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CNWRA

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1/24/96 CONTINUED INVESTIGATIONS OF EXPOSURES FROM EXTRUSIVE VOLCANISM

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PURPOSE: TO CONTINUE INVESTIGATIONS, AS ORIGINALLY SHOWN IN JARZEMBA (1995).

PROBABILITY OF VOLCANISM OCCURRING AT YM.

CONNOR AND HILL (1995) USE DIFFERING PROBABILITY ANALYSES TO DETERMINE THAT THE PROBABILITY OF A NEW CONE FORMING IN THE REPOSITORY AREA IN THE NEXT 10,000 YEARS IS:

$$1 \times 10^{-4} \text{ TO } 5 \times 10^{-4}$$

WHERE THE REPOSITORY AREA IS THE FOOTPRINT PLUS A 500 m BUFFER ZONE (EQUAL TO ABOUT $8\,km^2$)

ASSUMPTION: 1) PROBABILITY IS CONSTANT IN SPACE AND TIME OVER THE REPOSITORY AREA (FOOTPRINT PLUS SEVERAL km BUFFER ZONE).
2) USE MEAN VALUE FROM RANGE ABOVE, $3 \times 10^{-4}\ \frac{1}{10{,}000\,YR \cdot 8\,km^2}$

$$\text{RECURRANCE RATE} = RR. = \frac{3 \times 10^{-4}}{10^4\,YR \cdot 8\,km^2} = 3.75 \times 10^{-9}\ \frac{1}{YR \cdot km^2}$$

NEED TO FIND RR FOR THE AREA SHOWN IN FIGURE 2 FROM THE VOLCANO MODULE.

VOLCANO USES AN AREA w $\Delta Y = 12\,km$, $\Delta X = 12\,km$ OR AREA $= 144\,km^2$

PROBABILITY OVER VOLCANO AREA IS:

$$RR_V = 3.75 \times 10^{-9}\ \frac{1}{YR \cdot km^2}\left(144\,km^2\right) = \boxed{5.4 \times 10^{-7}\ \frac{1}{YR}}$$

