE(36)= DOSE FROM CLOUD SHINE
RESPONSE(37)= DOSE FROM GROUND SHINE
RESPONSE(38)= DIRECT INHALATION DOSE
RESPONSE(39)= RESUS. INHALATION DOSE
RESPONSE(40)= LEAFY VEG. INGESTION DOSE
RESPONSE(41)= ROOT INGESTION DOSE
RESPONSE(42)= MILK INGESTION DOSE
RESPONSE(43)= BEEF INGESTION DOSE
RESPONSE(44)= WHOLE BODY DOSE
RESPONSE(45)= DOSE TO BONE MARROW
RESPONSE(46)= DOSE TO THE LIVER
RESPONSE(47)= DOSE TO THE KIDNEY
RESPONSE(48)= DOSE TO THE GONADS
RESPONSE(49)= DOSE TO THE LUNGS
RESPONSE(50)= DOSE TO THE G. I. TRACT
RESPONSE(51)= DOSE TO THE THYROID
RESPONSE(52)= DOSE TO THE SKIN
```

Figure 5. Factors and responses.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	9	6	8	7	12	13	3	5	11	1	4	10	15	14
2	0	0	1	4	2	3	5	12	13	14	6	8	15	10	11
3	0	0	0	10	3	2	11	7	14	13	9	15	8	4	5
4	0	0	0	0	5	11	2	14	7	12	15	9	6	1	3
5	0	0	0	0	0	1	4	6	8	15	12	13	14	11	10
6	0	0	0	0	0	0	10	9	15	8	7	14	13	5	4
7	0	0	0	0	0	0	0	15	9	6	14	7	12	3	1
8	0	0	0	0	0	0	0	0	10	4	2	11	5	13	8
9	0	0	0	0	0	0	0	0	0	1	11	2	3	12	6
10	0	0	0	0	0	0	0	0	0	0	5	3	2	7	9
11	0	0	0	0	0	0	0	0	0	0	0	10	4	8	13
12	0	0	0	0	0	0	0	0	0	0	0	0	1	6	12
13	0	0	0	0	0	0	0	0	0	0	0	0	0	9	7
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 6. Confounding array.

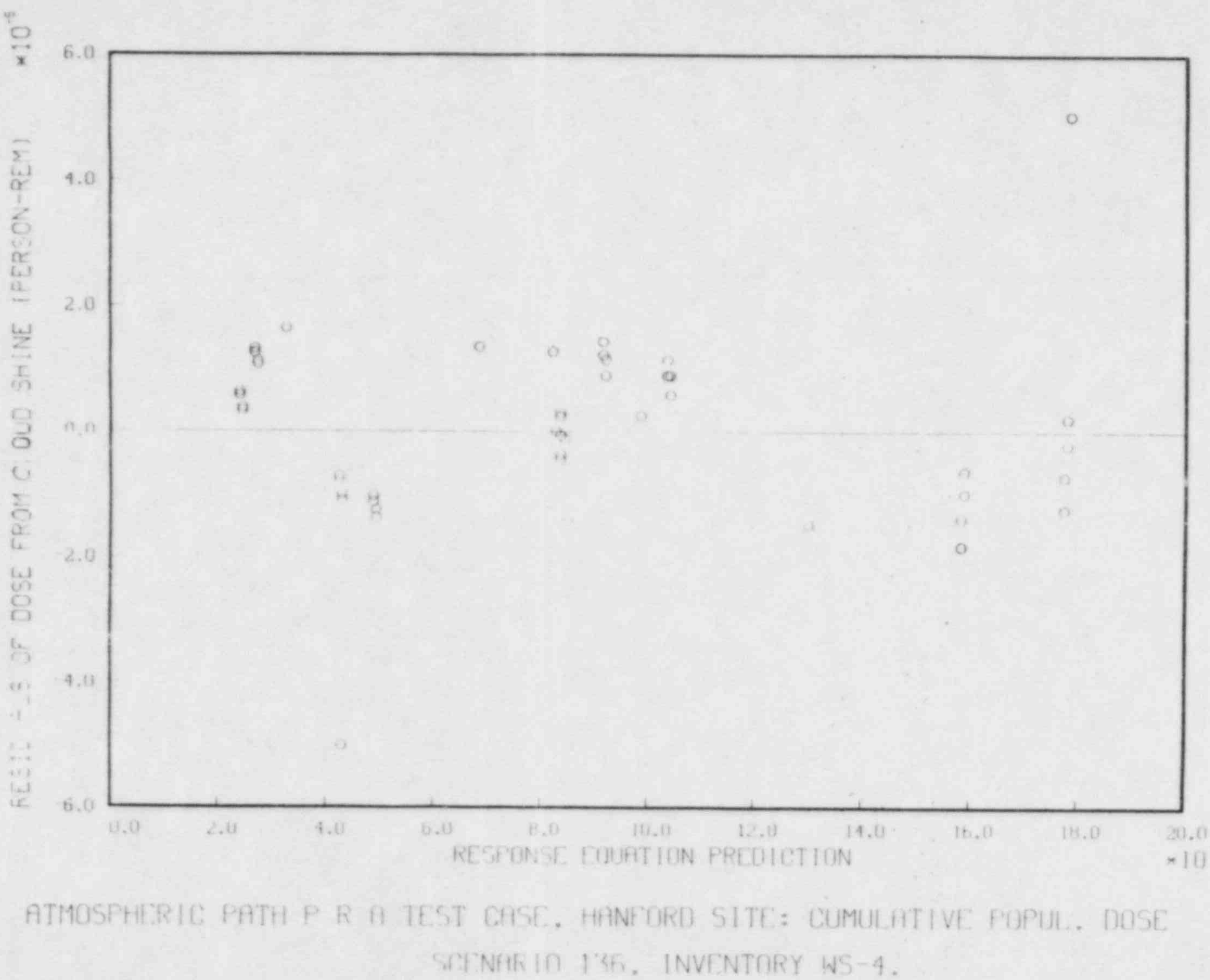
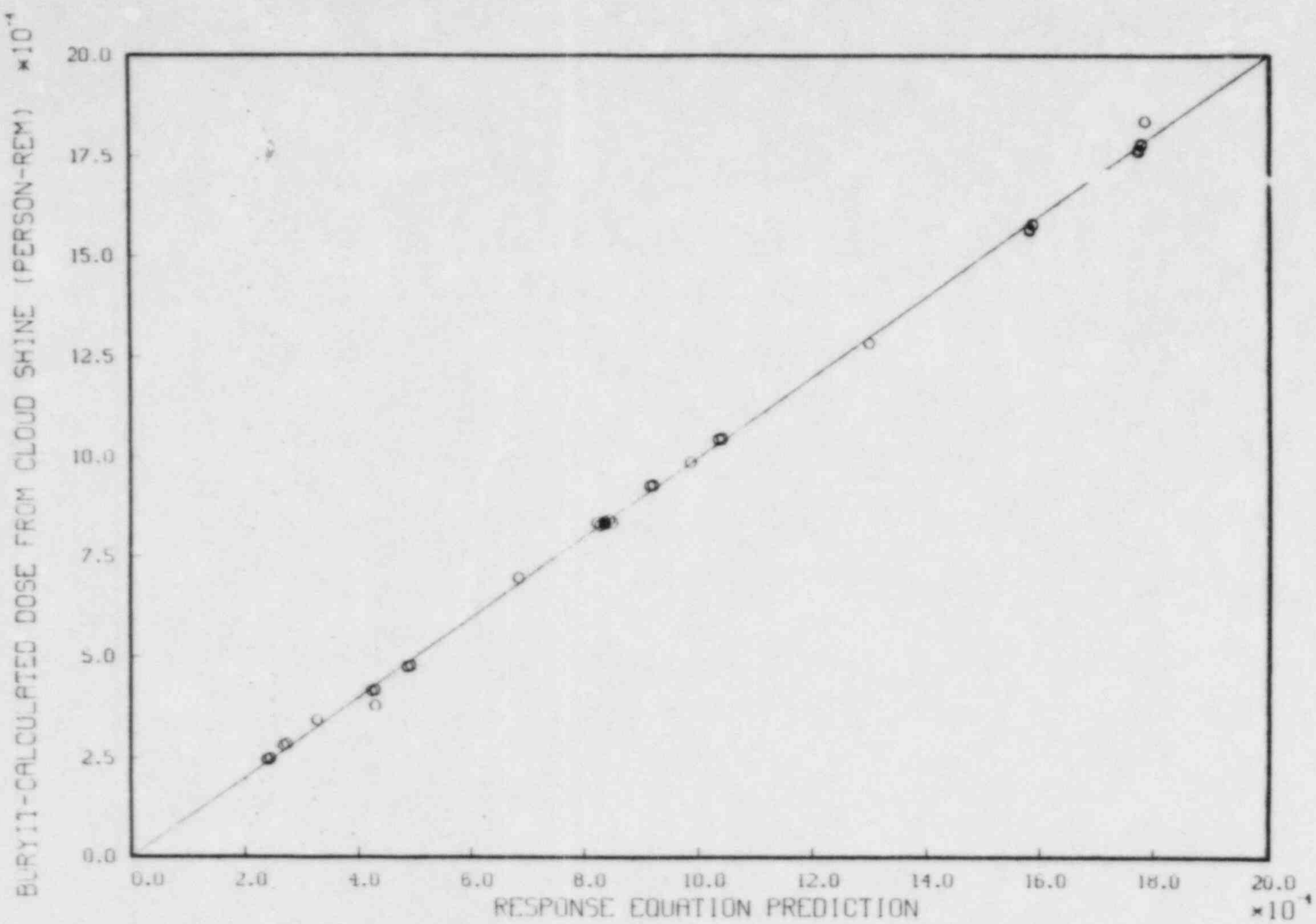


Figure 7. Residuals versus predictions.



ATMOSPHERIC PATH P R A TEST CASE, HANFORD SITE: CUMULATIVE POPUL. DOSE
SCENARIO 136, INVENTORY WS-4.

Figure 8. Dose from cloud shine versus response surface equations.

Table 11. Coefficients of response surface equation for dose from cloud shine from the example problem

Term Type					
Factor Number	Linear	Factor Number	Quadratic	Factor Pair	Interaction
1	0	1	0	1, 2	0
2	-5.04E-05	2	0	1, 3	0
3	4.86E-04	3	-2.27E-05	1, 4	0
4	-2.64E-05	4	0	1, 5	0
5	0	5	0	1, 6	0
6	0	6	0	1, 7	0
7	-4.50E-06	7	0	1, 8	0
8	0	8	0	1, 9	1.25E-04
9	0	9	0	1, 10	-1.32E-05
10	0	10	0	1, 11	-2.74E-05
11	0	11	0	1, 12	0
12	0	12	0	1, 13	0
13	0	13	0	1, 14	0
14	0	14	0	1, 15	0
15	2.26E-04	15	3.02E-05	2, 5	0

that LB(7) is aliased with the triple interaction (2, 3, 15). (Ways to do this are discussed in texts on experimental design.) Since LB(2), LB(3), and LB(15) are relatively large, their triple interaction is a reasonable identification of the source of lack-of-fit.

Table 12 also shows two quadratic coefficients, those being for Factors 3 and 15. In other words, the behavior of the response is somewhat nonlinear with variation in these two factors. At a perturbation of one standard deviation in Factor 3, the quadratic coefficient reduces the response change by about 10% of that predicted by the linear coefficient. Conversely, a perturbation of one standard deviation in Factor 15 increases the response change by about 10% over that of a linear variation only.

Three interaction coefficients also appear in Table 11. As stated earlier, these coefficients are confounded (or aliased) and do not necessarily correspond to the factors indicated by the table. (As will now be seen, none of these coefficients corresponds correctly.) Additional critical examination is required in order to identify the interactions in, for example, a sensitivity study.

Table 12. Moments of cloud shine dose

```
****************************************************************************************
**********                                                                    **********
**********  PROPERTIES OF THE FUNCTION OF INDEPENDENT RANDOM VARIABLES        **********
**********                                                                    **********
****************************************************************************************

ATMOSPHERIC PATH P R A TEST CASE, HANFORD SITE: CUMULATIVE POPUL. DOSE
SCENARIO 136, INVENTORY WS-4, RES # 36: DOSE FROM CLOUD SHINE (PERSON-REM)

            ****************************************************
            MEAN-INTERCEPT.......................... =   .7549731E-05
            MEAN.................................... =   .8442935E-03
            SECOND MOMENT (EDEL2)................... =   .3096790E-06
            VARIANCE (VARDL)........................ =   .3096220E-06
            THIRD MOMENT (EDEL3).................... =  -.1576982E-10
            THIRD CENTRAL MOMENT (MU3DL)............ =  -.2278294E-10
            COEFFICIENT OF SKEWNESS SQUARED (BETA1) =   .1748735E-01
            COEFFICIENT OF SKEWNESS (RTBT1)......... =  -.1322397E+00
            FOURTH MOMENT (EDEL4)................... =   .2967805E-12
            FOURTH CENTRAL MOMENT (MU4DL)........... =   .2973626E-12
            COEFFICIENT OF KURTOSIS (BETA2)......... =   .3101864E+01
```

A rule-of-thumb in examining an interaction from a response surface is that the coefficient probably does not correspond to the indicated factors if one factor or the other does not have a linear coefficient. Another way to say this is that a factor usually does not interact with others if it has no main effect. This rule, thus, suggests that not one of the three coefficients corresponds to the indicated factor pairs: (1, 9), (1, 10), and (1, 11). In fact, the interactions probably result from the three factors with real linear coefficients.

Identification of a probable factor pair is facilitated by Table 5 or the confounding array in Figure 6, from which the group containing the (1, 9) pair is repeated here.

1-9
2-7
3-15
4-5
6-14
8-13
10-11

The only pair here that also has linear coefficients is (3, 15). Furthermore, a study of the cloud shine dose model in BURYIT shows that only the (4, 5) pair could possibly enter the calculation aside from (3, 15). Examination of the responses at the star points of Factors 4 and 5 reveals that changes in the response occur at the third significant figure, as might be expected for insignificant linear coefficients. Thus, it is evident that the interaction coefficient printed as the (1, 9) pair really represents the (3, 15) pair. In a like manner, it may be determined that the (1, 10) pair in Table 11 is actually the (2, 15) pair; and the (1, 11) pair is actually the (2, 3) pair. This sort of analysis would be essential if disparate statistical distribution functions for the factors were being used in the subsequent evaluation of the uncertainty in the response and the risk. That is, it would be necessary to match the proper distribution function to each factor.

6.3.3 Response Uncertainty Results. The results next printed out by the ANALYZ subroutine deal with the uncertainty in the response variables of interest, LISTR. For each, a table containing the moments of the statistical distribution function of the response is printed. (This information is computed by the subroutine SOERP.). Table 12 contains the moments for the dose from cloud shine response. Potentially interesting information in the table or derivable from it includes the variance (3.10E-07) and the coefficient of variation (ratio of standard deviation to mean value expressed as a percentage, 66%). The coefficient of skewness indicates, by a negative value, skewness to the left, and the coefficient of kurtosis (3.1) indicates a distribution function somewhat more "peaked" than a Gaussian function.

Perhaps the most important result in this area is the identification of the largest contributors to the uncertainty in the response. This is given in a table of fractional contributions to variance, and an abbreviated table for the dose from cloud shine is given in Table 13. The interpretation of this table is that ~ 98% of the uncertainty in the computed dose from cloud shine arises from two factors only, numbers 3 and 15. Factor 3 is the wind-frequency factor, and Factor 15 is the lack-of-fit in the atmospheric transport model relative to field observations. If one wanted to reduce the uncertainty in this response, then one would first concentrate efforts on reducing the uncertainty in the wind-speed-frequency array. [Actually, one would probably not *want* to spend the effort to reduce the response uncertainty in this case, because the cloud shine dose is smaller than the total dose (6.93E + 03 rem) by a factor of eight million.]

Table 13. Fractional contributions to uncertainty in cloud shine dose

Term	Fraction
LB(3)	0.764
LB(15)	0.165
CB(3,15)	0.050
	sum = 0.979

The central moments of the response are matched to one of those of a family of mathematical distributions called the Pearson family. This is done in the subroutine PDFPLOT. Certain parameters of the selected Pearson distribution are printed, and this is followed by a tabulation of the fitted density function and the complementary cumulative distribution function (not reproduced here). Interpolations may be accomplished using the tabulation, and plots of the function may be obtained if desired.

The density function of dose from cloud shine appears in Figure 9. The two probability points on the plot are those specified in the input term PREF(I). Selected probability points are also tabulated, as shown in Table 14 for dose from cloud shine. The interpretation of the table is, for example: the probability of population dose from cloud shine exceeding 1.78E-03 rem is 0.05.

6.3.4 Risk Uncertainty Results. The next group of results in the printed output deals with the risk uncertainty. The probability of the occurrence of the release event and its error factor are input with the scenario number. For Scenario P-4, the probability assigned is 0.001 with an error factor of 5. A response surface equation for the risk is computed, and the subroutine SOERP computes the properties of the statistical distribution of the risk. In the case of dose from cloud shine, Table 15, the mean risk is 1.36E-06 rem and the standard deviation is 2.25E-06 rem. The resulting coefficient of variation is 166%. The risk distribution is positively skewed, RTBT1 = 6.8, and is far removed from a Gaussian distribution, BETA2 = 150, as may be seen in Figure 10. The larger contribution to the risk uncertainty variance (58%) is from the occurrence probability uncertainty. Selected probability values are listed in Table 16. From this tabulation, one can say that the probability of the risk from cloud shine exceeding 4.97E-06 rem is 0.05. When more than one scenario is run, bar charts comparing the total risks are a graphics option. In order to illustrate this option, a bar chart for a hypothetical set of scenarios is shown in Figure 11.

6.3.5 Sensitivity and Uncertainty for the Other Responses. The reader may recall that five responses were included in the call for risk evaluation, namely LISTR. In addition to dose from cloud shine, the responses treated include dose from ground shine, resuspended particle inhalation dose, dose from plutonium-242, and cumulative population dose. Since the tables and figures are similar to those already presented, they are not included in this report. Furthermore, the interpretation of the dose sensitivity analyses, the dose uncertainty analyses, and the risk evaluations would be done in the same way as described here.

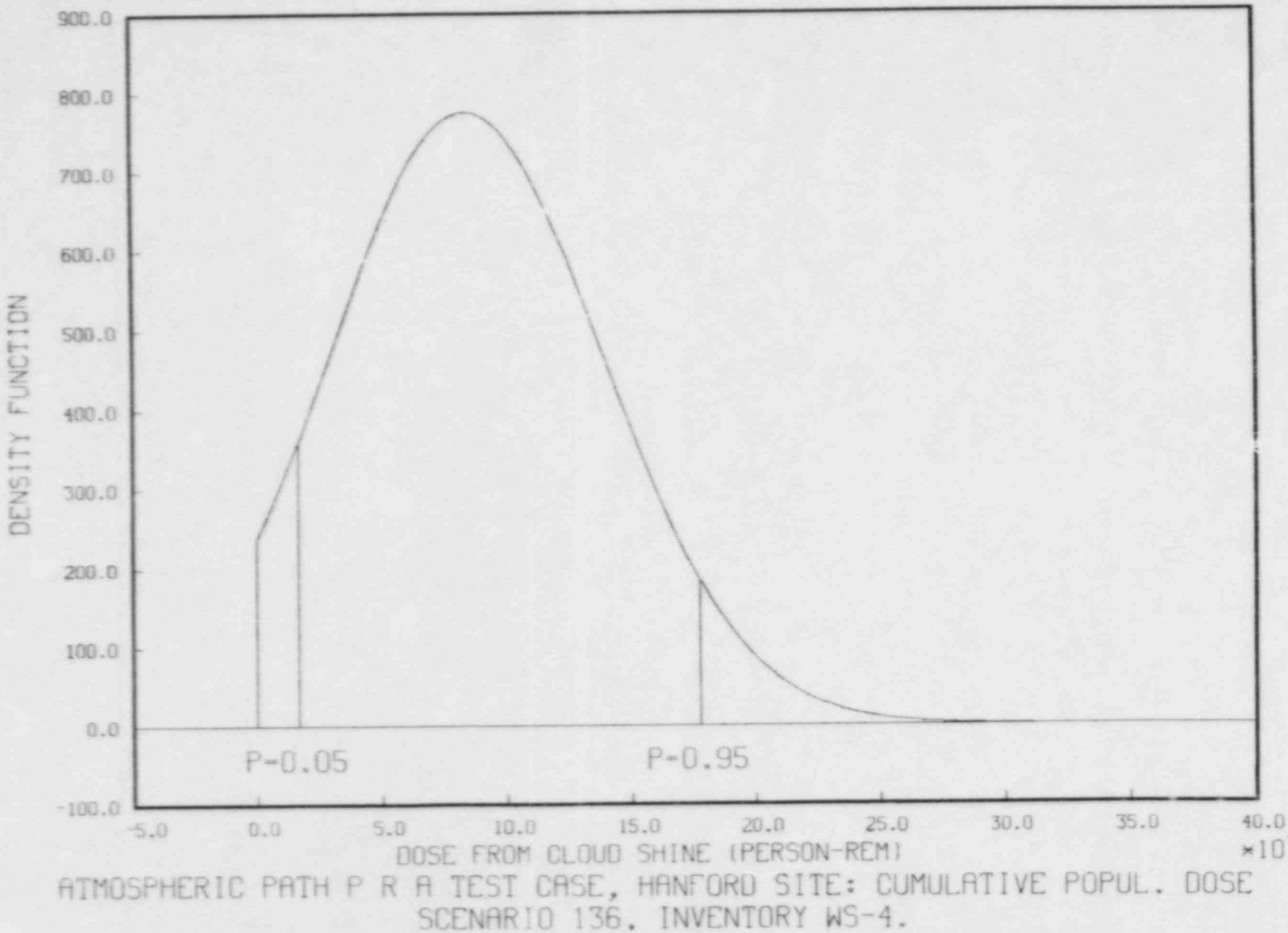


Figure 9. Density function for dose from cloud shine.

Table 14. Complementary cumulative probability for dose from cloud shine

TABLE OF PROBABILITY POINTS
FOR SELECTED PROBABILITY VALUES

****

MEAN= .84429E-03 VARIANCE= .30962E-06

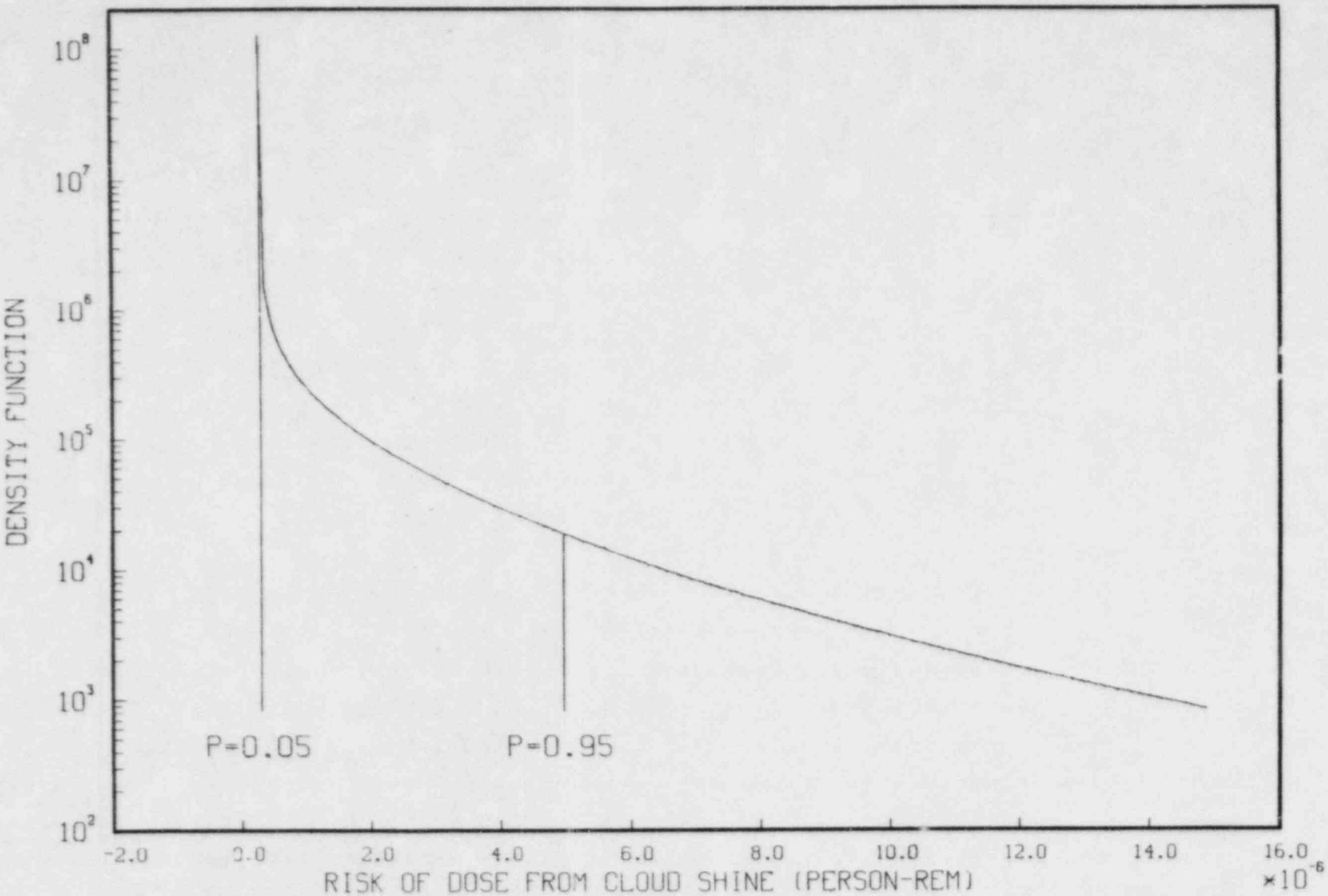
.990	.4008123E-04
.975	.9317651E-04
.950	.1684541E-03
.900	.2900977E-03
.500	.8885119E-03
.100	.1574571E-02
.050	.1776752E-02
.025	.1954732E-02
.010	.2166160E-02

Table 15. Moments of risk due to cloud shine

```
***************************************************************************************
**********                                                                   **********
**********  PROPERTIES OF THE FUNCTION OF INDEPENDENT RANDOM VARIABLES  **********
**********                                                                   **********
***************************************************************************************

ATMOSPHERIC PATH P R A TEST CASE, HANFORD SITE: MAXIMUM INDIVIDUAL DOSE
RISK CALCULATION FOR RESPONSE # 36: DOSE FROM CLOUD SHINE (PERSON-REM)

          **********************************************************
          MEAN-INTERCEPT.............................. =  0.
          MEAN........................................ =   .1362553E-05
          SECOND MOMENT (EDEL2)....................... =   .5079043E-11
          VARIANCE (VAROL)............................ =   .5079043E-11
          THIRD MOMENT (EDEL3)........................ =   .7794355E-16
          THIRD CENTRAL MOMENT (MU3DL)................ =   .7794355E-16
          COEFFICIENT OF SKEWNESS SQUARED (BETA1) =   .4636761E+02
          COEFFICIENT OF SKEWNESS (RTBT1)............ =   .6809377E+01
          FOURTH MOMENT (EDEL4)....................... =   .3861339E-20
          FOURTH CENTRAL MOMENT (MU4DL)............... =   .3861339E-20
          COEFFICIENT OF KURTOSIS (BETA2)............ =   .1496836E+03
```



ATMOSPHERIC PATH P R A TEST CASE, HANFORD SITE: CUMULATIVE POPUL. DOSE

SCENARIO 136, INVENTORY WS-4.

Figure 10. Densitv function for risk due to cloud shine.

Table 16. Complementary cumulative probability for risk due to cloud shine

TABLE OF PROBABILITY POINTS
FOR SELECTED PROBABILITY VALUES

****

MEAN= .13626E-05 VARIANCE= .50790E-11

.990	.2930283E-06
.975	.2965532E-06
.950	.3024280E-06
.900	.3141775E-06
.500	.5811416E-06
.100	.3254435E-05
.050	.4965645E-05
.025	.5959553E-05
.010	.9468002E-05

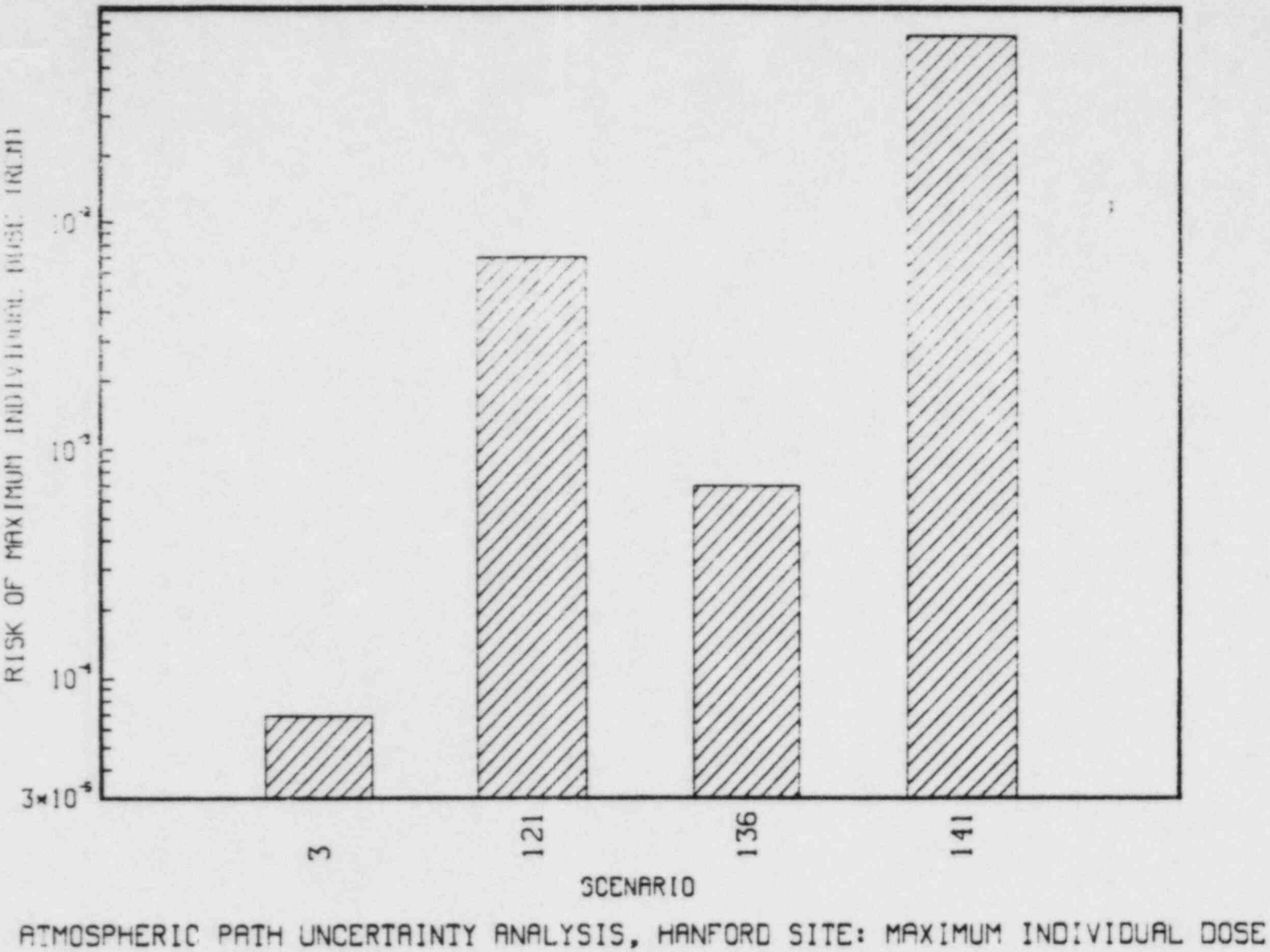


Figure 11. Bar chart illustration.

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APPENDIX A

EVALUATION OF POTENTIAL DOSE RECEIVED BY CONTAMINATION RESULTING FROM A PUNCTURE WOUND

S. K. Rope

October 1983

APPENDIX A

EVALUATION OF POTENTIAL DOSE RECEIVED BY CONTAMINATION RESULTING FROM A PUNCTURE WOUND

BURYIT, a risk assessment code for low-level waste[A-1] contains 15 scenarios (out of 302) which involve a puncture wound of an individual. At present, the code correlates the potential dose received by contamination at the wound site to inhalation of air containing a certain concentration of nuclides. No directions or basis for this correlation are given in the code. Thus, a logical way of modeling the potential dose in the puncture wound scenarios is needed.

The system can be viewed as follows:

Deposition → [Wound, W] Translocation → [Blood, B] → [body organs, excretion]

Once the contamination reaches the blood, the metabolism and dose can be described by the models which are used in the rest of the code. That is:

$$DCF_p = \frac{DCF_{ing}}{f_1} \qquad (1)$$

where

DCF_p = Dose conversion factor describing the dose per unit activity injected into blood (Sv/Bq)

DCF_{ing} = Dose conversion factor describing the dose per unit activity ingested (Sv/Bq)

f_1 = Fraction of the activity ingested which is assimilated into blood.

DCF_{ing} and f_1 values for the 44 nuclides in the BURYIT waste streams were obtained from ICRP Publication 30.[A-2] Resulting DCF_p values are listed in Table A-1.

Thus, it remains to describe the deposition and translocation of contamination from the wound site. Much of the animal and human data available on radionuclide contamination of wounds relate to the transuranics, because of the hazard of these long-lived nuclides when internal to the body. Several data summaries and case histories were studied.[A-3, -4, -5, -6]

The ICRP, in Publication 10A, discusses deposition in skeleton and excretion after contamination of wounds:[A-7]

> "If one knew the retention function for plutonium in a wound, $W_s(t)$, one could calculate its rate of movement from the site to blood, $W'_s(t)$, on the assumption that all the material leaving the site of deposition went first to blood.
>
> "The study of Hamilton et al., on the retention of plutonium at the site of intramuscular injection in rats showed that it left the site according to a power function of the form $W_s(t) = t^{-b}$, where b = 0.07 for Pu^{+3}, 0.21 for Pu^{+4}, and 0.34 for Pu^{+6}.
>
> "Measurement of local retention as well as excretion of plutonium following contamination under, in, or on the skin of man gave widely varying results. One could conclude or calculate that $W_s(t) = t^{-b}$, where b varies from 0 to 0.4. These variations are due to the chemical and physical nature of the plutonium and its site of deposition. The extreme variability makes it impossible to give a single formulation."

Thus, the retention function, L(t), for plutonium deposited at the wound site can be described by

$$L(t) = \frac{W(t)}{W(1)} = t^{-b} \qquad (2)$$

where t is in days and b varies from 0 to 0.4.

If b is zero, none of the activity leaves the wound site. Under such cases, excision of the localized contamination is often performed (Reference A-6). If b = 0.4, about 10% of the activity remains at the wound site after one year. The remaining 90% will have been translocated to blood. Plutonium is likely

Table A-1. DCF_p values for evaluation of puncture wound scenarios[a]

Nuclide	DCF_p (Sv/Bq)[b]	Nuclide	DCF_p (Sv/Bq)[b]
^{3}H	1.7×10^{-11}	^{137}Cs	1.4×10^{-8}
^{14}C	5.7×10^{-10}	^{144}Ce	1.8×10^{-5}
^{35}S	1.8×10^{-9}	^{152}Eu	1.6×10^{-6}
^{51}Cr	3.6×10^{-10}	^{154}Eu	2.4×10^{-6}
^{54}Mn	7.3×10^{-9}	^{155}Eu	3.7×10^{-7}
^{55}Fe	1.6×10^{-9}	^{226}Ra	1.8×10^{-6}
^{58}Co	1.6×10^{-8}	^{230}Th	7.5×10^{-4}
^{60}Co	5.4×10^{-8}	^{232}Th	3.7×10^{-3}
^{59}Ni	1.1×10^{-9}	^{235}U	3.4×10^{-6}
^{63}Ni	3.0×10^{-9}	^{238}U	3.1×10^{-6}
^{65}Zn	7.8×10^{-9}	^{237}Np	1.1×10^{-3}
^{90}Sr	3.2×10^{-7}	^{238}Pu	1.5×10^{-3}
^{94}Nb	1.4×10^{-7}	^{239}Pu	1.6×10^{-3}
^{95}Zr	4.6×10^{-7}	^{240}Pu	1.6×10^{-3}
^{99}Tc	4.3×10^{-10}	^{241}Pu	2.5×10^{-5}
^{106}Ru	1.2×10^{-7}	^{242}Pu	1.5×10^{-3}
^{124}Sb	2.5×10^{-7}	^{241}Am	1.2×10^{-3}
^{125}Sb	7.0×10^{-8}	^{242}Am	1.1×10^{-3}
^{125}I	1.0×10^{-8}	^{243}Am	1.2×10^{-3}
^{129}I	7.4×10^{-8}	^{242}Cm	3.6×10^{-5}
^{134}Cs	2.0×10^{-8}	^{243}Cm	7.8×10^{-4}
^{135}Cs	1.9×10^{-9}	^{244}Cm	6.0×10^{-4}

a. When ICRP gives more than one solubility class, the most conservative DCF/f_1 value is shown.

b. 1 Sv/Bq = 3.7×10^{12} rem/Ci.

to be one of the least mobile of elements in terms of translocation from the wound site to the blood. Its low mobility in intra- and intercellular fluids is evident by its very low uptake potential from the gut to blood (Reference A-2).

Because of these factors, and because of the uncertainties in formulating, *a priori*, the outcome of a given accident, it is proposed to assume that all activity deposited at the wound site enters the bloodstream within a year.

It is necessary to estimate the quantity of radioctive material which could be deposited at the wound site. Johnson and Lawrence (Reference A-6) report initial contamination of wounds with from 0.4 to 45 nCi (0.004 to 0.7 μg plutonium-239). Hammond and Putzier (Reference A-3) report cases in which up to 2.5 μg plutonium have been deposited in wounds. Excision of the contamination often follows.

It is proposed to assume that 1 μg of material could be deposited at the wound site and subsequently be translocated to the bloodstream. This parameter may be varied as part of the sensitivity analysis.

The dose from the puncture wound can thus be described by

$$D = \sum_{i=1}^{n} \frac{C_i * W(1) * DCF_{pi}}{\varrho} \times 10^{9}$$

where

D = dose resulting from puncture wound (rem)

n = total number of nuclides in the waste.

C_i = concentration of nuclide i in waste container (Ci/m^3)

W(1) = quantity of material deposited at the wound site (μg)

DCF_{pi} = blood-to-dose conversion factor for nuclide i (Sv/Bq)

ϱ = density of waste (kg/m^3)

DCF_{pi} values are given in Table A-1. C_i is defined in the BURYIT waste streams. A waste density for the different waste streams must be defined.

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APPENDIX B

CONFOUNDING PATTERN ALGORITHM FOR FRACTIONAL FACTORIAL DESIGNS

APPENDIX B

CONFOUNDING PATTERN ALGORITHM FOR FRACTIONAL FACTORIAL DESIGNS

Figure B-1 contains that part of subroutine DESIGN that computes confounding patterns for fractional factorial experimental designs. The pattern aids one in identifying real alias terms in a response surface equation, as illustrated in the text.