—— = 12 km × 12 km SQUARE CENTERED ON REPOSITORY

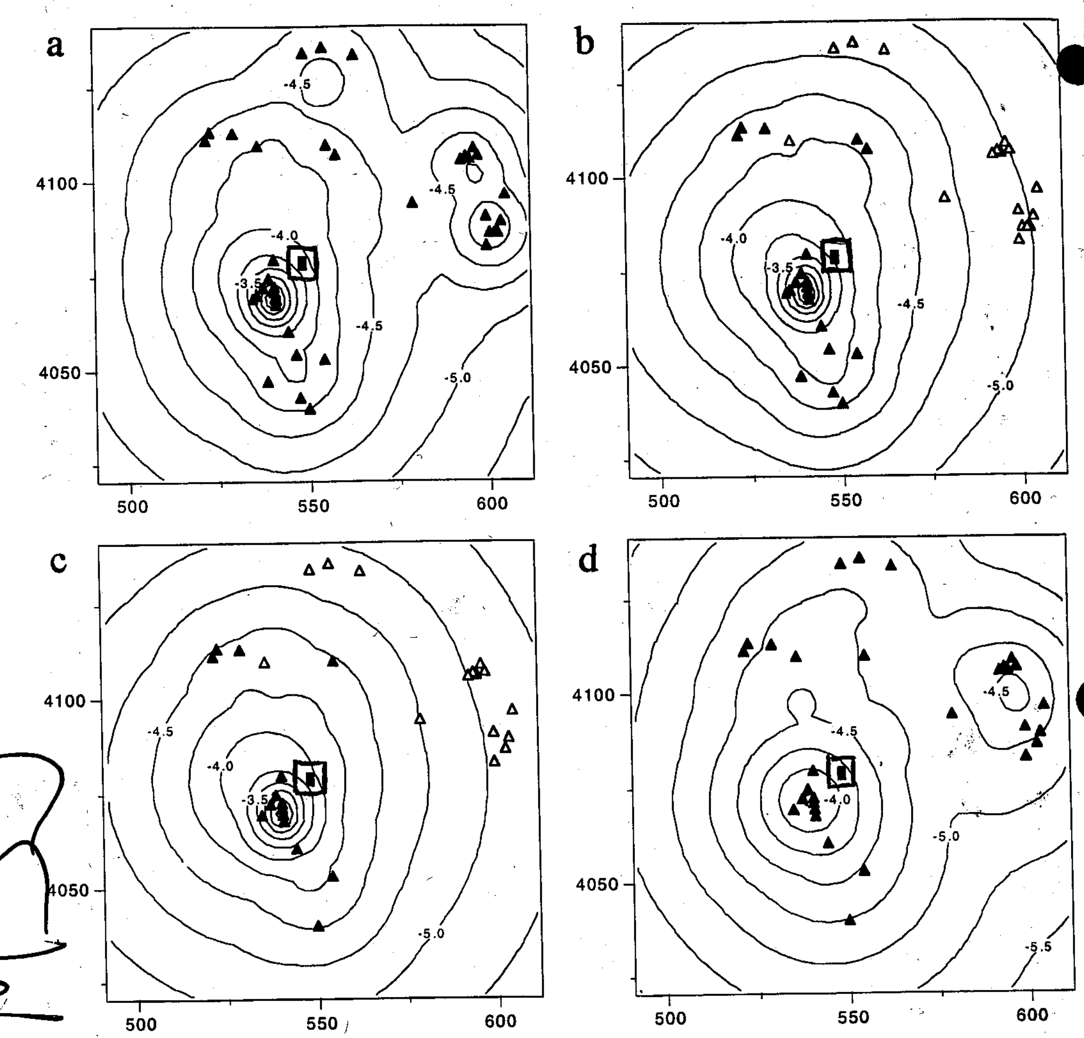
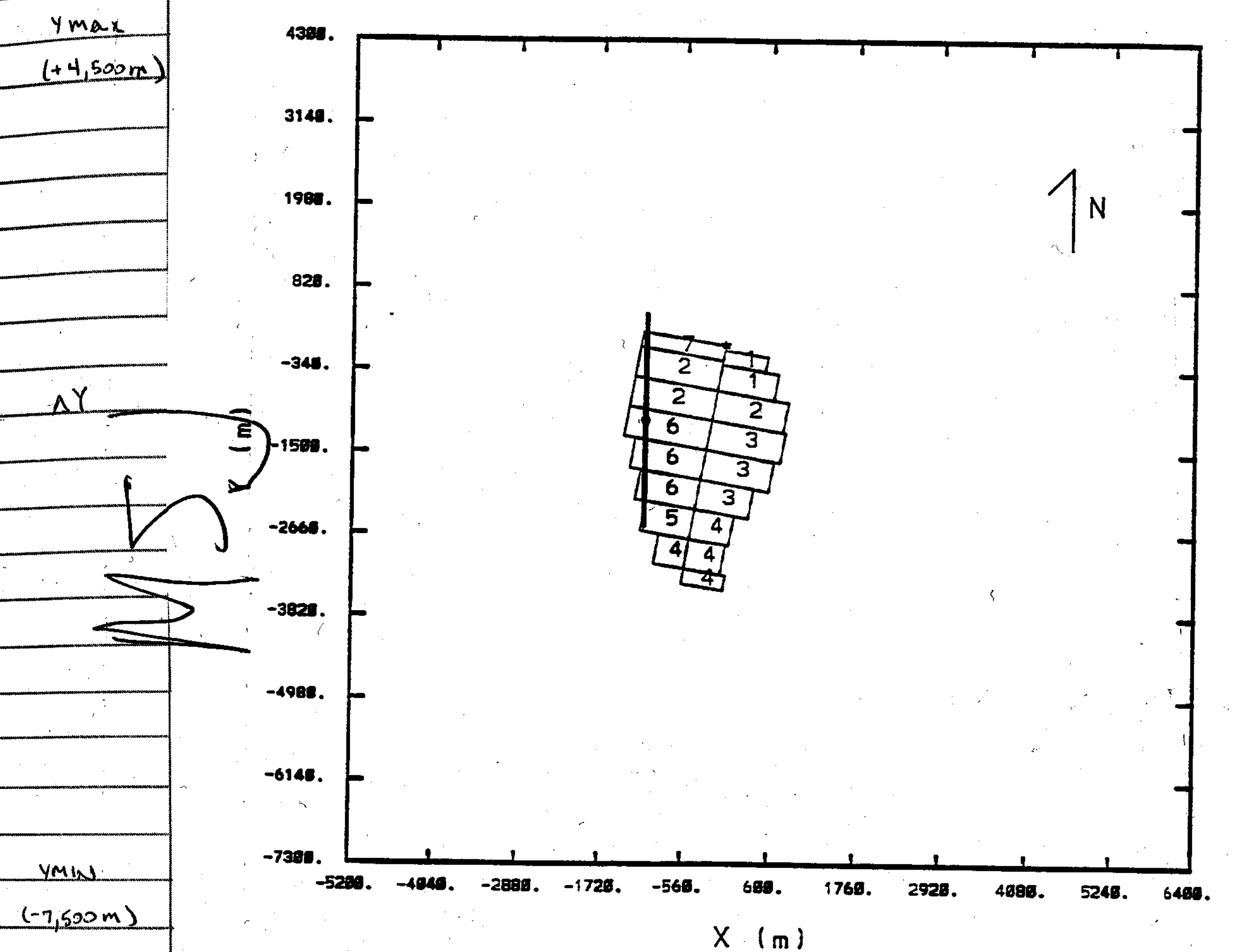


Figure 5. Probability of a new volcano forming during the next 10,000 years varies in the YMR because of the tendency for volcanoes to cluster. Here the logarithm of probability of a volcano forming within a 8 km^2 area during the next 10,000 years is contoured using (a) nine nearest neighbors and all volcanoes in data set 1, (b) eight nearest neighbors and all volcanoes in data set 1 formed <5 Ma, (c) seven nearest neighbors and all volcanoes in data set 2 formed <5 Ma, and (d) 11 nearest neighbors and all volcanoes in data set 2 formed <10 Ma. The four maps reflect different regional recurrence rates λ_r (Figure 3), ranging from λ_r = 3 v/m.y. (Figure 5d) to λ_r = 8.5 v/m.y. (Figure 5a). In these and all of the following maps, the solid triangles indicate the positions of volcanoes used in the calculation (data set 1 or 2), and open triangles indicate the positions of volcanoes that are part of the data set but are not included in the calculation because of their age. The location of the proposed repository (solid rectangle) is indicated. The contour interval is 0.25 log ($P[N \geq 1$, 10,000 years]) (e.g., −4 is a probability of 1×10^{-4} of a new volcano forming within an 8 km^2 area in 10,000 years). Map coordinates are in universal transverse mercator, North American Datum 1983.

FIGURE 1



XMIN (-6,000m)

ΔX

XMAX (6,000m)

Figure 2-3. Example of an extrusive volcanic event from the VOLCANO simulation

FIGURE 2

REFERENCES:

1) JARZEMBA, M.S., 1995 - STOCHASTIC RADIONUCLIDE DISTRIBUTIONS AFTER A BASALTIC ERUPTION FOR PERFORMANCE ASSESSMENTS OF YUCCA MOUNTAIN; SUBMITTED TO NUCLEAR TECHNOLOGY

2) CONNOR, C., HILL, B., 1995 - THREE NONHOMOGENEOUS POISSON MODELS FOR THE PROBABILITY OF BASALTIC VOLCANISM; APPLICATION TO THE YUCCA MOUNTAIN REGION.; JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 100, No B6, pp. 10,107 - 10,125

3) VOLCANO TPA MODULE USER'S MANUAL - CNWRA 93-010

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A NEW METHOD FOR DISTRIBUTION UO_2 (SPENT FUEL) IN THE ASH PARTICULATE MATTER

FIGURE THREE SHOWS A FUEL PELLET CROSS-SECTION AFTER IRRADIATION.

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

Clark, et al. "Thermal Analysis of Fuel Elements." Figure 8-18, p. 333. year unknown.

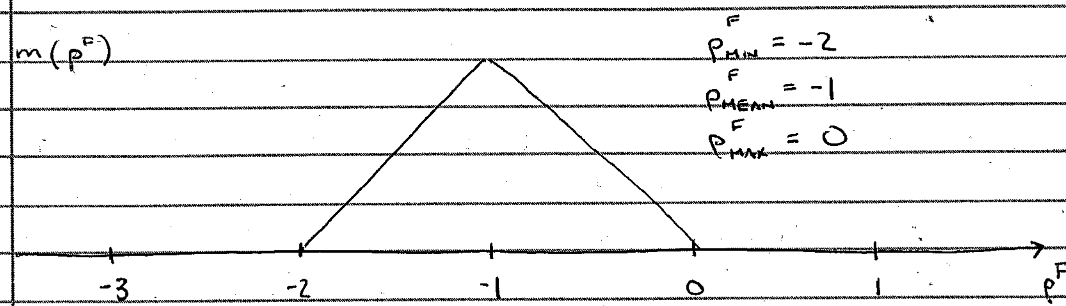
Figure 8-18 Example of a cracked fuel cross section. *(From Clark et al. [4].)*

FIGURE 3

FROM TODREAS AND KAZIMI (1989). NUCLEAR SYSTEMS I; THERMAL HYDRAULIC FUNDAMENTALS: HEMISPHERE PUBLISHING NEW YORK, NEW YORK.

FROM FIGURE 3 IT IS ASSUMED THAT THE DISTRIBUTION OF UO_2 MASS WITH THE LOG_{10} OF PARTICLE DIAMETER IS $(m(\rho^F))$

$\rho^F = LOG_{10}(d^F)$ d = PARTICLE DIAMETER IN cm (F FOR FUEL).



WHEN A DIKE INRUDES UPON A REPOSITORY IT IS ASSUMED THAT THE CONTAINMENT AND CLAD ARE ABSENT

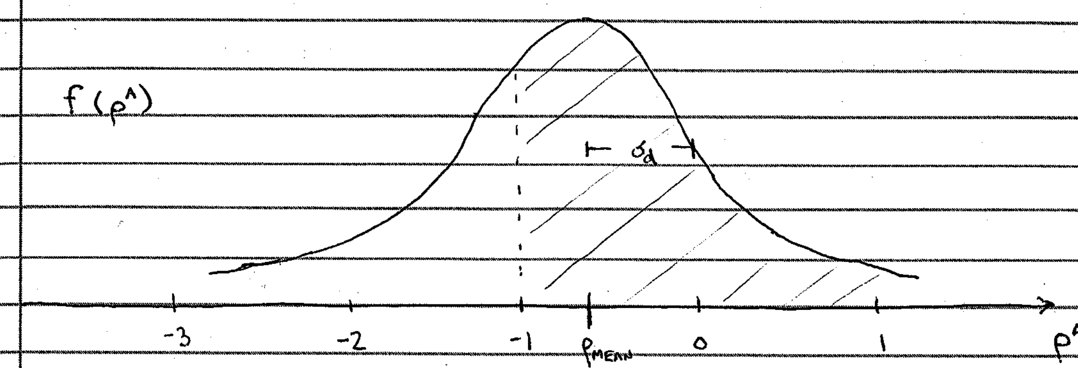
FROM JARZEMBA (1995) IT IS ASSUMED THAT THE ASH IS LOG-NORMALLY DISTRIBUTED $(f(\rho^A))$ SUCH THAT

$$f(\rho^A) = \frac{1}{\sqrt{2\pi}\,\sigma_d} \exp\left[\frac{-(\rho^A - \rho^A_{MEAN})^2}{2\sigma_d^2}\right]$$