```
C
  500 IF(LTYPE.NE.3.AND.LTYPE.NE.4) GO TO 700
C
C     OPTIONAL INPUT: READ IN QUADRATIC FACTORS INSTEAD OF USING
C     CODE-GENERATED (ORTHOGONAL) VALUES
C
      IF(IREAD.EQ.1) THEN
      READ(5,602) (STAR(I),I=1,NFAC)
      ENDIF
  602 FORMAT(10F5.0)
      RAD=(NRUN**2 + 2*NRUN*NFAC + NRUN)**0.5
      ALP=((NRUN-RAD)/(-2.))**0.5
      NFAC2=2*NFAC
      DO 610 I=1,NFAC2
      DO 610 J=1,NFAC
  610 D(NRUN+I,J)=0.
      DO 620 J=1,NFAC
      IF(IREAD.EQ.1) ALP=STAR(J)
      D(NRUN+2*J-1,J)=ALP
  620 D(NRUN+2*J,J)=-ALP
      NRUN=NRUN+2*NFAC+1
      DO 630 J=1,NFAC
  630 D(NRUN,J)=0.
C
C WRITE DESIGN MATRIX "D"
C
  700 IF(LPR.EQ.1) GO TO 705
      WRITE(6,701) NFAC,IP
      IF(LTYPE.EQ.2) WRITE(6,702)
      IF(LTYPE.EQ.3) WRITE(6,703)
      IF(LTYPE.EQ.4) WRITE(6,704)
  701 FORMAT(1H1,23H DESIGN MATRIX FOR A 2**(,I2,1H-,I2,22H) FRACTIONAL
     +FACTORIAL)
  702 FORMAT(1H ,24H INCLUDING FOLDOVER RUNS,/)
  703 FORMAT(1H ,20H PLUS QUADRATIC RUNS,/)
  704 FORMAT(1H ,38H INCLUDING FOLDOVER AND QUADRATIC RUNS,/)
      GO TO 708
  705 WRITE(6,706) NFAC,NRUN
  706 FORMAT(1H ,35H PLACKETT-BURMAN DESIGN MATRIX FOR ,I2,12H FACTORS
     +IN ,I3,5H RUNS,/)
  708 WRITE(6,709)(I,I=1,NFAC)
  709 FORMAT(1H ,8X,7HFACTORS/1H ,7H RUNS *,20I4/8X,20I4)
      NFACP2=NFAC+2
      WRITE(6,711)(NAM(5),I=1,NFACP2)
  711 FORMAT(22A4)
      DO 710 I=1,NRUN
  710 WRITE(6,800) I,(D(I,J),J=1,NFAC)
  800 FORMAT(I5,4H  * ,20F4.0/9H        * ,20F4.0)
      IF(LTYPE.GE.3)
     +WRITE(6,720) ALP
  720 FORMAT(1H ,9H ALPHA = ,F10.4,/)
C
C WRITE DESIGN GENERATORS
```

Figure B-1. Subroutine Design

```
C                                                                       DESIGN     262
      DO 750 I=1,15                                                     DESIGN     263
      DO 750 J=1,15                                                     DESIGN     264
  750 ICON(I,J)=0                                                       DESIGN     265
      IF(LPB.EQ.1) RETURN                                               DESIGN     266
      IF(NFAC.GT.15) RETURN                                             DESIGN     267
      IF(ISTART.EQ.1)RETURN                                             FIXO2        1
      IF(IPRINT.EQ.1)                                                   DESIGN     268
     +WRITE(6,949)                                                      DESIGN     269
  949 FORMAT(1H ,18H DESIGN GENERATORS,/)                               DESIGN     270
      DO 899 I=1,43                                                     DESIGN     271
      IF(IGEN(I,1).EQ.0) GO TO 902                                      DESIGN     272
  899 IF(IPRINT.EQ.1)                                                   DESIGN     273
     +WRITE(6,950) (IGEN(I,J),J=1,12)                                   DESIGN     274
  902 WRITE(6,903)                                                      DESIGN     275
  903 FORMAT(1H )                                                       DESIGN     276
C                                                                       DESIGN     277
C CALL SUB IDEA TO GET 2**P PATTERN OF COMBINATIONS OF DESIGN           DESIGN     278
C GENERATORS NECESSARY TO FORM ALL DEFINING RELATIONS                   DESIGN     279
C                                                                       DESIGN     280
C                                                                       DESIGN     281
C WRITE DEFINING RELATIONS AND THEIR 2 AND 2 FACTOR ALIASES             DESIGN     282
C                                                                       DESIGN     283
      NUMBER=2**IP - 1 - IP                                             DESIGN     284
      IF(IPRINT.EQ.1)                                                   DESIGN     285
     +WRITE(6,901)                                                      DESIGN     286
  901 FORMAT(25H  2**P DEFINING RELATIONS,/)                            DESIGN     287
C                                                                       DESIGN     288
C WRITE 1 AND 2 FACTOR ALIASES OF GENERATORS                            DESIGN     289
C                                                                       DESIGN     290
      NCON=1                                                            DESIGN     291
      DO 799 I=1,IP                                                     DESIGN     292
      KSUM=0                                                            DESIGN     293
      IF(IPRINT.EQ.1)                                                   DESIGN     294
     +WRITE(6,950) (IGEN(I,L),L=1,12)                                   DESIGN     295
      IF(IPRINT.EQ.1)                                                   DESIGN     296
     +WRITE(6,955)                                                      DESIGN     297
      DO 865 K=1,NFAC                                                   DESIGN     298
      DO 860 J=1,12                                                     DESIGN     299
      I2(J)=IGEN(I,J)                                                   DESIGN     300
      IAL(J)=0                                                          DESIGN     301
  860 I1(J)=0                                                           DESIGN     302
      I1(1)=K                                                           DESIGN     303
      CALL PROD(I1,I2,IAL)                                              DESIGN     304
      LSUM=0                                                            DESIGN     305
      DO 863 N=1,12                                                     DESIGN     306
  863 IF(IAL(N).GT.0) LSUM=LSUM+1                                       DESIGN     307
      IF(LSUM.GT.2) GO TO 865                                           DESIGN     308
      KSUM=KSUM+1                                                       DESIGN     309
      IF(ICON(K,K).GT.0) GO TO 864                                      DESIGN     310
      ICON(K,K)=NCON                                                    DESIGN     311
      ICON(IAL(1),IAL(2))=NCON                                          DESIGN     312
      NCON=NCON+1                                                       DESIGN     313
```

Figure B-1. (continued)

```
      GO TO 865
  864 ICON(IAL(1),IAL(2))=ICON(K,K)
  865 IF(IPRINT.EQ.1.AND.LSUM.LE.2) WRITE(6,966)K,(IAL(J),J=1,12)
      NFACM1=NFAC-1
      DO 880 K=1,NFACM1
      KP1=K+1
      DO 880 J=KP1,NFAC
      DO 870 M=1,12
      IAL(M)=0
      I2(M)=IGEN(I,M)
  870 I1(M)=0
      I1(1)=K
      I1(2)=J
      CALL PROD(I1,I2,IAL)
      LSUM=0
      DO 875 N=1,12
  875 IF(IAL(N).GT.0) LSUM=LSUM+1
      IF(LSUM.GT.2) GO TO 880
      KSUM=KSUM+1
      IF(KSUM.GT.3) GO TO 799
      IF(ICON(K,J).GT.0.OR.ICON(IAL(1),IAL(2)).GT.0) GO TO 878
      ICON(K,J)=NCON
      ICON(IAL(1),IAL(2))=NCON
      NCON=NCON+1
      GO TO 880
  878 IF(ICON(K,J).GT.0)ICON(IAL(1),IAL(2))=ICON(K,J)
      IF(ICON(IAL(1),IAL(2)).GT.0) ICON(K,J)=ICON(IAL(1),IAL(2))
  880 IF(IPRINT.EQ.1.AND.LSUM.LE.2)
     +                WRITE(6,981)K,J,(IAL(N),N=1,12)
  799 CONTINUE
      IF(NUMBER.LT.1) GO TO 1005
      DO 1000 I=1,NUMBER
      KSUM=0
C
C FORM DEFINING RELATION - IDR
C
      DO 905 K=1,12
  905 IDR(K)=0
      DO 910 K=1,12
      I1(K)=IGEN(ID(1),K)
  910 I2(K)=IGEN(ID(2),K)
      DO 930 J=3,12
      CALL PROD(I1,I2,IDR)
      IF(ID(J).EQ.0) GO TO 940
      DO 920 K=1,12
      I1(K)=IDR(K)
      IDR(K)=0
  920 I2(K)=IGEN(ID(J),K)
  930 CONTINUE
  940 IF(IPRINT.EQ.1)
     +WRITE(6,950) (IDR(K),K=1,12)
      IF(IPRINT.EQ.1)
     +WRITE(6,941) (ID(K),K=1,12)
```

Figure B-1. (continued)

```
  941 FORMAT(1H ,6H ID = ,12I3)
      DO 945 KK=1,12
  945 IDOLD(KK)=ID(KK)
      CALL IDEA(IDOLD,IP,ID)
  950 FORMAT(1H ,7H IDR = ,12I3)
      IF(IPRINT.EQ.1)
     +WRITE(6,955)
  955 FORMAT(1H ,10X,8H ALIASES,/)
C
C FIND 1 FACTOR ALIASES AND WRITE IF ALIAS IS 2 FACTORS OR LESS
C
      DO 965 K=1,NFAC
      DO 960 J=1,12
      I2(J)=IDR(J)
      IAL(J)=0
  960 I1(J)=0
      I1(1)=K
      CALL PROD(I1,I2,IAL)
      LSUM=0
      DO 963 N=1,12
  963 IF(IAL(N).GT.0) LSUM=LSUM+1
      IF(LSUM.GT.2) GO TO 965
      KSUM=KSUM+1
      IF(ICON(K,K).GT.0) GO TO 964
      ICON(K,K)=NCON
      ICON(IAL(1),IAL(2))=NCON
      NCON=NCON+1
      GO TO 965
  964 ICON(IAL(1),IAL(2))=ICON(K,K)
  965 IF(IPRINT.EQ.1.AND.LSUM.LE.2) WRITE(6,966)K,(IAL(J),J=1,12)
  966 FORMAT(1H ,10X,I3,3H = ,12I3)
C
C FIND 2 FACTOR ALIASES AND WRITE IF ALIAS IS 2 FACTORS OR LESS
C
      NFACM1=NFAC-1
      DO 980 K=1,NFACM1
      KP1=K+1
      DO 980 J=KP1,NFAC
      DO 970 M=1,12
      IAL(M)=0
      I2(M)=IDR(M)
  970 I1(M)=0
      I1(1)=K
      I1(2)=J
      CALL PROD(I1,I2,IAL)
      LSUM=0
      DO 975 N=1,12
  975 IF(IAL(N).GT.0) LSUM=LSUM+1
      IF(LSUM.GT.2) GO TO 980
      KSUM=KSUM+1
      IF(KSUM.GT.3) GO TO 1000
      IF(ICON(K,J).GT.0.OR.ICON(IAL(1),IAL(2)).GT.0) GO TO 978
      ICON(K,J)=NCON
```

Figure B-1. (continued)

```
              ICON(IAL(1),IAL(2))=NCON                                    DESIGN     420
              NCON=NCON+1                                                 DESIGN     421
              GO TO 980                                                   DESIGN     422
          978 IF(ICON(K,J).GT.0)ICON(IAL(1),IAL(2))=ICON(K,J)             DESIGN     423
              IF(ICON(IAL(1),IAL(2)).GT.0) ICON(K,J)=ICON(IAL(1),IAL(2))  DESIGN     424
          980 IF(IPRINT.EQ.1.AND.(SUM.LE.2) WRITE(6,981)K,J,(IAL(N),N=1,72)  DESIGN  425
          981 FORMAT(1H ,10X,2I3,3H = ,12I3)                               DESIGN     426
         1000 CONTINUE                                                    DESIGN     427
         1005 WRITE(6,1015)                                               DESIGN     428
         1015 FORMAT(1H ,19H CONFOUNDING ARRAY,//)                        DESIGN     429
              WRITE(6,1050) (I,I=1,NFAC)                                  DESIGN     430
         1050 FORMAT(1H ,4X,3H * ,20I4)                                   DESIGN     431
              WRITE(6,711)(NAM(I),I=1,NFACP2)                             DESIGN     432
              DO 1010 N=1,NFAC                                            DESIGN     433
         1010 WRITE(6,1020) N,(ICON(N,M),M=1,NFAC)                        DESIGN     434
         1020 FORMAT(1H ,I4,3H * ,19I4)                                   DESIGN     435
              RETURN                                                      DESIGN     436
              END                                                         DESIGN     437
```

```
--VARIABLE MAP--(LO=M/A/R)                                                    A=ARGLIST, C=CTRL OF DO, I=DATA INIT,
 -NAME---ADDRESS--BLOCK-----PROPERTIES-------TYPE---------SIZE---REFERENCES-  R=READ, S=STORE, U=I/O UNIT, W=WRITE

 ALP      4652B                             REAL                 222/S  228/S  229    230    259/W
 ALPHA    7741B   /DESNBL/                  REAL          100      8
 AMU      1346B   /DESNBL/                  REAL          800      8
 C         144B   /DESNBL/                  REAL          300      8
 D        3006B   /DESNBL/                  REAL         2520      8    55/S   58/S   76     76     76/S   91     91     91     91/S
                                                                 109    109    109    109    109/S  133/S  137    137/S  139    139/S
                                                                 142/S  152/S  156    156/S  158    158/S  161/S  172    172/S  173
                                                                 173/S  174    174/S  176/S  177/S  186    186/S  226/S  229/S  230/S
                                                                 233/S  257/W
 FACTOR     0B    /DESNBL/                  REAL          100      8
 I        4556B                             INTEGER               21/C   33     36/C   37     38     40     50/S   55     56     56/S
                                                                  58     59     59/S   73/C   76     76     76     90/C   91     91
                                                                  91     91    108/C  109    109    109    109    109    132/C  133
                                                                 133    135/C  136    137    137    139    139    151/C  152    152
                                                                 154/C  155    156    156    158    158    170/C  172    172    173
                                                                 173    174    174    175/C  176    177    184/C  186    186    218
                                                                 224/C  226    251/C  251/W  254/C  256/C  257/W  257    257    265/C
                                                                 267    274/C  275    276    276    295/C  297    297    303    326
                                                                 348/C  433/C  433/W  435/C
 IAL      4477B                             INTEGER        12     14    199/A  231    324/S  337/A  310    315    315    318    318
                                                                 319/W  325/S  330/A  333    337    337    339    339    342    342
                                                                 343    343    343    343    344/W  384/S  387/A  393    395    395
                                                                 398    398    399/W  419/S  414/A  417    421    421    423    423
                                                                 426    426    427    427    427    427    428/W
 ICON    10135B   /DESNBL/                  INTEGER       225      5    267/S  313    314/S  315/S  318    318/S  337    337    338/S
                                                                 339/S  342    342    342/S  343    343    343/S  393    394/S  395/S
                                                                 398    398/S  421    421    422/S  423/S  426    426    426/S  427
                                                                 427    427/S
 ICOUNT  16450B   /DESNBL/                  INTEGER                8    39/S  188/S
 ID       4400B                             INTEGER        12     12    17/I  356    357    360    364    368/W  372    373/A
```

Figure B-1. (continued)

APPENDIX C

SCENARIO CONTROL FILE TAPE7

APPENDIX C

SCENARIO CONTROL FILE TAPE7

This appendix contains a printout of Table C-1 of the scenario control file as it appears on TAPE7. The scenarios are in the same order as in Table I-1, Appendix I. The scenario list is identical to that in NUREG/CR-1963[C-1] even though it is probable that some are no longer applicable; for example, drums will be required to contain no more than a small amount of liquid.

Each scenario corresponds to three lines. The first line contains the scenario code in columns 1-4, taken from Reference C-1. Column 8 contains the number of release pathways in the scenario. Columns 14-25 contain a pair of numbers. The first of the pair is the calling sequence for the release pathway; e.g., 951 means UNSAT, EROSIO, AQUIFR, and ATMOS. (Recall that ATMOS is always called by EROSIO.) The second number of the pair is the fractional release of nuclides to the pathway. Additional pairs of numbers for calling sequence and release fraction appear in successive groups of 12 columns until the total number of pathways given in column one is reached. The second and third lines for the scenario contain a brief verbal description of the scenario.

Reference

C-1. D. Lester et al., *System Analysis of Shallow-Land Burial*, NUREG/CR-1963, Vol. 1-3, March 1981.

Table C-1. Scenario control file

```
A-1     2     3    1.0E+00 4     1.0E-02
A RUPTURED DRUM WITH LIQUID SUBSTANCE CAUSES SPILL TO CONTAMINATE
THE VEHICLE OR THE OVERPACK INTERIOR.
A-2     2     3    1.0E+00 4     1.0E-03
A RUPTURED DRUM WITH VOLATILE SUBSTANCE CAUSES RELEASE TO CONTAMINATE
THE VEHICLE OR THE OVERPACK INTERIOR.
A-3     2     3    1.0E+00 4     1.0E-01
A RUPTURED DRUM, CARTON OR BOX CONTAINING SOLIDS CAUSES RELEASES TO
CONTAMINATE THE VEHICLE OR THE OVERPACK INTERIOR.
A-4     2     3    1.0E+00 6     1.0E+00
WORKER IS INJURED BY CONTAMINATED SHARP OBJECT PROTRUDING FROM RUPTURED
DRUM, CARTON OR BOX DURING RECEIVING INSPECTION.
A-5     2     3    1.0E+00 2     2.0E-02
FIRE ERUPTS IN THE TRANSPORT VEHICLE OR OVERPACK CONTAINING COMBUSTIBLE
MATERIALS DURING RECEIVING INSPECTION.  FIRE IS ALLOWED TO BURN OUT.
A-6     3     3    1.0E-01 2     2.0E-02 951  1.0E-01
FIRE ERUPTS IN THE TRANSPORT VEHICLE OR OVERPACK CONTAINING COMBUSTIBLE
MATERIALS DURING RECEIVING INSPECTION.  FIRE IS QUENCHED WITH WATER.
A-7     2     3    1.0E+00 2     1.0E-03
EXPLOSION IN THE TRANSPORT VEHICLE OR OVERPACK CONTAINING DRUMS OR BOXES
WITH VOLATILE SUBSTANCES OR LIQUID CONTAINERS.
A-8     2     3    1.0E+00 2     1.0E-03
EXPLOSION IN THE TRANSPORT VEHICLE OR OVERPACK CONTAINING DRUMS, BOXES
OR CARTONS FILLED WITH SOLIDS OR LOOSE BUNDLES.
A-9     2     3    1.0E+00 4     1.0E-02
IRRADIATED/CONTAMINATED USABLE ITEMS ARE REMOVED FROM WASTES.