$\rho^A = LOG_{10}(d^A)$

ρ_{MEAN} = SAMPLED [JARZEMBA (1995)]

σ_d = SAMPLED [JARZEMBA (1995)]



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ASSUMPTION: ~~THE QUANTITY OF UO_2 W/ $\rho^F < \rho^{CUTOFF}$ UNIFORMLY~~

THE UO_2 PARTICULATE ~~HOMOGENOUSLY DISTRIBUTES~~ MSJ 1/24/96 ~~ITSELF ONLY INTO~~ MASS WITH $\rho^F < \rho^F_{CUTOFF}$ UNIFORMLY DISTRIBUTES ITSELF INTO THE ASH PARTICLE MASS WITH $\rho^A > 10\rho^F_{CUTOFF}$

IN NO CASE CAN AN ASH PARTICLE HAVE MORE THAN 1/10 OF ITS' MASS COMPRISED OF UO_2

$F(\rho^A)$ = CDF OF $f(\rho^A)$

$M(\rho^F)$ = CDF OF $m(\rho^F)$

Q = TOTAL MASS OF ASH EJECTED

U = TOTAL MASS OF URANIUM DIOXIDE EJECTED (FUEL)

$FF(\rho^A)$ = THE MASS OF UO_2 / MASS OF ASH IN A PARTICULATE

SHADED AREA ABOVE IS INDICATING MASS OF ASH THAT HAS THE ABILITY TO CARRY ANY UO_2 GIVEN DISTRIBUTION ON pg. 6.

ρ^A	$FF(\rho^A)$
$\rho^A < \rho^F_{MIN} + 1$	$FF(\rho^A) = 0$
$\rho^F_{MIN} + 1 < \rho^A < \rho^F_{MAX} + 1$ $Q[1-F(\rho^A)] < 10U \cdot M(\rho^A - 1)$	$FF(\rho^A) = 1/10$
$\rho^F_{MIN} + 1 < \rho^A < \rho^F_{MAX} + 1$ $Q[1-F(\rho^A)] > 10\,U \cdot M(\rho^A - 1)$	$FF(\rho^A) = \dfrac{U \cdot M(\rho^A - 1)}{Q[1-F(\rho^A)]}$
$\rho^A > \rho^F_{MAX} + 1$ $Q[1-F(\rho^A)] < 10 \cdot U$	$FF(\rho^A) = 1/10$
$\rho^A > \rho^F_{MAX} + 1$ $Q[1-F(\rho^A)] > 10 \cdot U$	$FF(\rho^A) = \dfrac{U}{Q[1-F(\rho^A)]}$

MUST NORMALIZE TO ASSURE THAT NO MORE MASS OF UO_2 IS ~~REL~~ DISTRIBUTED THAN THAT WHICH IS RELEASED (U)
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LESS MASS DISTRIBUTED THAN RELEASED IS OK SINCE THERE MAY NOT BE ENOUGH ASH MASS AT GIVEN ρ^A'S TO CARRY THE SPENT FUEL AWAY VIA THIS MECHANISM.

$$\text{TOTAL ASH MASS DISTRIBUTED} = \int_{\rho^A_{MIN}}^{\rho^A_{MAX}} FF(\rho^A) \cdot Q \cdot f(\rho^A)\, d\rho^A$$

TOTAL ASH MASS RELEASED = U

$\overline{FF}(\rho^A)$ = NORMALIZED MASS FRACTION

$$= FF(\rho^A) \quad \text{IF} \quad U > \int_{\rho^A_{MIN}}^{\rho^A_{MAX}} FF(\rho^A) \cdot Q \cdot f(\rho^A)\, d\rho^A$$

$$= N \cdot FF(\rho^A) \quad \text{IF} \quad U < \int_{\rho^A_{MIN}}^{\rho^A_{MAX}} FF(\rho^A) \cdot Q \cdot f(\rho^A)\, d\rho^A$$

WHERE:

$$N = \frac{U}{\int_{\rho^A_{MIN}}^{\rho^A_{MAX}} FF(\rho^A) \cdot Q \cdot f(\rho^A)\, d\rho^A}$$

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DERIVATION OF FUNCTION $M(\rho^F)$

$m(\rho^F) = m(\rho)$ FOR NOTATIONAL SIMPLICITY FOR NOW.

$$m(\rho) = \frac{2\,(\rho - \rho_{MIN})}{(\rho_{MAX} - \rho_{MIN})(\rho_{MEAN} - \rho_{MIN})} = K_1(\rho^F - \rho^F_{MIN}) \qquad \rho_{MIN} < \rho < \rho_{MEAN}$$

$$= \frac{-2\,(\rho - \rho_{MEAN})}{(\rho_{MAX} - \rho_{MIN})(\rho_{MAX} - \rho_{MEAN})} = K_2(\rho^F - \rho^F_{median}) + K_1(\rho^F_{med} - \rho^F_{min}) \qquad \rho_{MEAN} < \rho < \rho_{MAX}$$

$$= 0 \qquad \text{ELSEWISE}$$

$$M(\rho) = \int_{\rho_{min}}^{\rho} K_1(\rho - \rho_{min})\, d\rho$$

$$= \left[\tfrac{1}{2} K_1 \rho^2 - K_1 \rho \rho_{min} \right]_{\rho_{min}}^{\rho}$$

$$= \tfrac{1}{2} K_1 \rho^2 - K_1 \rho \rho_{MIN} - \tfrac{1}{2} K_1 \rho_{MIN}^2 + K_1 \rho_{min}^2$$

$$= \tfrac{1}{2} K_1 \rho^2 - K_1 \rho \rho_{min} + \tfrac{1}{2} K_1 \rho_{min}^2$$

$$= \tfrac{1}{2} K_1 (\rho^2 - 2\rho\rho_{min} + \rho_{min}^2)$$

$$\boxed{M(\rho^F) = \tfrac{1}{2} K_1 (\rho - \rho_{min})^2 \qquad \rho_{min} < \rho < \rho_{med}}$$

$$M(\rho) = \int_{\rho_{med}}^{\rho} \left[K_2(\rho - \rho_{med}) + K_1(\rho_{med} - \rho_{min}) \right] d\rho + 0.5$$

$$= \int_{\rho_{med}}^{\rho} K_2(\rho - \rho_{med})\, d\rho + \int_{\rho_{med}}^{\rho} K_1(\rho_{med} - \rho_{min})\, d\rho + 0.5$$

$$= \left(\tfrac{1}{2} K_2 \rho^2 - K_2 \rho \rho_{med} \right) \Big|_{\rho_{med}}^{\rho} + K_1(\rho_{med} - \rho_{min})(\rho - \rho_{med}) + 0.5$$

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$= \frac{1}{2} k_2 (\rho^2 - 2\rho\rho_{med})\Big|_{\rho_{med}}^{\rho} + K_1(\rho_{med} - \rho_{min})(\rho - \rho_{med})$ ~~$\Big|_{\rho_{med}}$~~

$= \frac{1}{2} k_2 (\rho^2 - 2\rho\rho_{med} - \rho_{med}^2 + 2\rho_{med}^2) + K_1(\rho_{med} - \rho_{min})(\rho - \rho_{med}) + 0.5$

$= \frac{1}{2} k_2 (\rho^2 - 2\rho\rho_{med} + \rho_{med}^2) + K_1(\rho_{med} - \rho_{min})(\rho - \rho_{med}) + 0.5$

$= \frac{1}{2} k_2 (\rho - \rho_{med})^2 + K_1(\rho_{med} - \rho_{min})(\rho - \rho_{med}) + 0.5$

$$M(\rho^f) = \frac{1}{2} k_2 (\rho^f - \rho^f_{med})^2 + K_1(\rho^f_{med} - \rho^f_{min})(\rho^f - \rho^f_{med}) + 0.5 \qquad \rho^f_{med} < \rho^f < \rho^f_{max}$$

~~For all other ρ^f; $M(\rho^F$~~ MSJ 1-23-96

$\rho^f < \rho^f_{min} \Rightarrow M(\rho^f) = 0$

$\rho^f > \rho^f_{max} \Rightarrow M(\rho^f) = 1$

NOTE: ρ_{MED} AND ρ_{MEAN} HAVE BEEN USED INTERCHANGABLY

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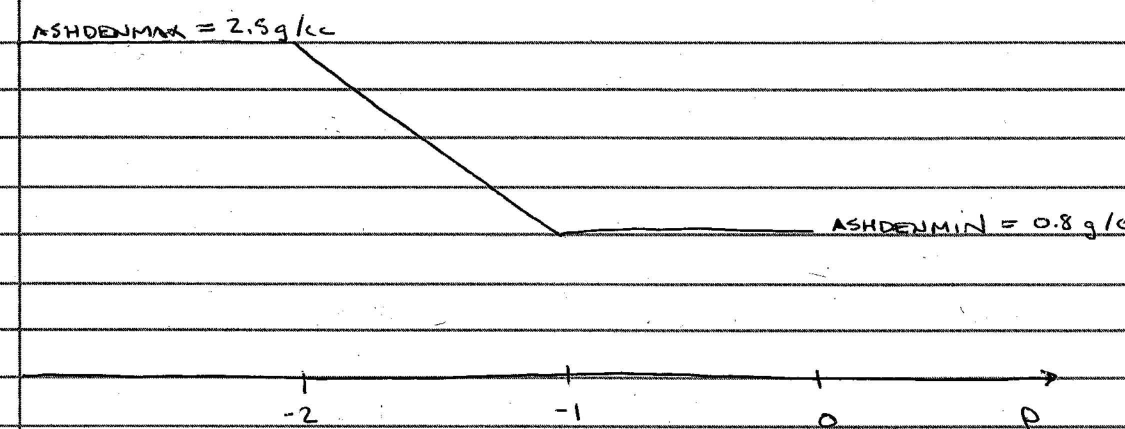
DERIVATION OF NEW ASH DENSITY FUNCTION – $\Psi_A(\rho)$