A-10    1     3    1.0E+00
CHRONIC DIRECT RADIATION TO WORKERS ENGAGED IN THE PRE-ENTRY INSPECTION
OF DRUMS, BOXES, CARTONS AND LOOSE BUNDLES.
A-11    1     2    1.0E-05
CHRONIC ESCAPE TO ATMOSPHERE OF RADIONUCLIDES DURING THE PRE-ENTRY
INSPECTION OF DRUMS, BOXES, CARTONS AND LOOSE BUNDLES.
B-1     2     3    1.0E+00 951  1.0E-01
LINER CONTAINING HIGHLY ACTIVATED LWR COMPONENTS IS RUPTURED DURING
TRANSFER TO TRENCH.  WASTES ARE SPILLED FROM THE LINER.
B-2     1     3    1.0E-06
CHRONIC DIRECT RAD. TO WORKERS REMOVING THE LINER, CONT. HIGHLY ACTIVATED
LWR COMPONENTS, FROM SHIELDED CASK AND MANIPULATING IT INTO TRENCH.
B-3     1     3    1.0E+00
DRUM WITH LIQUID WASTE CONTAINERS IS RUPTURED DURING TRANSFER FROM
TRANSPORTATION OVERPACK TO TRENCH.  LIQUID IS SPILLED INTO OVERPACK.
B-4     1     951  1.0E-01
DRUM WITH LIQUID WASTE CONTAINERS IS RUPTURED DURING TRANSFER FROM
TRANSPORTATION OVERPACK TO TRENCH.  LIQUID IS SPILLED INTO TRENCH.
B-5     1     2    1.0E-03
DRUM CONTAINING VOLATILE SUBSTANCE IS RUPTURED DURING TRANSFER FROM
TRANSPORTATION OVERPACK TO TRENCH.  VOLATILE SUBSTANCE ESCAPES TO ATMOS.
B-6     2     2    1.0E-03 91    1.0E-01
DRUM, CARTON OR BOX CONTAINING SOLID SUBSTANCE IS RUPTURED DURING
TRANSFER FROM TRANSPORTATION OVERPACK TO BURIAL TRENCH.
B-7     2     3    1.0E+00 2     2.0E-02
FIRE ERUPTS IN THE TRANSPORTATION OVERPACK OR IN THE TRENCH CONTAINING
COMBUSTIBLE MATERIALS.  FIRE IS ALLOWED TO BURN OUT.
B-8     3     3    1.0E-01 2     2.0E-02 951  1.0E-01
FIRE ERUPTS IN THE TRANSPORTATION OVERPACK OR IN THE TRENCH CONTAINING
COMBUSTIBLE MATERIALS.  FIRE IS QUENCHED WITH WATER.
B-9     3     3    1.0E+00 2     2.0E-02 951  1.0E-01
EXPLOSION IN THE TRANSPORTATION OVERPACK OR IN THE TRENCH CONTAINING
DRUMS OR BOXES WITH VOLATILE SUBSTANCES OR LIQUID CONTAINERS.
B-10    3     3    1.0E+00 2     1.0E-03 951  1.0E-01
EXPLOSION IN THE TRANSPORTATION OVERPACK OR IN THE TRENCH CONTAINING
DRUMS, BOXES, CARTONS FILLED WITH SOLIDS OR LOOSE MATERIALS.
B-11    1     3    1.0E+00
CHRONIC DIRECT RADIATION TO WORKERS ENGAGED IN UNLOADING OF DRUMS,
BOXES, CARTONS AND LOOSE BUNDLES FROM TRANSPORTATION OVERPACK.
B-12    3     3    1.0E+00 2     1.0E-03 951  1.0E-01
CHRONIC ESCAPE TO ATMOSPHERE OF RADIONUCLIDES DURING UNLOADING OF
DRUMS, BOXES, CARTONS, AND BUNDLES FROM TRANSPORTATION OVERPACK.
B-13    2     3    1.0E+00 4     1.0E-02
THE TRANSPORTATION OVERPACKS AND/OR VEHICLE INADEQUATELY DECONTAMINATED
PRIOR TO RELEASE.
```

Table C-1. (continued)

```
B-14    2    3    1.0E+00 4    1.0E-02
IRRADIATED/CONTAMINATED USABLE ITEMS ARE REMOVED FROM WASTES DURING
HANDLING.
C-1     1    2    2.0E-02
FIRE ERUPTS IN THE UNCOVERED TRENCH CONTAINING BURNABLE CARTONS, BOXES
OR LOOSE BUNDLES.  FIRE IS ALLOWED TO BURN OUT.
C-2     2    2    2.0E-02 951  1.0E-01
FIRE ERUPTS IN THE UNCOVERED TRENCH CONTAINING BURNABLE CARTONS, BOXES
OR LOOSE BUNDLES.  FIRE IS QUENCHED WITH WATER.
C-3     1    951  1.0E-01
UNCOVERED TRENCH IS FLOODED FROM RAINFALL.

C-4     2    3    1.0E+00 2    2.0E-01
HIGH VELOCITY WIND CAUSES LIFTING AND DISPERSAL OF THOSE RADIONUCLIDES
FROM UNCOVERED TRENCH WHICH ARE ATTACHED TO DUST ETC.  MATERIALS DISPERSED.
C-5     2    3    1.0E+00 4    1.0E-02
IRRADIATED/CONTAMINATED USABLE ITEMS ARE REMOVED FROM WASTES.

C-6     1    4    1.0E-04
ANIMALS (RATS, RABBITS, ETC.) INTRUDE INTO UNCOVERED WASTES, BECOME
CONTAMINATED, AND CARRY RADIONUCLIDES OUTSIDE OF THE TRENCH.
C-7     1    3    1.0E+00
CHRONIC DIRECT RADIATION TO WORKERS ENGAGED IN THE ACTIVITIES IN THE
VICINITY OF UNCOVERED WASTES.
C-8     1    2    1.0E-05
CHRONIC ESACAPE TO ATMOSPHERE OF RADIONUCLIDES FROM THE UNCOVERED
WASTES.
D-1     2    3    1.0E+00 951  1.0E-01
LINER CONTAINING HIGHLY ACTIVATED LWR COMPONENTS IS RUPTURED DURING
BURIAL OR BACKFILL.  WASTES ARE SPILLED FROM LINER.
D-2     1    3    1.0E-06
CHRONIC DIRECT RADIATION TO WORKERS ENGAGED IN BURYING THE LINER
CONTAINING HIGHLY ACTIVATED LWR COMPONENTS.
D-3     1    3    1.0E+00
DRUM WITH LIQUID WASTE CONTAINERS IS RUPTURED DURING BURIAL OR BACKFILL
OPERATION.  LIQUID IS SPILLED INTO OVERPACK.
D-4     1    951  1.0E-01
DRUM WITH LIQUID WASTE CONTAINERS IS RUPTURED DURING BURIAL OR BACKFILL
OPERATION.  LIQUID IS SPILLED INTO TRENCH.
D-5     1    2    1.0E+00
DRUM CONTAINING VOLATILE SUBSTANCE IS RUPTURED DURING BURIAL OR BACKFILL
OPERATION.  VOLATILE SUBSTANCE ESCAPES TO ATMOSPHERE.
D-6     1    2    1.0E-03
DRUM, CARTON OR BOX CONTAINING SOLID WASTES IS RUPTURED DURING BURIAL OR
BACKFILL OPERATION
D-7     1    2    2.0E-02
FIRE ERUPTS IN THE TRENCH CONTAINING BURNABLE CARBONS, BOXES OR LOOSE
BUNDLES DURING BURIAL OR BACKFILL.  FIRE IS ALLOWED TO BURN OUT.
D-8     2    2    2.0E-02 951  1.0E-01
FIRE ERUPTS IN THE TRENCH CONTAINING BURNABLE CARBONS, BOXES OR LOOSE
BUNDLES DURING BURIAL OR BACKFILL.  FIRE IS QUENCHED WITH WATER.
D-9     3    3    1.0E+00 2    1.0E-03 951  1.0E-01
EXPLOSION IN THE TRENCH CONTAINING  DRUMS OR BOXES WITH VOLATILE
SUBSTANCES OR LIQUID CONTAINERS DURING BACKFILL OPERATIONS.
D-10    3    3    1.0E+00 2    1.0E-03 951  1.0E-01
EXPLOSION IN THE TRENCH CONTAINING DRUMS, BOXES, CARTONS OR LOOSE
BUNDLES (IN SOLID STATE) DURING BURIAL AND BACKFILL OPERATIONS.
D-11    1    3    1.0E+00
CHRONIC DIRECT RADIATION TO WORKERS ENGAGED IN BURIAL AND BACKFILL
OPERATIONS.
E-1     1    951  1.0E-01
EROSION OR WASHING OUT OF BACKFILL INADEQUATE BACKFILL DEPTH.

E-2     1    91   1.0E-01
INTRUSION OF SURFACE WATER, WATER SEEPAGE TO WATER TABLE THROUGH
BURIED WASTES.
E-3     2    3    1.0E+00 4    1.0E-02
INTRUSION BY SCAVENGERS (SITE WORKER/OUTSIDE PERSON).  REMOVAL OF
CONTAMINATED ITEMS.
```

Table C-1. (continued)

E-4 1 4 1.0E-04
INTRUSION BY ANIMALS (RATS, RABBITS, ETC.) ANIMALS BECOME CONTAMINATED.

F-1 1 951 1.0E-01
EROSION OR WASHING OUT OF BACKFILL. INADEQUATE BACKFILL DEPTH.

F-2 1 91 1.0E-01
INTRUSION OF SURFACE WATER. WATER SEEPAGE TO WATER TABLE THROUGH BURIED WASTES.

F-3 2 3 1.0E+00 4 1.0E-02
INTRUSION BY SCAVENGERS DIGGING FOR ARTIFACTS. REMOVAL OF CONTAMINATED ITEMS.

F-4 1 4 3.0E-03
FARMING OF THE BURIAL SITE FOR CROPS.

F-5 1 4 3.0E-03
USE OF THE BURIAL SITE AS A PASTURE FOR DOMESTIC ANIMALS.

F-6 1 4 1.0E-04
INTRUSION BY ANIMALS. ANIMALS BECOME CONTAMINATED.

F-7 1 951 1.0E-01
LONG-TERM FLOODING OF THE BURIAL SITE.

F-8 1 3 1.0E+00
UNCOVERING OF THE BURIED WASTE BY EARTHQUAKE.

P-1 1 3 1.0E+00
HIGHLY ACTIVATED LWR COMPONENTS ARE MISHANDLED DURING PACKAGING INTO A SHIELDED CASK, CAUSING WORKERS' EXPOSURE.

P-2 1 3 1.0E+00
CHRONIC DIRECT RADIATION TO WORKERS ENGAGED IN PACKAGING HIGHLY ACTIVATED LWR COMPONENTS INTO SHIELDED CASKS.

P-3 1 3 1.0E+00
LIQUID WASTE CONTAINERS ARE RUPTURED DURING PACKAGING, LIQUID IS SPILLED.

P-4 1 2 1.0E+00
CONTAINER WITH VOLATILE SUBSTANCE IS RUPTURED DURING PACKAGING. VOLATILE SUBSTANCE ESCAPES TO ATMOSPHERE.

P-5 2 2 1.0E-03 951 1.0E-01
SOLID WASTES ARE SPILLED AND DISPERSED DURING PACKAGING.

P-6 2 3 1.0E+00 2 2.0E-02
FIRE ERUPTS DURING PACKAGING OF COMBUSTIBLE WASTES. FIRE IS ALLOWED TO BURN OUT.

P-7 3 3 1.0E-01 2 2.0E-02 951 1.0E-01
FIRE ERUPTS DURING PACKAGING OF COMBUSTIBLE WASTES. FIRE IS QUENCHED WITH WATER.

P-8 3 3 1.0E+00 2 1.0E-03 951 1.0E-01
EXPLOSION DURING PACKAGING OF VOLATILE SUBSTANCES OR LIQUID.

P-9 3 3 1.0E+00 2 1.0E-03 951 1.0E-01
EXPLOSION DURING PACKAGING OF SOLID WASTES.

P-10 1 3 1.0E+00
CHRONIC DIRECT RADIATION TO WORKERS ENGAGED IN PACKAGING OF WASTES OR PROCESSING.

P-11 1 2 1.0E-03
CHRONIC DISCHARGE TO ATMOSPHERE OF RADIONUCLIDES FROM FACILITY OFF-GAS STACK DURING PACKAGING/PROCESSING OF WASTES.

P-12 1 2 1.0E-06
CHRONIC DISCHARGE TO ATMOSPHERE OF RADIONUCLIDES DURING INCINERATION OF WASTES.

P-13 1 2 1.0E-06
DISCHARGE OF RADIONUCLIDES THROUGH OFF-GAS STACK WITH FAILED FILTERS DURING PACKAGING/PROCESSING OF WASTES.

P-14 1 2 1.0E-03
DISCHARGE OF RADIONUCLIDES THROUGH OFF-GAS SYSTEM WITH FAILED FILTERS DURING WASTE INCINERATION.

P-15 2 3 1.0E+00 4 1.0E-02
THE PACKAGE CONTAINING WASTES INADEQUATELY DECONTAMINATED PRIOR TO RELEASE TO SHIPMENT.

P-16 2 3 1.0E+00 4 1.0E-02
IRRADIATED/CONTAMINATED USABLE ITEMS ARE REMOVED FROM WASTES DURING PACKAGING OR PROCESSING.

P-17 2 3 1.0E+00 6 1.0E+00
WORKER IS INJURED BY CONTAMINATED SHARP OBJECT DURING PACKAGING OR PROCESSING.

Table C-1. (continued)

```
S-1     2     3     1.0E+00 4     1.0E-02
A RUPTURED CONTAINER WITH LIQUID SUBSTANCE CAUSES SPILL TO CONTAMINATE
THE STORAGE OR HANDLING AREA.
S-2     2     3     1.0E+00 4     1.0E-03
A RUPTURED CONTAINER WITH VOLATILE SUBSTANCE CAUSES RELEASE TO
CONTAMINATE THE STORAGE OR HANDLING AREA.
S-3     2     3     1.0E+00 4     1.0E-01
A RUPTURED DRUM, CARTON OR BOX CONTAINING SOLIDS CAUSES RELEASE TO
CONTAMINATE THE STORAGE OR HANDLING AREA.
S-4     2     3     1.0E+00 6     1.0E+00
WORKER IS INJURED BY CONTAMINATED SHARP OBJECT PROTRUDING FROM RUPTURED

S-5     2     3     1.0E+00 2     2.0E-02
FIRE ERUPTS IN THE HANDLING OR STORAGE AREA CONTAINING COMBUSTIBLE
CARTONS, BOXES OR LOOSE BUNDLES.  FIRE IS ALLOWED TO BURN OUT
S-6     3     3     1.0E-01 2     2.0E-02 951  1.0E-01
FIRE ERUPTS IN THE HANDLING OR STORAGE AREA CONTAINING COMBUSTIBLE
CARTONS, BOXES OR LOOSE BUNDLES.  FIRE IS QUENCHED WITH WATER.
S-7     2     3     1.0E+00 2     1.0E-03
EXPLOSION IN THE HANDLING OR STORAGE AREA CONTAINING DRUMS OR BOXES
WITH VOLATILE SUBSTANCES OR LIQUID CONTAINERS.
S-8     2     3     1.0E+00 2     1.0E-03
EXPLOSION IN THE HANDLING OR STORAGE AREA CONTAINING DRUMS, BOXES OR
CARTONS FILLED WITH SOLIDS OR LOOSE BUNDLES.
S-9     2     3     1.0E+00 4     1.0E-02
IRRADIATED/CONTAMINATED USABLE ITEMS ARE REMOVED FROM WASTES.