DATA FROM WALKER ET. AL. (1971) SUGGESTS THAT PARTICLE DENSITY IS A FUNCTION OF ρ. ROUGHLY CORRESPONDING TO:



$\Psi_A(\rho) =$ ASHDENMAX $\qquad \rho < -2$

$\Psi_A(\rho) =$ ASHDENMAX – $(\rho+2)$ [ASHDENMAX – ASHDENMIN] $\qquad -2 < \rho < -1$

$\Psi_A(\rho) =$ ASHDENMIN $\qquad \rho > -1$

REFERENCE: WALKER, GPL, WILSON, L., BOWELL, ELG – EXPLOSIVE VOLCANIC ERUPTIONS – I; THE RATE OF FALL OF PYROCLASTS. GEOPHYSICAL JOURNAL OF THE ROYAL ASTROLOGICAL SOCIETY, VOL. 22 pp. 377-383 (1971)

2/12/96 — Calculation of Expected Dose Values for different P.O.I. and distances downwind.

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All doses converted using surficial DCF's; Volumetric DCF's unavailable at this time

POI	Distance Downwind (km)	Expected Dose ($\frac{mrem}{yr}$)	Max Dose ($\frac{mrem}{yr}$)
10K	2km	107	6.6×10^7
10K	5 km	9	7×10^6
10K	10 km	0.8	2.6×10^5
10K	20 km	1.3	2.3×10^6 [Sr-90 dominated]
1M	2 km	541	3.1×10^6
1M	5 km	56	1.4×10^5
1M	10 km	6	1.5×10^4
1M	20 km	0.9	1×10^4

2/20/96 — Doses with volumetric DCF's for thicknesses > 1m

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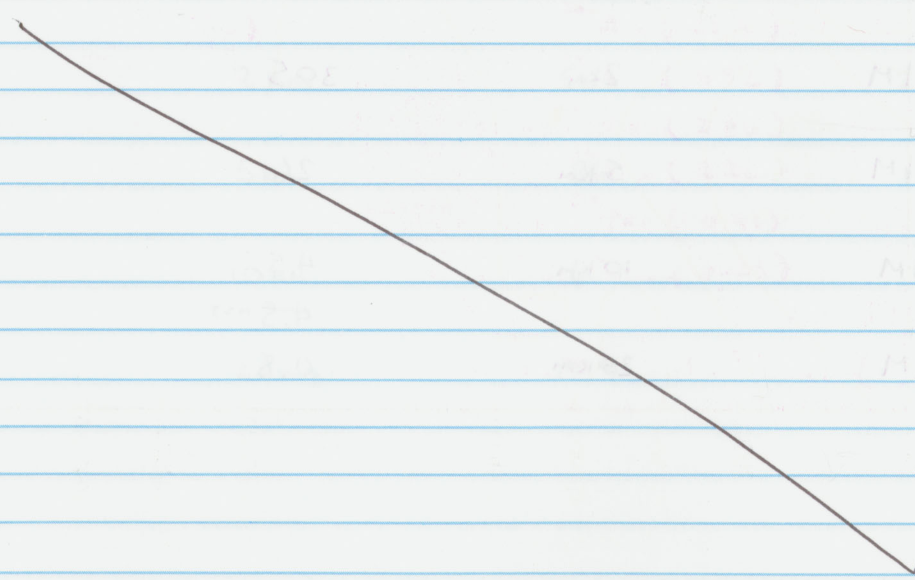
POI	Distance Downwind (km)	Expected Dose ($\frac{mrem}{yr}$)	Max Dose ($\frac{mrem}{yr}$)
~~10K~~ MSJ			
10K	2 km	25.9	2.2×10^7
10K	5 km	2.9	2.9×10^6
10K	10 km	0.5	2.0×10^5
10K	20 km	1.3	2.3×10^6
			~~2.3×10^6~~ MSJ
1M	2 km	305	4.4×10^6
1M	5 km	26	1.4×10^5
1M	10 km	4.5	1.5×10^4
		~~4.5~~ MSJ	~~1.5×10^4~~ MSJ
1M	20 km	0.8	1×10^4

3/28/96 More dose calculations

Pts. on Earth's surface to be calculated (from NW to SE)