S-10    1     3     1.0E+00
CHRONIC DIRECT RADIATION TO WORKERS ENGAGED IN THE HANDLING AND STORAGE
OF DRUMS, BOXES, CARTONS AND LOOSE BUNDLES.
S-11    1     2     1.0E-09
CHRONIC ESCAPE TO ATMOSPHERE OF RADIONUCLIDES DURING THE HANDLING AND
STORAGE OF DRUMS, BOXES, CARTONS AND LOOSE BUNDLES.
T-1     1     3     1.0E+00
CHRONIC DIRECT RADIATION TO WORKERS ENGAGED IN THE LOADING OF DRUMS,
BOXES, CARTONS AND LOOSE BUNDLES ON TRANSPORT VEHICLES.
T-2     1     2     1.0E+00
CHRONIC ESCAPE TO ATMOSPHERE OF RADIONUCLIDES DURING INSPECTION, PRIOR
TO LOADING ON TRANSP. VEHICLES, OF DRUMS, BOXES, CARTONS AND BUNDLES.
T-3     2     3     1.0E+00 4     1.0E-02
IRRADIATED/CONTAMINATED USABLE ITEMS ARE REMOVED FROM WASTE DURING
LOADING ON TRANSPORT VEHICLE.
T-4     2     3     1.0E+00 4     1.0E-02
A RUPTURED DRUM WITH LIQUID SUBSTANCE CAUSES SPILL TO CONTAMINATE THE
VEHICLE OR THE OVERPACK INTERIOR.
T-5     2     3     1.0E+00 4     1.0E-03
A RUPTURED DRUM WITH VOLATILE SUBSTANCE CAUSES RELEASE TO CONTAMINATE
THE VEHICLE OR THE OVERPACK INTERIOR.
T-6     2     3     1.0E+00 4     1.0E-01
A RUPTURED DRUM, CARTON OR BOX CONTAINING SOLIDS CAUSES RELEASE TO
CONTAMINATE THE VEHICLE OR THE OVERPACK INTERIOR.
T-7     2     3     1.0E+00 6     1.0E+00
WORKER IS INJURED BY CONTAMINATED SHARP OBJECT PROTRUDING FROM RUPTURED
DRUM, CARTON OR BOX DURING RECEIVING INSPECTION.
T-8     2     3     1.0E+00 2     2.0E-02
FIRE ERUPTS IN THE TRANSPORT VEHICLE OR IN THE OVERPACK CONTAINING
MATERIALS DURING TRANSPORT.  FIRE IS ALLOWED TO BURN OUT.
T-9     3     3     1.0E-01 2     2.0E-02 951  1.0E-01
FIRE ERUPTS IN THE TRANSPORT VEHICLE OR IN THE OVERPACK CONTAINING
MATERIALS DURING TRANSPORT.  FIRE IS QUENCHED WITH WATER.
T-10    2     3     1.0E+00 2     1.0E-03
EXPLOSION IN THE TRANSPORT VEHICLE OR IN THE OVERPACK CONTAINING DRUMS
OR BOXES WITH VOLATILE SUBSTANCES OR LIQUID CONTAINERS.
```

Table C-1. (continued)

```
T-11    2     3    1.0E+00 2    1.0E-03
EXPLOSION IN THE TRANSPORT VEHICLE OR IN THE OVERPACK CONTAINING DRUMS,
BOXES OR CARTONS FILLED WITH SOLIDS OR LOOSE BUNDLES.
T-12    3     3    1.0E+00 4    1.0E-02 951  1.0E-01
A TRANSPORT VEHICLE IS ABANDONED OR DESTROYED DURING TRANSIT.  LIQUID
SUBSTANCE IS SPILLED FROM DAMAGED CONTAINERS ONTO THE ROADWAY.
T-13    1     2    1.0E-03
A TRANSPORT VEHICLE IS DAMAGED OR DESTROYED DURING TRANSIT. VOLATILE
SUBSTANCE IS SPILLED FROM DAMAGED CONTAINERS ONTO THE ROADWAY.
T-14    1     951  1.0E-01
A TRANSPORT VEHICLE IS DAMAGED OR DESTROYED DURING TRANSIT. SOLID OR
LIQUID WASTES SPILLED ON THE ROADWAY ARE FLOODED BY RAINFALL.
T-15    2     3    1.0E+00 2    0.2E+00
A TRANSPORT VEHICLE IS DAMAGED OR DESTROYED IN TRANSIT.  SOLID OR LIQUID
WASTE SPILLED ON ROAD, DISPERSED BY HIGH VELOCITY WINDS.
T-16    2     3    1.0E+00 4    1.0E-02
IRRADIATED/CONTAMINATED ITEMS ARE REMOVED FROM WASTE SCATTERED AS A
RESULT OF TRANSPORT VEHICLE DAMAGE OR DESTRUCTION.
T-17    2     3    1.0E+00 6    1.0E+00
A WORKER IS INJURED BY CONTAMINATED SHARP OBJECT PROTRUDING FROM
RUPTURED CONTAINER DURING POST-ACCIDENT CLEANUP OF THE ROADWAY.
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APPENDIX D

NUCLIDE (WASTE) INVENTORY FILE TAPE12

APPENDIX D

NUCLIDE (WASTE) INVENTORY FILE TAPE12

This appendix contains a listing in Table D-1 of the nuclide (waste) inventory file on TAPE12. The inventories designated as WS-1 through WS-6 are the same as those published in NUREG/CR-1963, Volume 1[D-1].

The number appearing immediately on the right side of the inventory designator is the number of nuclides in the inventory. The number next on the right is the density of the waste, in kg/m^3. This density is used only for scenarios involving puncture wounds. On the right side of each nuclide, the specific activity is given, in Ci/m^3.

Reference

D-1. D. Lester et al., *System Analysis of Shallow-Land Burial*, NUREG/CR-1963, Vol. 1-3, March 1981.

Table D-1. Listing of the nuclide (waste) inventory file.

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          0         1         2
          1234567890123456789012345

THIS IS AN ECHO OF TAPE 12

  1       WS-1            1    480.
  2       CO60      .3000E+04
  3       WS-2           33    680.
  4       CR51      .1820E+00
  5       CO58      .1820E+00
  6       FE55      .1820E+00
  7       ZN65      .9100E-02
  8       ZR95      .9100E-02
  9       RU106     .9100E-02
 10       SB124     .9100E-02
 11       SB125     .9100E-02
 12       EU152     .1820E-04
 13       EU154     .1820E-03
 14       EU155     .1820E-03
 15       SR90      .1820E-02
 16       CS137     .3770E+00
 17       MN54      .9100E-01
 18       CS134     .2080E+00
 19       H3        .2210E-01
 20       C14       .1040E-02
 21       NI59      .2600E-03
 22       TC99      .2600E-03
 23       I129      .1300E-04
 24       CS135     .1300E-04
 25       NP237     .1300E-04
 26       PU238     .1690E-04
 27       PU239     .1820E-04
 28       PU240     .2600E-04
 29       PU241     .7020E-02
 30       PU242     .7280E-02
 31       AM241     .1690E-03
 32       AM242M    .5200E-04
 33       AM243     .1300E-04
 34       CM242     .1170E-03
 35       CM243     .1300E-04
 36       CM244     .7800E-04
 37       WS-3            6    480.
 38       FE55      .1368E+00
 39       CO60      .1243E+01
 40       NI63      .2405E+01
 41       NI59      .1292E-01
 42       C14       .1140E-02
 43       NB94      .1520E-03
 44       WS-4           33   1400.
 45       CR51      .4480E+01
 46       CO58      .4480E+01
 47       FE55      .4480E+01
 48       ZN65      .2240E+00
 49       ZR95      .2240E+00
 50       RU106     .2240E+00
 51       SB124     .2240E+00

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          0         1         2
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 52       SB125     .2240E+00
 53       EU152     .4480E-03
 54       EU154     .4480E-02
 55       EU155     .4480E-02
 56       SR90      .4480E-01
 57       CS137     .9280E+01
 58       MN54      .2240E+01
 59       CS134     .5120E+01
 60       H3        .5440E+00
 61       C14       .2560E-01
 62       NI59      .6400E-02
 63       TC99      .6400E-02
 64       I129      .3200E-03
 65       CS135     .3200E-03
 66       NP237     .3200E-03
 67       PU238     .4160E-03
 68       PU239     .4480E-03
 69       PU240     .6400E-03
 70       PU241     .1728E+00
 71       PU242     .1792E+00
 72       AM241     .4160E-02
 73       AM242M    .1280E-02
 74       AM243     .3200E-03
 75       CM242     .2880E-02
 76       CM243     .3200E-03
 77       CM244     .1920E-02
 78       WS-5            4    570.
 79       H3        .1235E+00
 80       C14       .3900E-02
 81       S35       .9100E-03
 82       I125      .1690E-02
 83       WS-6           44    660.
 84       H3        .1200E+00
 85       C14       .3800E-02
 86       S35       .8600E-03
 87       CR51      .4300E+00
 88       MN54      .2500E+00
 89       FE55      .4300E+00
 90       CO58      .4300E+00
 91       CO60      .1300E+01
 92       NI59      .1300E-01
 93       NI63      .2400E+01
 94       ZN65      .2000E-01
 95       SR90      .4800E-02
 96       NB94      .1400E-03
 97       ZR95      .2000E-01
 98       TC99      .3200E-04
 99       RU106     .2000E-01
100       SB124     .5000E-02
101       SB125     .5000E-02
102       I125      .1500E-02
103       I129      .6400E-05
104       CS134     .4800E+00
105       CS135     .3200E-04

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          0         1         2
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106       CS137     .8600E+03
107       CE144     .2600E-01
108       EU152     .4800E-04
109       EU154     .4800E-03
110       EU155     .4800E-03
111       RA226     .1150E-03
112       TH230     .7100E-04
113       TH232     .8400E-05
114       U235      .3200E-04
115       U238      .7100E-03
116       NP237     .4600E-07
117       PU238     .3200E-03
118       PU239     .4300E-04
119       PU240     .6700E-04
120       PU241     .1650E-01
121       PU242     .2400E-06
122       AM241     .3000E-04
123       AM242M    .1600E-05
124       AM243     .2100E-05
125       CM242     .2500E-02
126       CM243     .6000E-06
127       CM244     .1900E-03

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APPENDIX E

PROBABILITY ASSIGNMENTS CONTAINED IN TAPE97

APPENDIX E

PROBABILITY ASSIGNMENTS CONTAINED IN TAPE97

Tentatively, probabilities or frequencies for the events leading to radioactive releases have been assigned. These are tabulated in Table E-1 where the material is categorized according to the type of event appearing in the first column. For each event type, the information source, upon which the probability or frequency is based or deduced, is given. One may observe that in eight cases, the information source is subjective judgment. All probabilities and frequencies are, of course, subject to revision.

Also, there is tabulated an error factor (EF) for each probability or frequency that is used to set an upper or lower bound according to whether the EF is used as a multiplier or divisor. Note that the use of the EF implies that the logarithm of probability is a random variable. Where data were available, the bounds thus computed are estimates of 90% (double-sided) confidence bounds (assuming the Gaussian distribution of the logarithm of probability). In most cases, however, the EF is a subjective judgment of what would be reasonable and conservative for 90% confidence bounds. (In this context, conservative means that the computed upper bound radioactive release is larger than that resulting when data are available. For example, the vehicle accident EF of 12 yields an upper bound of about 24 accidents per year for a single reference site as opposed to an expected number of about 2.)

The rationale of some of the assignments is now discussed in more depth. For example, chronic events always exist during the operational phase and, therefore, are assigned unit probability. Typical of such events is direct radiation.

During the postburial administrative period and/or the postburial unrestricted use period, some events are considered inevitable; thus, each is assigned unit probability. Such events include surface water intrusion, scavenger intrusion, farming intrusion, and pasturage intrusion. The former of these always occurs to some extent while no effort is made to prevent the latter three during the unrestricted-use period. Subsidence is considered inevitable during the administrative control period for unsolidified waste (a conservative assumption). However, the probability for washout during a 500-year unrestricted-use period is assigned 0.11 in order to account for a crash of a small aircraft that causes damage to one or more trench covers.

With respect to events with subjective evaluations, those considered highly unlikely because of licensing requirements were assigned frequencies on the order of 10^{-6}. Those considered unlikely were assigned frequencies on the order of 10^{-4}. Washout of solidified waste during the administrative control period was assigned the same frequency as an earthquake opening a trench, since the latter event can initiate the former one. The removal of a contaminated item from the facility was assigned a frequency of 1.0/year based on the assumption that one person could be sufficiently tempted each year despite warnings and work rules. The error factor for this theft event allows for the participation of up to 10 persons. For the joint frequency of a theft and a truck accident, a reduction in theft frequency to 0.1 is made because usable items will not be uncovered in most accidents.

The frequency of a puncture wound is taken as that for nonfatal lost time accidents in municipal refuse collection and disposal as reported to the National Safety Council for the years 1970 and 1971 (References E-2 and E-3). The frequency of fire on board a truck during the arrival phase is based on the occurrence of one similar event during the operations at 22 Atomic Energy Commission jurisdictions during 25 years (Reference E-4). The remaining frequencies with cited references are either derived in a similar fashion or are taken directly from the references. In the latter case, the frequencies are judged to be reasonable. All the above information is entered in TAPE97.

Table E-1. Probability estimates for scenarios

Type of Event	Activity Phase	Scenario Description	Probability or Frequency Estimate	Error Factor	Reference Used to Derive
Chronic	Arrival	A-10, -11	1 (for each phase)	—	By definition
	On-Site	B-2, -11, -12			
	Trench	C-7, -8			
	Backfill	D-2, -11			
	Packaging	P-2, -10, -11, -12			
	Interim	S-10, -11			
	Transportation	T-1, -2			
Surface Water Intrusion	Maintenance	E-2	1.0 (for phase)	—	E-11, Inevitable
	Unrestricted Use	F-2	1.0 (for phase)	—	E-11, Inevitable
Scavenger Intrusion	Maintenance	E-3	1E-4/y (unlikely)	30	E-11, Subjective
	Unrestricted Use	F-3	1.0 (for phase)	—	E-11, Inevitable
Farming Intrusion	Unrestricted Use	F-4	1.0 (for phase)	—	E-11, Inevitable
Pasturage Intrusion	Unrestricted Use	F-5	1.0 (for phase)	—	E-11, Inevitable
Washout or Subsidence					
Unsolidified	Maintenance	E-1	1.0/Phase	10	E-10, Subjective
Solidified	Maintenance	E-1	1E-3/y	10	E-10, Subjective
	Unrestricted Use	F-1	0.11 (for 500 years)	1.1	Attachment 1
Earthquake Opens Trench	Unrestricted Use	F-8	1E-3/y	10	E-7, Attachment 3
Animal Intrusion	Open Trench	C-6	1.0/each phase	—	Inevitable
	Maintenance	E-4			
	Unrestricted Use Period	F-6			
Explosion Aboard Truck	Arrival	A-7, -8	1E-6/y (highly unlikely)	100	Subjective
Ruptured Liner	On-Site	B-1	3E-6/y (highly unlikely)	65	E-1
	Backfill	D-1			
Explosion in Waste	On-Site	B-9, -10	1E-6/y (highly unlikely)	100	Subjective
	Backfill	D-9, -10			
	Packaging	P-8, -9			
	Interim Storage	S-7, -8			
	Transportation	T-10, -11			
Long Term Flooding	Unrestricted Use	F-7	1E-4/y (unlikely)	30	Subjective, Site Dependent. However, see Attachment 2.
Removal of Item from Facility	Arrival	A-9	1.0/y	10	Subjective (one per year)
	On-Site	B-14			
	Trench	C-5			
	Packaging	P-16			
	Interim	S-9			
	Transportation	T-3			
Theft After Truck Accident	Transportation	T-16	7E-5/truck-y (O.1) (7E-4)	120	E-2, -5, Subjective
Puncture Wound	Arrival	A-4, T-7	0.2/person-y	2	E-2, -3
	Packaging	P-17			
	Interim Storage	S-4			
	Shipping	T-7			
Truck Accident and Puncture Wound (400 Mile Trip)	Transportation	T-17	1.4E-4/truck-y	20	E-2, -5

Table E-1. (continued)

Fire Aboard Truck	Arrival	A-5, -6	0.002/y	10	E-4
Ruptured Drum	Arrival On-Site Backfill Packaging Interim Storage Transportation	A-1, -2, -3 B-3, -4, -5, -6 D-3, -4, -5, -6 P-3, -4, -5 S-1, -2, -3 T-4, -5, -6	0.001/drum-y	5	E-1
Fire in Waste	On-Site Trench Backfill Packaging Interim	B-7, -8 C-1, -2 D-7, -8 P-6, -7 S-5, -6	0.4/y	2	E-9
Trench Flooded	Open Trench	C-3	0.1/y (site dependent)	4	E-9
Dispersal by High Wind	Open Trench	C-4	1E-3/y	10	Attachment 4
Vehicle Accident	Transportation	T-12, -13, -14	7E-4/truck-y (1.7E-6/mile) x (400 mile)	12	E-5
Vehicle Accident and High Wind	Transportation	T-15	7E-7/truck-y	120	E-5, Attachments 4 and 5.
Fire Aboard Truck	Transportation	T-8, -9	0.0002/truck-y (400 mile trip)	10	E-1
Vehicle Contaminated (One Way Trip)	On-Site	B-13	0.05/truck-y	5	Subjective
Container Contaminated	Packaging	P-15	2E-3/container-y	25	E-6
Cask Mishandled	Packaging	P-1	1E-3/cask-y	10	E-6, -1
Off-Gas Release, Processing	Packaging	P-13	6E-5/y	10	E-8
Off-Gas Release, Incineration	Packaging	P-14	6E-5/y	10	E-8

ATTACHMENT 1

Aircraft Hazard

A crash of an aircraft into a low-level waste (LLW) disposal site is a potential initiator of radionuclide releases during the 500-year unrestricted-use period. For example, a crash of a sufficiently large airplane, such as a commercial airliner, could cause a crater that penetrates into the buried waste below the surface. The crash itself could eject radionuclides into the atmosphere. Furthermore, the LLW would be open to water intrusion if the damage to the trench caps were not repaired. As another example, the crash of a small, general aviation airplane could scar one or more trench caps and initiate water erosion. Eventually, rainwater would enter the disposed LLW. The purpose of this section is to estimate the frequency of such an initiating event so that subsequent evaluation of the radiological hazard may be made.

During the period 1970-77, certificated and supplemental air carriers experienced 342 accidents.[E-12] This number excludes foreign carrier accidents in the United States (U.S.) and all military accidents. The average annual number of accidents is 42.75 and the sample standard deviation is 10.4. Many of these accidents occur in the immediate vicinity of an airport. An LLW site should not be sited near an airport in order to minimize the hazard. We estimate the fraction of accidents in the vicinity of an airport using data on "Notable Aircraft Disasters."[E-13] In the period 1953-80, 75 such events occurred. From the brief narrative given, 27 are apparently close to an airport; that is, about 36%. This factor is used to adjust the average annual number of accidents to 27.4 away from airports, with a corresponding change in standard deviation to 6.7. We now use the total U.S. land area (7.7E + 12 m^2) to estimate an areal crash frequency of 3.6E-12 (y/m^2). A typical LLW site would occupy about 6E + 05 m^2. We use the Poisson probability function now to estimate the probability of at least one crash of a large aircraft onto an LLW site in the 500-year unrestricted-use period:

$$\text{Pr(crash of large ship)} = 1 - e^{-(3.6E\text{-}12)(6E+05)(500)}$$
$$= 1.1E\text{-}03$$

with the sample standard deviation being 0.3E-03.

During the period 1970-77, general aviation experienced 35 012 accidents (Reference E-12). Using the same reduction factor for air carriers to estimate those accidents away from airports yields 22 408. The average annual number of such accidents is 2800 and the sample standard deviation is 128.

Following the same procedure as above yields:

estimated areal crash frequency—364E-12 (y/m^2)

Pr(at least one crash of small ship) = 0.11 (in 500-year period). Standard deviation = 0.005.

ATTACHMENT 2

Hurricane Hazard

Most people in the United States (U.S.) are familiar to some extent with storms known as hurricanes. Born at sea, these storms build up into huge heat engines and cover large areas, typically having a diameter of 370 km (200 miles). When these storms come inland, their high winds and heavy rainfall begin to dissipate; but not always before flooding and wind damage occur. Such a storm would be apt to produce serious damage to a low-level waste disposal site in its unrestricted-use period. The heavy rainfall and possible attendant flooding could wash out the trench caps and open the disposed waste to continuous water percolation and wind erosion. Some concern for the hurricane hazard is called for.

In the 81-year period 1900 to 1980, 22 major hurricanes have entered the U.S. through the Atlantic and Gulf coastlines.[E-14] (Such storms in the Pacific Ocean are called typhoons and apparently do not enter the contiguous U.S.) We judge that severe flooding could occur as far inland as 185 km (100 miles). The Atlantic and Gulf coastlines comprise 5.9 Mm (3700 miles). Assuming each hurricane had a diameter of 370 km (200 miles) when it crossed the coastline, the entire coastline has been exposed 1.2 times during 81 years. We assume the occurrence of major hurricanes follows the Poisson distribution function so that the Poisson rate is estimated as (22/81 year) or 0.27/y.[E-15] This yields a probability of one or more major hurricanes in one year of about 0.24. The expected number of hurricanes during the unrestricted-use period (500 years) is about 136. These would expose the entire coastline on the average 7.3 times (136 x 370 km/5.9 Mm).

ATTACHMENT 3

Earthquake Hazard

An earthquake, with enough magnitude to rupture the ground surface, would expose the buried low-level waste (LLW) to water and wind intrusion during the unrestricted-use period. Radionuclides would then be released to water and air pathways. Such an earthquake would have an intensity of VII or greater on the Mercalli Intensity Scale.[E-16] The acceleration of the ground would be 200 cm/s^2 (0.2 g) or larger[E-17] and would have to attain Richter magnitude of 5.5 or larger (Reference E-16). Such earthquakes are not uncommon in certain areas of the U.S., including Alaska, and Canada. Sixty-one earthquakes with an intensity of VIII or larger, have occurred in the two nations during the 334-year period of 1638 to 1971, inclusive (Reference E-16). Since the unrestricted-use period of an LLW disposal site is considered to be 500 years, there must be some concern about preventing earthquake-induced releases.

Perhaps the best way to minimize the effect of an earthquake is selecting the site judiciously. The tectonic plate patterns assist this selection. According to the Reference E-16, page 15, 95% of the total seismic energy of earthquakes around the world is released in the vicinity of ocean ridges and plate subduction zones (where plates are moving toward the interior of the earth).

Major earthquakes have occurred within the contiguous U.S. at points not apparently connected to a subduction zone. These were probably caused by tectonic plate movement, but the mechanisms are as yet unknown. These areas may be identified through historical records. One active region is along the western slopes of the Rocky Mountains from Arizona into Montana, the Intermountain Seismic Belt. There are relatively seismically quiet (aseismic) regions on either side of this belt; for example, the Snake River Plain, southeastern Utah, and parts of southern Arizona. There are two identifiable active zones underlying Nevada.[E-17] Both seem to connect with the active zones underlying California, and one seems to connect with the Intermountain Seismic Belt (Reference E-16, p. 175).

Continuing with historical records, major earthquakes have occurred in Missouri near the southern tip of Illinois (New Madrid and Charleston, Missouri). A major earthquake occurred at Charleston, South Carolina (Mercalli X). This writer concludes that the Missouri earthquakes may be tectonically related to the one at Charleston, South Carolina.

Four major earthquakes have occurred around the St. Lawrence River during the period 1663 to 1941. Two major earthquakes that may be tectonically related occurred in Massachusetts (1638 and 1755). In addition, two major earthquakes in New York and three others in Canada may also be related.

The figure in Reference E-16, p. 175, is a seismic risk map of the U.S. that was prepared for the Applied Technology Council in 1976 and 1977. This map shows four other areas of moderate seismic activity, accelerations up to 100 cm/s^2. The map also shows vast areas of no significant seismic risk which, in turn, translate to little or no radiological hazard due to an earthquake in the area of an LLW burial site. An eyeball estimate of the fractional area of the contiguous U.S. with little seismic risk is 60%. However, all of this land may not be suitable because of other constraints, such as potential volcanic activity.

The exposure of LLW, due to earthquakes, could conceivably result in a significant radiological hazard. The risk assessment of LLW disposal, therefore, requires an estimate of the probability of at least a Mercalli intensity of VII earthquake at a disposal site. Two independent sources of information are used to derive frequency estimates, one based on statistical modeling and the other on reported insurance premiums.

The TERA Corporation has developed a method for estimating the frequency of an earthquake with a specific acceleration or larger.[E-18,-17] The method is based on seismic measurements at a specific site. The occurrences of seismic events are modeled with a statistical distribution function, from which the desired frequency estimate is extracted. TERA studied the Idaho National Engineering Laboratory (INEL) on the Snake River Plain and predicted the return period of earthquake with peak acceleration of 0.2 g (Reference E-17). The predicted period was 2000 years with a 1 σ upper limit of 2800 years and a 1 σ lower limit of

900 years. These numbers translate to frequencies of 0.5×10^{-3}/y, 0.36×10^{-3}/y, and 1.1×10^{-3}/y, respectively.

TERA also demonstrated that method on two hypothetical cases said to be typical for low and high seismicity regions (Reference E-18). For the low seismicity region, similar to parts of the eastern U.S., the estimated frequency of the 0.2 g earthquake was about 10^{-4}/y. For the region of high seismicity, similar to Central American or southern Alaska, the estimated frequency was about 10^{-2}/y.

In Reference E-16 (p. 167), Bolt gives some insurance premium information dating from 1973. In all cases, there was a deductible amount before coverage took effect. For purposes of estimating earthquake frequency here, this deductible is assumed to represent damage from an earthquake with Mercalli intensity rating of VI or less. The premium for the insurance was assumed to contain a component for profit and overhead. Let this fraction be denoted by, f. The remainder of the premium, P, was assumed to represent an even proposition with respect to coverage, C, so that a return period, R, could be estimated by

$$R = C/(1 - f) P.$$

This calculation was done with f taken as 0.1 and 0.2 for aseismic regions in New Zealand, United Kingdom, France, Canada, and Australia. The computed frequencies, 1/R, ranged from 0.4×10^{-3} to 1.2×10^{-3}/y. Considering the assumptions made, this range seems reasonable. Insurance premium information is also given for two regions of high seismicity: highest zone in California and Newfoundland, Canada. The estimates here ranged from 1.6×10^{-3} to 2.7×10^{-3}/y. These are at least a factor of 2 greater than the low seismicity frequencies.

Based on the above considerations, it is possible to assign a frequency to the occurrence of a major earthquake for the purposes of probabilistic risk assessment of LLW burial. For the aseismic regions, the frequency may be taken as 10^{-3} (return period = 1000 years). An error factor, EF, may be taken as 10 for one standard deviation. (The error factor is defined such that the upper bound of the estimate, E, is 10E, while the lower bound is E/10.) The resulting bounds more than cover the uncertainty in Reference E-18 and the results using insurance premiums (returns period bounds: 100 years, 10,000 years).

Should the site to be assessed be one of high seismicity, an expected frequency of 10^{-2} is recommended, again with an error factor of 10. (Thus, the return period bounds are 10 years, 1000 years.)

ATTACHMENT 4

High Wind Hazard

When one examines the information on wind hazards,[E-19,-20,-21] one quickly becomes aware that relatively few tornadoes occur in the western states but that fast straight winds are frequent. The converse is generally true for those states east of the Rocky Mountains. Given this observation, the generic probability of damage due to high wind velocity, applicable to the contiguous United States (U.S.), should be the sum of probabilities for straight winds and tornadoes. Assuming that 161 km/h (100 mile/h) is a threshold velocity for wind-induced damage to buildings and trucks, the references, especially E-19, show that the return periods cluster in the order-of-magnitude of 1000. A few return periods are an order-of-magnitude lower, and a few are an order-of-magnitude higher. An error factor of 100 encompasses all 19 sites in the U.S. covered in Reference E-19. These observations lead to a generic high wind frequency of 0.001/y with an error factor of 100 to represent two standard deviations. (The error factor for one standard deviation is 10.) The lognormal distribution function is assumed.

ATTACHMENT 5

Truck Accident Probability

Motor transportation accident rates for 1977 are published in Reference E-3, p. 58. The data for three types of vehicles we consider representative of those that carry low-level waste (LLW) are reproduced here (Table E-2).

From these numbers, others may be derived as in Table E-3.

Table E-2. Accident rates for intercity carriers

Type of Vehicle	Vehicle Miles (thousands)	Accident Rate Per Million Miles	Number of Vehicles
Common carrier	1 350 643	3.07	9 408
Private carrier	270 321	4.34	3 920
Contract carrier	33 248	4.63	410
Combined	1 654 212	3.31	13 738

Table E-3. Truck accident probabilities

	Probability of Accident	
Type of Vehicle	Per 1000 Miles	Per Vehicle Day
Common carrier	0.0031	0.9E-03
Private carrier	0.0043	0.8E-03
Contract carrier	0.0046	3.1E-03
Combined	0.0033	1.1E-03

References

E-1. W. E. Prout et al., *Management of Radioactive Waste Gases from the Nuclear Fuel Cycle Volume II Evaluation of Storage/Disposal Alternatives*, NUREG/CR-1546, DPST-81-1, Vol. II, January 1982.

E-2. National Safety Council, *Work Survey Rates 1972 Edition*, Chicago, National Safety Council, 1972.

E-3. National Safety Council, *Accident Facts 1978 Edition*, Chicago: National Safety Council, 1978.

E-4. U.S. Atomic Energy Commission, *Operational Accidents and Radiation Exposure Experience*, Washington, D.C.: Government Printing Office, December 1968.

E-5. L. B. Shappert et al., "Probability and Consequences of Transportation Accidents Involving Radioactive-Material Shipments in the Nuclear Fuel Cycle," *Nuclear Safety, 14*, 6, November through December 1973, pp. 597-604.

E-6. S. W. Heaberlin, *Plutonium Transport Package Closure Survey*, BNWL-2288, April 1978, pp. 6-7.

E-7. N. D. Cox et al., *Low-Level Waste Risk Methodology Development*, NUREG/CR-3210, EGG-2247, April 1983.

E-8. U.S. Nuclear Regulatory Commission, *Reactor Safety Study*, WASH-1400, Appendix II, 1975, pp. II-579.

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APPENDIX F

PARAMETER AND UNCERTAINTY VALUES FOR FACTORS IN TABLE 8

APPENDIX F

PARAMETER AND UNCERTAINTY VALUES FOR FACTORS IN TABLE 8

This appendix (Table F-1) provides 29 parameter values and uncertainty standard deviations for factors listed in Table 8. Thirteen of the 29 factors have arbitrarily been assigned standard deviations equal to 10% of the nominal values. This was an expediency to enable an early test of the program package.

Table F-1. Uncertainty factor nominal values and statistical properties in the example problem

	Parameter	Program Symbol	Nominal Value	Standard Deviation	Parameter Source	Uncertainty Source
1	Rainfall time, (h)	TIMWET	480	10%	(site specific)	None (site specific)
2	Stack energy (W)	SQ	29×10^6	10%	(site specific)	None (site specific)
3	Wind frequency array	U,F	See Section 6.1	—	(site specific)	None (site specific)
4	Crossrange standard deviation (m)	SIGY	See Reference F-1 Vol. 2, pp. 6-13	10%	F-1	None
5	Vertical standard deviation (m)	SIGZ		10%	F-1	None
6	Deposition velocity (m/s)	VD	0.01	10%	F-1	None
7	Stack height (m)	SH	5	1.6	(site specific)	None (site specific)
8	Annual rainfall (m)	RF	0.2	10%	(site specific)	None (site specific)
9	Wet period rainfall rate (m/s)	RAIN	3.2×10^{-7}	10%	(site specific)	None (site specific)
10	Breathing rate (m^3/y)	BR			F-2	F-3
	Child		8 320	1 930		
	Teen		12 180	3 150		
	Adult		10 160	2 070		
11	Water use (L/y)	WU			F-2	F-4
	Child		515	60		
	Teen		455	45		
	Adult		675	85		
12	Fruit, veg., grain consumption, MAXI (kg/y)	FVG			F-2	F-5
	Child		685			
	Teen		885	10%		
	Adult		840			
13	Leafy veg. consump. MAXI (kg/y)	VL			F-2	F-4, F-5
	Child		26			
	Teen		42	10%		
	Adult		64			

Table F-1. (continued)

	Parameter	Program Symbol	Nominal Value	Standard Deviation	Parameter Source	Uncertainty Source
14	Milk consumption MAXI (L/y)	XMILK			F-2	F-5
	Child		330	40		
	Teen		400	70		
	Adult		310	40		
15	Meat consumption MAXI (kg/y)	XMEAT			F-2	F-5
	Child		65			
	Teen		140	10%		
	Adult		210			
16	Grain consumption Avg. (kg/y)	UGRAIN			F-2	F-4, F-5
	Child		295			
	Teen		380	10%		
	Adult		355			
17	Milk consumption Avg. (L/y)	UMILK			F-2	F-3
	Child		170	40		
	Teen		200	70		
	Adult		110	40		
18	Meat consumption Avg. (kg/y)	UMEAT			F-2	F-4, F-5
	Child		55			
	Teen		85	10%		
	Adult		135			
19	Veg. consumption Avg. (kg/y)	UVEG			F-2	F-4, F-5
	Child		6			
	Teen		10	10%		
	Adult		15			
20	Leafy veg. crop density (kg/m^2)	CDLV	2.1	60%	F-2	F-4
21	Areal grass density (kg/m^2)	AGD	0.7	80%	F-2	F-4
22	Grass consumption, steer (kg/d)	QF	64	10	F-2	F-4
23	Beef dressout fraction	FD	0.58	0.01	F-1	F-6
24	Beef slaughter fraction	FS	0.36	0.03	F-1	F-7
25	Cow weight (kg)	WT	471	26	F-6	F-6
26	Milk per cow (L/y)	QM	5 296	630	F-6	F-6
27	Soil pool areal density (kg/m^2)	POOL	211	12%	F-2	F-4
28	Crop deposition fraction	RI	0.47	28%	F-2	F-4
29	Plume model lack-of-fit	—		30%	F-1	F-8

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APPENDIX G

UNCERTAINTIES FOR SOME FACTORS NOT INCLUDED IN TABLE 8

APPENDIX G

UNCERTAINTIES FOR SOME FACTORS NOT INCLUDED IN TAPLE 8

The procedure to follow in order to add uncertainty factors other than those in Table 8 to an analysis has been described in the text of this manual. The purpose of this appendix is to provide uncertainty information gleaned from the literature for certain other factors. It is hoped this information, presented in Table G-1, will be useful; but no claim is made for coverage of all important factors.

Table G-1. Suggested uncertainties for factors not in Table 8

Computer Subroutine	Parameter	Standard Deviation: Percent of Mean	Standard Deviation: Error Factor	Distribution Type	Source
DOSET	Resuspension factor, DUM when KK = 4.	—	6	Lognormal	G-1
PREDOS	Food concentration factor, PBIV	—	10	Lognormal	G-2
	Milk concentration factor, PFM	—	2	Lognormal	G-2
	Meat concentration factor, PFF	—	2	Lognormal	G-2
	Deposition velocity, VD1	80	1.8	Lognormal	G-3
	Dose factors, DOSFAC	—	5	Lognormal	G-4
BURYIT	Waste curie content, INVET	30	—	Normal	G-1
AQUIFER	Inverse equilibrium constant	—	—	—	G-5
	(Inverse retardation factor) RNWV	—	4	Lognormal	G-6
	Aquifer water velocity, VZ	—	4	Lognormal	G-6, G-7
	Axial dispersion coefficient, EI	10	—	Normal	G-8
UNSAT	Sorption distribution coefficient, XD	—	4	Lognormal	G-6
	Soil density, DNSTY	5	—	Normal	G-9
	Hydraulic conductivity, E	70	—	Normal	G-10
	Water content, W	9	—	Normal	G-9
ATMOS	Wind speed, U	45	—	Normal	G-11
	Rainout coefficient, RC	—	10	Normal	
	Plume rise lack-of-fit, BUOY	18	—	Normal	G-12
EROSIO	Percentage of eroded soil which remains suspended, SAIR	100	—	Normal	G-1
NOT USED DIRECTLY	Porosity	10	—	Normal	G-10
	Cation exchange capacity	35	—	Normal	G-8

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APPENDIX H

REFERENCE SITES

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REFERENCE SITES

Five geographic regions were selected as being representative of those in the United States where low-level waste may be disposed. These five regions are designated as northeast, southeast, midwest, northwest, and southwest. Tables H-1 through H-6 provide most of the information needed to use the predictive program BURYIT for estimating the dose commitments resulting from a low-level shallow-land burial site. Much of the information was gleaned from the sources listed in the references for this appendix. However, the reader should recognize that some data were not available, so that subjective judgments were required. Thus, the results from BURYIT using these tabulations should be used for relative comparisons.

Table H-1 contains input for the EROSIO subroutine that is placed on TAPE8. The dimensions of the site correspond to those for the disposal of 1 million m^3 of waste. The percentage of soil greater in size than 0.84 mm and the percentage of soil lofted that remains suspended are rough estimates. The mean annual temperature of the northeast site is less than 10°C, but BURYIT cannot handle such a number. Hence, the MAT at the northeast site was set arbitrarily at 10.1°C. At all sites, the field angle was set arbitrarily perpendicular to the prevailing wind direction.

Table H-2 contains wind data for TAPE9. Only the average annual wind speed is given for each site. The stability class frequency numbers should be considered as preliminary. The release height, SH, and the stack energy release rate, SQ, should be selected by the modeler to suit his/her needs.

Table H-3 contains geology and rainfall data for input on TAPE10. Note that the actual number of distinct soil layers is given rather than the divisions needed for the computer model (variable JK). The user must select JK in accordance with the accuracy desired from the solution of the differential equation. This selection also affects the soil layer containing the waste, variable IN. The entries for moisture contents at layer boundaries pertain to the actual soil layers. The soil density entries pertain to the actual soil layers. All other data in Table H-3 should be clear from Section 5.2.2.3.

Table H-4 contains aquifer data for input on TAPE11. The variable FLOWR pertains to the dilution water into which the aquifer empties. All the other variables should be clear.

Table H-5 contains input data needed for TAPE14. Section 5.2.2.1 defines the variables.

Table H-6 contains the agriculture and population input data for TAPE15. The variables FVA and PRODUC should be regarded as rough estimates. The population values, IPOP, pertain to a single compass segment of 22.5 degrees.