Pt	x (km)	y (km)
1	-15	-15
2	0	-20
3	0	-25
4	0	-30
5	0	-35
6	14.5	-35

Sampled wind direction



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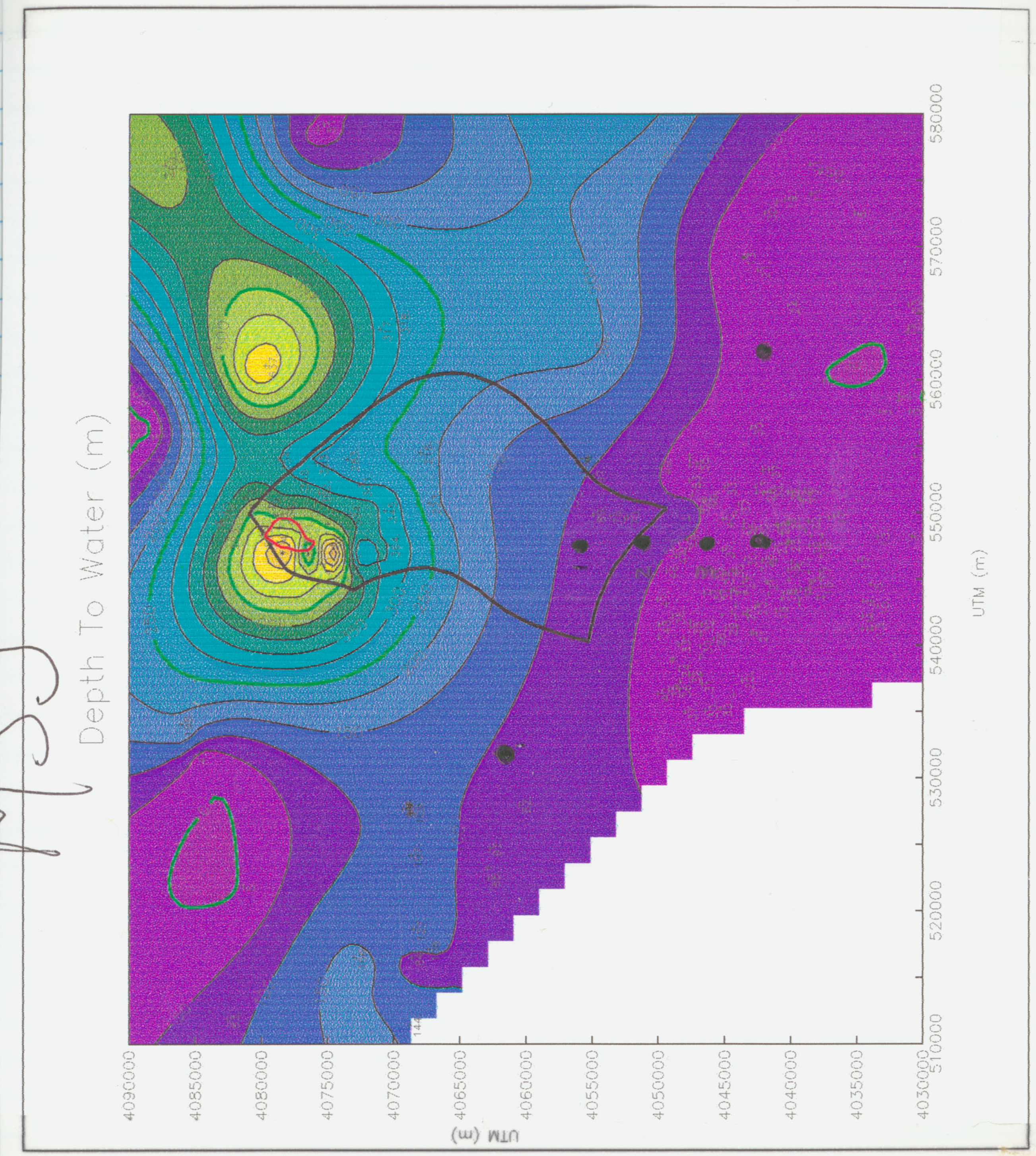

6/4/96
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ASSESSMENT OF THE RELATIVE IMPORTANCE OF THE RADIONUCLIDES FOR THE VOLCANISM SCENARIO

POI (YR)	DOSE PT.	NUCLIDE (% CONT. TO E(Ḋ))	
10K	1	^{241}Am (88.9)	
	(0.0, -20.0)	^{243}Am (5.37)	
		^{240}Pu (2.59)	
		^{239}Pu (2.02)	
		^{237}Np (0.83)	
		ALL OTHERS (0.29)	
1M	1	^{237}Np (36.3)	^{239}Pu (0.79)
	(0.0, -20.0)	^{210}Pb (26.6)	^{129}I (0.34)
		^{229}Th (22.4)	^{99}Tc (0.30)
		^{226}Ra (5.34)	^{233}U (0.19)
		^{230}Th (2.23)	^{234}U (0.12)
		^{231}Pa (2.09)	^{242}Pu (0.17)
		^{227}Ac (2.70)	ALL OTHERS (0.43)
10K	2	^{241}Am (87.8)	
	(0.0, -25.0)	^{243}Am (5.92)	
		^{240}Pu (2.86)	
		^{239}Pu (2.22)	
		^{237}Np (0.91)	
		ALL OTHERS (0.29)	
1M	2	^{237}Np (34.3)	^{239}Pu (0.52)
	(0.0, -25.0)	^{210}Pb (30.1)	^{129}I (0.31)
		^{229}Th (20.7)	^{99}Tc (0.34)
		^{226}Ra (6.04)	^{233}U (0.17)
		^{230}Th (2.52)	^{234}U (0.13)
		^{231}Pa (1.87)	^{242}Pu (0.20)
		^{227}Ac (2.40)	ALL OTHERS (0.40)