Table H-1. Reference site data needed for BURYIT/ANALYZ—erosion data, TAPE8

			Reference Site				
Input Parameter	Description	Units	Northeast	Southeast	Midwest	Northwest	Southwest
IK1	Erodibility control	—	3	3	3	3	3
PAG84	Percent of soil greater than 0.84 mm	%	20	40	10	25	25
IK3	Roughness control	—	2	2	2	2	2
MAT	Mean annual temperature	°C	10.1	18	11	12	19
ANGL	Field angle	Degrees	157.5	112.5	90	22.5	135
ANGWND	Direction from which wind blows	Degrees	247.5	202.5	180	292.5	225
HTBR	Barrier height	m	0	0	0	0	0

Table H-1. (continued)

Input Parameter	Description	Units	Reference Site: Northeast	Southeast	Midwest	Northwest	Southwest
FW	Field width	m	550	550	550	550	550
FL	Field length	m	917	917	917	917	917
R	Vegetative cover	kg/m^{-2}	1.6	1.6	1.6	1.6	1.6
CK5	Control	—	1	1	1	1	1
CK8	Control	—	0	0	0	0	0
CK11	Control	—	0	0	0	0	0
CK13	Control	—	0	0	0	0	0
SAIR	Percent soil lofted that remains suspended	%	20	20	20	20	20
KLSP	Percent knoll slope	%	3.	3.	3.	3.	3.
RDGHT	Ridge height	m	0.46	0.46	0.46	0.46	0.46
RDGSP	Ridge spacing	m	10.7	10.7	10.7	10.7	10.7

Table H-2. Reference site data needed for BURYIT/ANALYZ—wind data, TAPE9

Input Parameter	Description	Units	Reference Site: Northeast	Southeast	Midwest	Northwest	Southwest
SH	Release height—modeler's choice	—	0	0	0	0	0
SQ	Stack energy release rate—modeler's choice	W	0	0	0	0	0
NU	Number of entries in wind speed vector (10 max)	—	1	1	1	1	1
KS	Option for one wind speed or all	—	0	0	0	0	0
NS	Number of stability categories (7 max)	—	7	7	7	7	7
U	Wind speed vector	m/s	4.6	3.4	4.7	4.5	3.8
F	Wind speed—stability class frequency	—					
	(A)		0	0.212	0.04	0.0	0
	(B)		0	0.118	0.02	0.30	0
	(C)		0.33	0.171	0.07	0.14	0.33
	(D)		0.34	0.284	0.33	0.0	0.34
	(E)		0.33	0.172	0.54	0.32	0.33
	(F)		0	0.035	0	0.24	0
	(G)		0	0.008	0	0.0	0

Table H-3. Reference site data needed for BURYIT/ANALYZ—geology and rainfall data, TAPE10

			Reference Site				
Input Parameter	Description	Units	Northeast	Southeast	Midwest	Northwest	Southwest
	Actual number of distinct soil layers at site	—	1	3	2	6	2
ND	Number of entries in the hydraulic conductivity and pressure head arrays (max = 52)	—	32	26	32	33	10
	Number of the actual soil layer initially containing the waste	—	1	2	2	1	1
DELW	Water content increment	Volume Fraction	0.0078	0.02	0.012	0.009	0.05
RAIN	Rainfall rate during wet period	m/s	9.4E-08	1.3E-07	8.9E-08	1.6E-08	5.1E-08
DRY	Evapotranspiration during dry period	m/s	-0.18E-7	-0.19E-7	-0.19E-7	-0.21E-8	-0.16E-7
DD	Actual soil layer boundaries, starting with 0	m					
	DD (1)		0	0	0	0	0
	(2)		12	1.2	3.06	14.94	10
	(3)			7.3	12	37.00	250
	(4)			13.7		41.00	
	(5)					43.00	
	(6)					47.00	
	(7)					60.05	
P	Pressure head array (ND entries)	m					
	P (1)		-1.97	-8.16	-1.97	-1.48	-408
	(2)		-1.97	-7.65	-1.97	-1.48	-188
	(3)		-1.97	-7.14	-1.97	-1.48	-24
	(4)		-1.97	-6.63	-1.97	-1.48	-7
	(5)		-1.97	-6.12	-1.97	-1.48	-3
	(6)		-1.97	-5.61	-1.97	-1.48	-1.6
	(7)		-1.97	-5.10	-1.97	-1.48	-0.9
	(8)		-1.97	-4.59	-1.97	-1.0	-0.02
	(9)		-1.97	-4.08	-1.97	-0.84	0.0
	(10)		-1.97	-3.57	-1.97	-0.71	0.1
	(11)		-1.97	-3.06	-1.97	-0.61	
	(12)		-1.97	-2.55	-1.97	-0.55	
	(13)		-1.97	-2.04	-1.97	-0.49	
	(14)		-1.73	-1.53	-1.73	-0.45	
	(15)		-1.57	-1.07	-1.57	-0.42	
	(16)		-1.43	-0.90	-1.43	-0.39	
	(17)		-1.33	-0.80	-1.33	-0.37	
	(18)		-1.23	-0.74	-1.23	-0.35	
	P (19)		-1.16	-0.63	-1.16	-0.33	
	(20)		-1.09	-0.63	-1.09	-0.31	
	(21)		-1.04	-0.58	-1.04	-0.30	
	(22)		-1.00	-0.53	-1.1	-0.28	
	(23)		-0.96	-0.35	-0.96	-0.27	
	(24)		-0.92	-0.18	-0.92	-0.264	
	(25)		-0.89	0.0	-0.89	-0.258	
	(26)		-0.87	0.01	-0.87	-0.246	
	(27)		-0.85		-0.85	-0.233	
	(28)		-0.82		-0.83	-0.221	
	(29)		-0.79		-0.79	-0.209	
	(30)		-0.73		-0.73	-0.203	
	(31)		0.0		0.0	-0.0625	
	(32)		0.1		0.1	0.0	
	(33)					0.1	

Table H-3. (continued)

Input Parameter	Description	Units	Reference Site: Northeast	Southeast	Midwest	Northwest	Southwest
E	Hydraulic conductivity array (ND entries)	m/s					
	E (1)		8.8E-12	4.5E-8	2.6E-7	2.2E-10	3E-14
	(2)		8.8E-12	4.5E-8	2.6E-7	2.2E-10	2E-13
	(3)		8.8E-12	4.5E-8	2.6E-7	2.2E-10	3.3E-11
	(4)		8.8E-12	4.5E-8	2.6E-7	2.2E-10	6.6E-10
	(5)		8.8E-12	4.5E-8	2.6E-7	2.2E-10	5.5E-9
	(6)		8.8E-12	4.5E-8	2.6E-7	2.2E-10	2.9E-8
	(7)		8.8E-12	4.5E-8	2.6E-7	2.2E-10	1.1E-7
	(8)		8.8E-12	4.5E-8	2.6E-7	1.3E-9	3.4E-7
	(9)		8.8E-12	4.5E-8	2.6E-7	3.1E-9	9.2E-7
	(10)		8.8E-12	4.5E-8	2.6E-7	6.6E-9	9.2E-7
	(11)		8.8E-12	4.5E-8	2.6E-7	1.3E-8	
	(12)		8.8E-12	4.5E-8	2.6E-7	2.1E-8	
	(13)		8.8E-12	4.5E-8	2.6E-7	3.7E-8	
	(14)		1.2E-11	4.5E-8	3.6E-7	5.6E-8	
	(15)		1.7E-11	4.6E-8	4.9E-7	7.8E-8	
	(16)		2.2E-11	5.8E-8	6.5E-7	1.1E-7	
	(17)		3.0E-11	7.9E-8	8.7E-7	1.4E-7	
	(18)		3.8E-11	1.1E-7	1.1E-6	1.8E-7	
	(19)		5.0E-11	1.5E-7	1.5E-6	2.2E-7	
	(20)		6.2E-11	2.0E-7	1.8E-6	3.0E-7	
	(21)		6.9E-11	2.9E-7	2.0E-6	4.0E-7	
	(22)		8.0E-11	4.1E-7	2.6E-6	4.8E-7	
	(23)		9.9E-11	4.1E-7	2.9E-6	5.9E-7	
	(24)		1.2E-10	4.1E-7	3.4E-6	6.5E-7	
	(25)		1.4E-10	4.1E-7	4.0E-6	7.3E-7	
	(26)		1.5E-10	4.1E-7	4.5E-6	9.1E-7	
	E (27)		1.8E-10		5.2E-6	1.2E-6	
	(28)		2.0E-10		5.8E-6	1.5E-6	
	(29)		2.2E-10		6.4E-6	1.9E-6	
	(30)		2.4E-10		7.1E-6	2.4E-6	
	(31)		2.6E-10		7.6E-6	2.6E-6	
	(32)		2.6E-10		7.6E-6	2.6E-6	
	(33)					2.6E-6	
W	Initial water content at each layer boundary	Fraction by Volume					
	W (1)		0.0936	0.300	0.144	0.054	0.089
	(2)		0.234	0.300	0.236	0.102	0.089
	(3)			0.300	0.360	0.185	0.40
	(4)			0.420		0.200	
	(5)					0.212	
	(6)					0.223	
	(7)					0.270	
HDRY	Pressure head which corresponds to WATL water content	m	-1.97	-1.27	-1.97	-1.48	-34.2
HWET	Pressure head which corresponds to WATH water content	m	0	0	0	0	0
WATL	Minimum water content (bound water)	Volume Fraction	0.0936	0.270	0.144	0.054	0.089
WATH	Maximum water content at soil saturation	Volume Fraction	0.234	0.420	0.360	0.270	0.40

Table H-3. (continued)

			Reference Site				
Input Parameter	Description	Units	Northeast	Southeast	Midwest	Northwest	Southwest
XD(I,LYR)	Distribution coefficients (K_d)	mL/g					
	(1) ^{3}H		0	0	0	0	0
	(2) ^{14}C		100	100	3	100	3
	(3) ^{35}S		100	100	100	100	100
	(4) ^{51}Cr		100	10	10	10	10
	(5) ^{54}Mn		100	10	10	10	10
	(6) ^{55}Fe		1500	150	800	150	400
	(7) ^{58}Co		1000	100	100	100	250
	(8) ^{60}Co		1000	100	100	100	250
	(9) ^{59}Ni		1000	100	500	100	250
	(10) ^{63}Ni		1000	100	500	100	250
	(11) ^{65}Zn		100	100	100	100	100
	(12) ^{90}Sr		20	2	10	2	5
	(13) ^{94}Nb		3000	100	1350	100	600
	(14) ^{95}Zr		100	100	100	100	100
XD(I,LYR) (continued)							
	(15) ^{99}Tc		1	0.1	1	0.1	1
	(16) ^{106}Ru		300	300	300	300	300
	(17) ^{124}Sb		3	3	3	3	3
	(18) ^{125}Sb		3	3	3	3	3
	(19) ^{125}I		1	0.1	0.1	0.1	1
	(20) ^{129}I		1	0.1	0.1	0.1	1
	(21) ^{134}Cs		200	20	100	20	50
	(22) ^{135}Cs		200	20	100	20	50
	(23) ^{137}Cs		200	20	100	20	50
	(24) ^{144}Ce		100	100	100	100	100
	(25) ^{152}Eu		1200	1200	1200	1200	1200
	(26) ^{154}Eu		1200	1200	1200	1200	1200
	(27) ^{155}Eu		1200	1200	1200	1200	1200
	(28) ^{226}Ra		50	50	50	50	50
	(29) ^{230}Th		1200	1200	1200	1200	1200
	(30) ^{232}Th		1200	1200	1200	1200	1200
	(31) ^{235}U		2100	2	1000	2	500
	(32) ^{238}U		2100	2	1000	2	500
	(33) ^{237}Np		700	70	70	70	170
	(34) ^{238}Pu		2000	200	1000	200	500
	(35) ^{239}Pu		2000	200	1000	200	500
	(36) ^{240}Pu		2000	200	1000	200	500
	(37) ^{241}Pu		2000	200	1000	200	500
	(38) ^{242}Pu		2000	200	1000	200	500
	(39) ^{241}Am		700	70	350	70	170
	(40) ^{242}Am		700	70	350	70	170
	(41) ^{243}Am		700	70	350	70	170
	(42) ^{242}Cm		700	70	350	70	170
	(43) ^{243}Cm		700	70	350	70	170
	(44) ^{244}Cm		700	70	350	70	170
CONCOF	Conductivity factors for correction of hydraulic conductivity (E) to the soil characteristics of a layer	Dimensionless					
	CONCOF(1)		1	1	1	1	1
	(2)			10	0.01	0.1E-02	12.5
	(3)			10000		0.1E-04	
	(4)					0.1E-05	
	(5)					0.1	
	(6)					1	
	(7)						

Table H-3. (continued)

Input Parameter	Description	Units	Northeast	Southeast	Midwest	Northwest	Southwest
			Reference Site				
DNSTY	Density of soil layer	kg/m^3					
	DNSTY (1)		1665	1600	1665	1500	1630
	(2)			1600	1720	1500	1460
	(3)			1500		1500	
	(4)					1500	
	(5)					1500	
	(6)					1500	
SOLFAC	Nuclide solubilities	Ci/m^3	Contained in text, Table 3.				

Table H-4. Reference site data needed for BURYIT/ANALYZ—aquifer data, TAPE11

Input Parameter	Description	Northeast	Southeast	Midwest	Northwest	Southwest
			Reference Site			
XZ	Length of aquifer (m)	500	500 (wells)	1250	2000	30 (wells)
EI	Axial dispersion coefficient (m^2/s)	1E-9	1E-9	1E-9	1E-9	1E-9
VZ	Velocity of aquifer (m/s)	6E-09	4E-08	2E-08	3E-07	3E-6
FLOWR	Flow rate (L/y)	3.1E+09	8.9E+09	2.7E+09	2.5E+09	7700 (one person)
RNWV	Inverse equilibrium constant—$1/K^a$					
	(1) ^{3}H*	1	1	1	1	1
	(2) ^{14}C*	1.0E-01	1.0E-01	1.0E-01	2.9E-03	1.0E-01
	(3) ^{35}S	2.9E-3	2.9E-3	2.9E-3	2.9E-03	2.9E-3
	(4) ^{51}Cr	2.9E-03	2.9E-2	2.9E-2	2.9E-02	2.9E-2
	(5) ^{54}Mn	2.9E-03	2.9E-2	2.9E-2	2.9E-02	2.9E-2
	(6) ^{55}Fe*	2.0E-04	4.0E-04	4.0E-04	2.0E-03	7.8E-4
	(7) ^{58}Co	2.9E-04	2.9E-3	2.9E-3	2.9E-03	1.2E-3
	(8) ^{60}Co*	2.9E-04	6.0E-04	6.0E-04	2.9E-03	1.2E-3
	(9) ^{59}Ni*	3.0E-04	6.0E-04	6.0E-04	2.9E-03	1.2E-3
	(10) ^{63}Ni*	3.0E-04	6.0E-04	6.0E-04	2.9E-03	1.2E-3
	(11) ^{65}Zn	2.9E-3	2.9E-3	2.9E-3	2.9E-03	2.9E-3
	(12) ^{90}Sr*	1.5E-02	2.8E-02	2.8E-02	1.2E-01	5.6E-2
	(13) ^{94}Nb*	1.0E-04	2.0E-04	2.0E-04	2.9E-03	4.7E-4
	(14) ^{95}Zr*	2.9E-3	2.9E-3	2.9E-3	2.9E-03	2.9E-3
	(15) ^{99}Tc*	2.0E-01	2.5E-01	2.5E-01	7.7E-01	3.3E-1
	(16) ^{106}Ru	1.E-3	1.E-3	1.E-3	1.0E-03	1.E-3
	(17) ^{124}Sb	1.E-1	1.E-1	1.E-1	1.0E-01	1.E-1
	(18) ^{125}Sb	1.E-1	1.E-1	1.E-1	1.0E-01	1.E-1
	(19) ^{125}I	2.E-01	7.E-01	7.E-01	7.E-01	2.E-1
	(20) ^{129}I*	2.E-01	7.E-01	7.E-01	7.E-01	2.E-1
	(21) ^{134}Cs	1.4E-03	1.4E-2	2.9E-03	1.4E-02	5.8E-3
	(22) ^{135}Cs*	1.4E-03	1.4E-2	2.9E-03	1.4E-02	5.8E-3
	(23) ^{137}Cs*	1.4E-03	1.4E-2	2.9E-03	1.4E-02	5.8E-3
	(24) ^{144}Ce	2.0E-3	2.9E-3	2.9E-3	2.9E-03	2.9E-3

Table H-4. (continued)

Input Parameter	Description	Northeast	Southeast	Midwest	Northwest	Southwest
			Reference Site			
	(25) ^{152}Eu	2.5E-4	2.5E-4	2.5E-4	2.5E-04	2.5E-4
	(26) ^{154}Eu	2.5E-4	2.5E-4	2.5E-4	2.5E-04	2.5E-4
	(27) ^{155}Eu	2.5E-4	2.5E-4	2.5E-4	2.5E-04	2.5E-4
	(28) ^{226}Ra	5.8E-3	5.8E-3	5.8E-3	5.8E-03	5.8E-3
	(29) ^{230}Th	2.5E-4	2.5E-4	2.5E-4	2.5E-04	2.5E-4
	(30) ^{232}Th	2.5E-4	2.5E-4	2.5E-4	2.5E-04	2.5E-4
	(31) ^{235}U*	1.0E-04	3.0E-04	3.0E-04	1.2E-01	5.8E-4
	(32) ^{238}U*	1.0E-04	3.0E-04	3.0E-04	1.2E-01	5.8E-4
	(33) ^{237}Np*	4.0E-04	8.0E-04	8.0E-04	4.2E-03	1.7E-3
	(34) ^{238}Pu*	1.4E-04	3.0E-04	3.0E-04	1.5E-03	5.8E-4
	(35) ^{239}Pu*	1.4E-04	3.0E-04	3.0E-04	1.5E-03	5.8E-4
	(36) ^{240}Pu*	1.4E-04	3.0E-04	3.0E-04	1.5E-03	5.8E-4
	(37) ^{241}Pu*	1.4E-04	3.0E-04	3.0E-04	1.5E-03	5.8E-4
	(38) ^{242}Pu*	1.4E-04	3.0E-04	3.0E-04	1.5E-03	5.8E-4
	(39) ^{241}Am*	4.0E-04	8.0E-04	8.0E-04	4.2E-03	1.7E-3
	(40) ^{242}Am*	4.0E-04	8.0E-04	8.0E-04	4.2E-03	1.7E-3
	(41) ^{243}Am*	4.0E-04	8.0E-04	8.0E-04	4.2E-03	1.7E-3
	(42) ^{242}Cm*	4.0E-04	8.0E-04	8.0E-04	4.2E-03	1.7E-3
	(43) ^{243}Cm*	4.0E-04	8.0E-04	8.0E-04	4.2E-03	1.7E-3
	(44) ^{244}Cm*	4.0E-04	8.0E-04	8.0E-04	4.2E-03	1.7E-3
NUMUC	Number of Nuclides in the inventory specified by the user's inventory choice.					

a $K = 1 + \frac{K_d \varrho}{\varepsilon}$

where

K_d = distribution coefficient

ϱ = density

ε = void fraction.

Table H-5. Reference site data needed for BURYIT/ANALYZ—BURYIT control, TAPE14

Input Parameter	Description	Reference Site Northeast	Southeast	Midwest	Northwest	Southwest
RF	Annual Rainfall (m/y)	1.04	1.20	0.77	0.16	0.11
EMEF	Emplacement efficiency in trench (m^3/m^3)	0.5	0.5	0.5	0.5	0.5
TIMWET	Time for the rain cycle (h)	3072	2664	2400	720	600
TIMCYC	Total time in one cycle of rain and dry periods (h)	8760	8760	8760	8760	8760
VOL	Volume of package (m^3)	—[a]	—[a]	—[a]	—[a]	—[a]
UD	Wind velocity of hypothetical cloud (m/s)	—[b]	—[b]	—[b]	—[b]	—[b]
DI	Diameter of hypothetical cloud (m)	—[a]	—[a]	—[a]	—[a]	—[a]

a. Modeler's choice.

b. Moderler's choice > 2.24.

Table H-6. Reference site data needed for BURYIT/ANALYZ—agriculture and population data, TAPE15

Input Parameter	Description	Reference Site Northeast	Southeast	Midwest	Northwest	Southwest
NR	Number of radial increments	6	6	6	6	6
RM	Distance to center of radial increments (m)					
	(1)	4 020	4 020	4 020	4 020	4 020
	(2)	12 070	12 070	12 070	12 070	12 070
	(3)	24 140	24 140	24 140	24 140	24 140
	(4)	40 230	40 230	40 230	40 230	40 230
	(5)	56 330	56 330	56 330	56 330	56 330
	(6)	72 420	72 420	72 420	72 420	72 420
BEEF	Number of beef cattle per unit area $(km)^{-2}$	1	4	9	3	1
COWS	Number of milk cows per unit area $(km)^{-2}$	9	1	2	2	0.05
FAGE	Age group fraction breakdown —					
	(1)	0.2	0.24	0.2	0.22	0.2
	(2)	0.12	0.16	0.12	0.16	0.12
	(3)	0.68	0.60	0.68	0.62	0.68

Table H-6. (continued)

Input Parameter	Description	Reference Site: Northeast	Southeast	Midwest	Northwest	Southwest
FVA	Fraction of area planted to leafy — vegetables	0.5	0.3	0.65	0.5	0.1
NCPY	Number of crops/y	1	1	1	1	1
PRODUC	Food crop production kg/(y - km^2)	14E + 05	9E + 05	13E + 05	1E + 05	23E + 05
IPOP	Population in each radial increment — (within 22.5 degrees)					
	(1)	210	130	190	0	2
	(2)	1 280	510	310	1	18
	(3)	4 600	2 250	1 740	365	60
	(4)	7 600	7 810	6 510	4 060	142
	(5)	34 790	12 710	7 620	3 980	214
	(6)	63 300	6 560	22 440	6 980	285

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APPENDIX I

SCENARIO LIST

APPENDIX I

SCENARIO LIST

The scenarios available for BURYIT analysis are shown in Table I-1. Included in this table is a description of the scenario and the files required for the calculation. Each scenario may be used in conjunction with any one of the six inventories defined in Appendix D.

Table I-1. Required files for scenario input

Scenario Code	TAPE11 Aquifer	TAPE10 Geology	TAPE8 Erosion	TAPE9 Atmospheric	TAPE15 Agriculture	TAPE20 Direct	Scenario Description
A-1	0	0	0	0	1	1	A ruptured drum with liquid substance causes spill to contaminate the vehicle or the overpack interior.
A-2	0	0	0	0	1	1	A ruptured drum with volatile substance causes release to contaminate the vehicle or the overpack interior.
A-3	0	0	0	0	1	1	A ruptured drum, carton, or box containing solids causes release to contaminate the vehicle or the overpack interior.
A-4	0	0	0	0	0	1	Worker is injured by contaminated sharp object protruding from ruptured drum, carton, or box during receiving inspection.
A-5	0	0	0	1	1	1	Fire erupts in the transport vehicle or in the overpack containing combustible cartons or loose bundles during receiving inspection. Fire is allowed to burn out.
A-6	0	[illegible]	1	1	1	1	Fire erupts in the transport vehicle or in the overpack containing combustible cartons, boxes, or loose bundles during receiving inspection. Fire is quenched with water.
A-7	1	0	0	1	1	1	Explosion in the transport vehicle or in the overpack containing drums or boxes with volatile substances or liquid containers.
A-8	0	0	0	1	1	1	Explosion in the transport vehicle or in the overpack containing drums, boxes, or cartons filled with solids or loose bundles.
A-9	0	0	0	0	1	1	Irradiated/contaminated usable items are removed from wastes.
A-10	0	0	0	0	0	1	Chronic direct radiation to workers engaged in the pre-entry inspection of drums, boxes, cartons, and loose bundles.
A-11	0	0	0	1	1	0	Chronic escape to atmosphere of radionuclides during the pre-entry inspection of drums, boxes, cartons, and loose bundles.
B-1	1	1	1	1	1	1	Liner containing highly activated LWR components is accidentally ruptured during transfer into the burial trench. Wastes are spilled from the liner.
B-2	0	0	0	0	0	1	Chronic direct radiation to workers engaged in removing the liner, containing highly activated LWR components from shielded cask, and manipulating it into the burial trench.

Table I-1. (continued)

Scenario Code	TAPE11 Aquifer	TAPE10 Geology	TAPE8 Erosion	TAPE9 Atmospheric	TAPE15 Agriculture	TAPE20 Direct	Scenario Description
B-3	0	0	0	0	0	1	Drum with liquid waste containers is ruptured to burial trench. Liquid is spilled into overpack.
B-4	1	1	1	1	1	0	Drum with liquid waste containers is ruptured during transfer from the transportation overpack to burial trench. Liquid is spilled into trench.
B-5	0	0	0	1	1	0	Drum containing volatile substance is ruptured during transfer from the transportation overpack to burial trench. Volatile substance escapes to atmosphere.
B-6	1	1	0	1	1	0	Drums, carton, or box containing solid substance is ruptured during transfer from the transportation overpack to burial trench.
B-7	0	0	0	1	1	1	Fire erupts in the transportation overpack or in loose bundles. Fire is allowed to burn out.
B-8	1	1	1	1	1	1	Fire erupts in the transportation overpack or in the trench containing combustible cartons, boxes, or loose bundles. Fire is quenched with water.
B-9	1	1	1	1	1	1	Explosion in the transportation overpack or in the trench containing drums or boxes with volatile substances or liquid containers.
B-10	1	1	1	1	1	1	Explosion in the transportation overpack or in the trench containing drums, boxes, or cartons filled with solids, or loose bundles.
B-11	0	0	0	0	0	1	Chronic direct radiation to workers engaged in unloading of drums, boxes, cartons, and loose bundles from the transportation overpacks.
B-12	1	1	1	1	1	1	Chronic escape of radionuclides to atmosphere during unloading of drums, boxes, cartons, and loose bundles from the transportation overpacks.
B-13	0	0	0	0	1	1	The transportation overpacks and/or vehicle inadequately decontaminated prior to release.
B-14	0	0	0	0	1	1	Irradiated/contaminated usable items are removed from wastes during handling.
C-1	0	0	0	1	1	0	Fire erupts in the uncovered trench containing burnable cartons, boxes, or loose bundles. Fire is allowed to burn out.
C-2	1	1	1	1	1	0	Fire erupts in the uncovered trench containing burnable cartons, boxes, or loose bundles.
C-3	1	1	1	1	1	0	Uncovered trench is flooded from rainfall.
C-4	0	0	0	1	1	1	High velocity wind causes lifting and dispersal of those radionuclides from the uncovered trench which are attached to dust, light powders, loose papers, or boards, etc. The materials lifted from the trench are dispersed over the site.
C-5	0	0	0	0	1	1	Irradiated/contaminated usable items are removed from wastes.
C-6	0	0	0	0	1	0	Animals (rats, rabbits, etc.) intrude into uncovered wastes, become contaminated, and carry radionuclides outside of the trench.

Table I-1. (continued)

Scenario Code	TAPE11 Aquifer	TAPE10 Geology	TAPE8 Erosion	TAPE9 Atmospheric	TAPE15 Agriculture	TAPE20 Direct	Scenario Description
C-7	0	0	0	0	0	1	Chronic direct radiation to workers engaged in the activities in the vicinity of uncovered wastes.
C-8	0	0	0	1	1	0	Chronic escape of radionuclides to atmosphere from the uncovered wastes.
D-1	1	1	1	1	1	1	Liner containing highly activated LWR components is accidently ruptured during burial or backfill operation. Wastes are spilled from the liner.
D-2	0	0	0	0	0	1	Chronic direct radiation to workers engaged in burying the liner, containing highly activated LWR components.
D-3	0	0	0	0	0	1	Drum with liquid waste containers is ruptured during burial or backfill operation. Liquid is spilled into backfill.
D-4	1	1	1	1	1	0	Drum with liquid waste containers is ruptured during burial or backfill operation. Liquid is spilled into trench.
D-5	0	0	0	1	1	0	Drum containing volatile substance is ruptured during burial or backfill operation. Volatile substance escapes to atmosphere.
D-6	0	0	0	1	1	0	Drum, carton, or box containing solid wastes is ruptured during burial and backfill operation.
D-7	0	0	0	1	1	0	Fire erupts in the trench containing burnable cartons, boxes, or loose bundles during burial and backfill operations. Fire is allowed to burn out.
D-8	1	1	1	1	1	0	Fire erupts in the trench containing burnable cartons, boxes, or loose bundles during burial and backfill operations. Fire is quenched with water.
D-9	1	1	1	1	1	1	Explosion in the trench containing drums or boxes with volatile substances or liquid containers during backfill operations.
D-10	1	1	1	1	1	1	Explosion in the trench containing drums, boxes cartons, or loose bundles (in solid state) during burial and backfill operations.
D-11	0	0	0	0	0	1	Chronic direct radiation to workers engaged in burial and backfill operations.
E-1	1	1	1	1	1	0	Erosion or washout of backfill. Inadequate backfill depth.
E-2	1	1	0	0	1	0	Intrusion of surface water. Water seepage to water table through buried wastes.
E-3	0	0	0	0	1	1	Intrusion by scavengers (site worker/outside person). Removal of contaminated items.
E-4	0	0	0	0	1	0	Intrusion by animals (rats, rabbits, etc.). Animals become contaminated.
F-1	1	1	1	1	1	0	Erosion or washout of backfill. Inadequate backfill depth.
F-2	1	1	0	0	1	0	Intrusion of surface water. Water seepage to water table through buried wastes.

Table I-1. (continued)

Scenario Code	TAPE11 Aquifer	TAPE10 Geology	TAPE8 Erosion	TAPE9 Atmospheric	TAPE15 Agriculture	TAPE20 Direct	Scenario Description
F-3	0	0	0	0	1	1	Intrusions by scavengers digging for artifacts. Removal of contaminated items.
F-4	0	0	0	0	1	0	Farming of the burial site for crops.
F-5	0	0	0	0	1	0	Use of the burial site as a pasture for domestic animals.
F-6	0	0	0	0	1	0	Intrusion by animals. Animals become contaminated.
F-7	1	1	1	1	1	0	Long-term flooding of the burial site.
F-8	0	0	0	0	0	1	Uncovering of the buried waste by earthquake.
P-1	0	0	0	0	0	1	Highly activated LWR components are mishandled during packaging into a shielded cask, causing direct radiation exposure to workers.
P-2	0	0	0	0	0	1	Chronic direct radiation to workers engaged in packaging highly activated LWR components into shielded casks.
P-3	0	0	0	0	0	1	Liquid waste containers are ruptured during packaging. Liquid is spilled.
P-4	0	0	0	1	1	0	Container with volatile substance is ruptured during packaging. Volatile substances escape to atmosphere.
P-5	1	1	1	1	1	0	Solid wastes are spilled and dispersed during packing.
P-6	0	0	0	1	1	1	Fire erupts during packaging of combustible wastes. Fire is allowed to burn out.
P-7	1	1	1	1	1	1	Fire erupts during packaging of combustible wastes. Fire is quenched with water.
P-8	1	1	1	1	1	1	Explosion during packaging of volatile substances or liquid.
P-9	1	1	1	1	1	1	Explosion during packaging of solid wastes.
P-10	0	0	0	0	0	1	Chronic direct radiation to workers engaged in packaging of wastes or processing.
P-11	0	0	0	1	1	0	Chronic discharge of radionuclides to atmosphere from facility off-gas stack during packaging/processing of wastes.
P-12	0	0	0	1	1	0	Chronic discharge of radionuclides to atmosphere during incineration of wastes.
P-13	0	0	0	1	1	0	Discharge of radionuclides through off-gas stack with failed filters during packaging/processing of wastes.
P-14	0	0	0	1	1	0	Discharge of radionuclides through off-gas system with failed filters during waste incineration.
P-15	0	0	0	0	1	1	The package containing wastes inadequately decontaminated prior to release to shipment.
P-16	0	0	0	0	1	1	Irradiated/contaminated usable items are removed from wastes during packaging or processing.
P-17	0	0	0	0	0	1	Worker is injured by contaminated sharp object during packaging or processing.

Table I-1. (continued)

Scenario Code	TAPE11 Aquifer	TAPE10 Geology	TAPE8 Erosion	TAPE9 Atmospheric	TAPE15 Agriculture	TAPE20 Direct	Scenario Description
S-1	0	0	0	0	1	1	A ruptured container with liquid substance causes spill to contaminate the storage or handling area.
S-2	0	0	0	0	1	1	A ruptured container with volatile substance causes release to contaminate the handling or storage area.
S-3	0	0	0	0	1	1	A ruptured drum, carton, or box containing solids causes release to contaminate the handling or storage area.
S-4	0	0	0	0	0	1	Worker is injured by contaminated sharp object protruding from ruptured drum, carton, or box during interim handling or storage.
S-5	0	0	0	1	1	1	Fire erupts in the handling or storage area containing combustible cartons, boxes, or loose bundles. Fire is allowed to burn out.
S-6	1	1	1	1	1	1	Fire erupts in the handling or storage area containing combustible cartons, boxes, or loose bundles. Fire is quenched with water.
S-7	0	0	0	1	1	1	Explosion in the handling or storage area containing drums or boxes with volatile substances or liquid containers.
S-8	0	0	0	1	1	1	Explosion in the handling or storage area containing drums, boxes, or cartons filled with solids or loose bundles.
S-9	0	0	0	0	1	1	Irradiated/contaminated usable items are removed from wastes.
S-10	0	0	0	0	0	1	Chronic direct radiation to workers engaged in the handling and storage of drums, boxes, cartons, and loose bundles.
S-11	0	0	0	1	1	0	Chronic escape of radionuclides to atmosphere during the handling and storage of drums, boxes, cartons, and loose bundles.
T-1	0	0	0	0	0	1	Chronic direct radiation to workers engaged in the loading of drums, boxes, cartons, and loose bundles on transport vehicles.
T-2	0	0	0	1	1	0	Chronic escape of radionuclides to atmosphere during the inspection of drums, boxes, cartons, and loose bundles prior to loading on transport vehicle.
T-3	0	0	0	0	1	1	Irradiated/contaminated usable items are removed from waste during loading on transport vehicle.
T-4	0	0	0	0	1	1	A ruptured drum with liquid substance causes spill to contaminate the vehicle or the overpack interior.
T-5	0	0	0	0	1	1	A ruptured drum with volatile substance causes release to contaminate the vehicle or the overpack interior.
T-6	0	0	0	0	1	1	A ruptured drum, carton, or box containing solids causes release to contaminate the vehicle or overpack interior.
T-7	0	0	0	0	0	1	Worker is injured by contaminated sharp object protruding from ruptured drum, carton, or box during receiving inspection.

Table I-1. (continued)

Scenario Code	TAPE11 Aquifer	TAPE10 Geology	TAPE8 Erosion	TAPE9 Atmospheric	TAPE15 Agriculture	TAPE20 Direct	Scenario Description
T-8	0	0	0	1	1	1	Fire erupts in the transport vehicle or in the overpack containing combustible cartons, boxes, or loose bundles along transportation route. Fire is allowed to burn out.
T-9	1	1	1	1	1	1	Fire erupts in the transport vehicle or in the overpack containing combustible cartons, boxes, or loose bundles along transportation route. Fire is quenched with water.
T-10	0	0	0	1	1	1	Explosion in the transport vehicle or in the overpack containing drums or boxes with volatile substances or liquid containers.
T-11	0	0	0	1	1	1	Explosion in the transport vehicle or in the overpack containing drums, boxes, or cartons filled with solids or loose bundles.
T-12	1	1	1	1	1	1	A transport vehicle is abandoned or destroyed during transit. Liquid substance is spilled from damaged containers onto the roadway.
T-13	0	0	0	1	1	0	A transport vehicle is damaged or destroyed during transit. Volatile substance is spilled from damaged containers onto the roadway.
T-14	1	1	1	1	1	0	A transport vehicle is damaged or destroyed during transit. Solid or liquid wastes spilled on the roadway are flooded by rainfall.
T-15	0	0	0	1	1	1	A transport vehicle is damaged or destroyed during transit. Solid waste is spilled on the roadway. High velocity wind causes lifting and dispersal of those radionuclides which are attached to dust, light powders, loose papers, boards, etc. The materials are dispersed over the roadway and neighboring countryside.
T-16	0	0	0	0	1	1	Irradiated/contaminated items are removed from waste scattered as a result of transport vehicle damage or destruction.
T-17	0	0	0	0	1	1	A worker is injured by contaminated sharp object protruding from ruptured waste container during post-accident cleanup of the roadway.

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13. ABSTRACT (200 words or less)

This report is a user's manual for a partially completed code for risk assessment of a low-level waste shallow-land burial site, to be used in the licensing of burial sites. This code is intended as a tool to be used for considering nuclide transport mechanisms, including atmospheric, groundwater, erosion, and infiltration to an underlying aquifer. It also calculates doses to individuals and the population through direct exposure, inhalation, and ingestion.

The methodology of the risk assessment is based primarily on the response surface method of uncertainty analysis. The parameters of a model for predicting dose commitment due to a release are treated as statistical variables in order to compute statistical distributions for various dose commitment contributions. The likelihood of a release is also accounted for by statistically evaluating the arithmetic product of the dose commitment distributions with the probability of release occurrence.

An example is given using the atmospheric transport pathway as modeled by a code called BURYIT. The framework for using other release pathways is described in this manual. Information on parameter uncertainties, reference site characteristics, and probabilities of release events is included.

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