10K	3	^{241}Am (90.9)	
	(0.0, -30.0)	^{243}Am (4.46)	
		^{240}Pu (2.13)	
		^{239}Pu (1.63)	
		^{237}Np (0.65)	
		ALL OTHERS (0.23)	
1M	3	^{237}Np (34.0)	^{239}Pu (0.42)
	(0.0, -30.0)	^{210}Pb (30.6)	^{129}I (0.31)
		^{229}Th (20.5)	^{99}Tc (0.35)
		^{226}Ra (6.14)	^{233}U (0.17)
		^{230}Th (2.55)	^{234}U (0.13)
		^{231}Pa (1.86)	^{242}Pu (0.20)
		^{227}Ac (2.39)	ALL OTHERS (0.38)

DOSE PT AVERAGED

10K	^{241}Am (89.2)	
	^{243}Am (5.25)	
	^{240}Pu (2.53)	
	^{239}Pu (1.96)	
	^{237}Np (0.80)	
	ALL OTHERS (0.26)	
1M	^{237}Np (34.9)	^{239}Pu (0.58)
	^{210}Pb (29.1)	^{129}I (0.32)
	^{229}Th (21.2)	^{99}Tc (0.33)
	^{226}Ra (5.84)	^{233}U (0.18)
	^{230}Th (2.43)	^{234}U (0.13)
	^{231}Pa (1.94)	^{242}Pu (0.19)
	^{227}Ac (2.50)	ALL OTHERS (0.36)

8/17/96 FINAL DOCUMENTATION OF CALCULATIONS
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PRELIMINARY CALCULATIONS OF EXPECTED DOSE FROM EXTRUSIVE VOLCANIC EVENTS AT YUCCA MOUNTAIN

Prepared for

Nuclear Regulatory Commission
Contract NRC-02-93-005

Prepared by

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Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

May 1996

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PRELIMINARY CALCULATIONS OF EXPECTED DOSE FROM EXTRUSIVE VOLCANIC EVENTS AT YUCCA MOUNTAIN

Mark S. Jarzemba and Patrick A. LaPlante

1 INTRODUCTION

1.1 STATEMENT OF PURPOSE

The purpose of this report is to demonstrate a calculational technique and to provide a preliminary estimate of radiation doses for the scenario of extrusive volcanism at the Yucca Mountain (YM) site. Calculations are based in part on a probabilistic volcanic ash (tephra) distribution model developed by Suzuki (1983) and extended by Jarzemba (1996). In addition, a new model for distributing spent fuel within the ash particles has been developed to more realistically model (than previous methods) radionuclide distributions on the earth's surface after a volcanic event. Dose modeling of radiation exposures from the contaminated ash blanket has also been performed. The dose pathways considered in these analyses were: ingestion (from contaminated animal products and crops), inhalation from resuspension and external radiation. Dose Conversion Factors (DCFs) as a function of these important pathways, and as a total of all the pathways, were derived for contaminated soil in a manner similar to that described in LaPlante et al., (1995) for an Amargosa Desert farmer/rancher residing at the point of interest on the earth's surface (the dose point) immediately after the volcanic event occurs. The analyses herein were performed for two different time periods of interest: 10,000 yr and 1,000,000 yr.

1.2 BACKGROUND

This section summarizes the modeling that was done in Suzuki (1983) and extended by Jarzemba (1996) to calculate radioactive volcanic ash distributions after an event.

In Suzuki (1983), the theoretical distribution of volcanic ash after an event was investigated using a two-dimensional, simultaneous convection/diffusion model. The model was based on the following processes:

- lateral diffusion of volcanic particles while in the vertical eruption column
- horizontal transport of these particles in the direction of the prevailing wind
- horizontal diffusion of these particles perpendicular to the direction of the prevailing wind due to atmospheric turbulence
- sinking of the particles in the atmosphere due to gravitational settling

The model in Suzuki (1983) is valid only for volcanic particles larger than about 15 microns as atmospheric turbulence is generally great enough to keep smaller particles aloft for a greater time than

this model would predict [Suzuki (1983), Cember (1983)]. Suzuki's model predicted the areal volcanic ash densities (in g/cm^2) at specified points on the earth's surface, hence it can be used to generate volcanic ash isopach maps after an event.

In order to make predictions of volcanic ash isopachs, the model in Suzuki (1983) required that numerous parameters characterizing the eruption be known. These parameters are as follows:

The total mass of erupted volcanic ash (q) - The mass of ash erupted in the event with particle sizes greater than 15 microns.

The volcanic column height (H) - The height of the volcanic column above the vent.

The distribution of volcanic ash mass with particle log-diameter $\left[f(\rho^a)\right]$ - Suzuki (1983) assumed a log-normal distribution that was characterized by the mean particle log-diameter $\left(\rho^a_{mean}\right)$ and the standard deviation of the particle log-diameter (σ_d).

Beta (β) - A constant determining the diffusion of volcanic ash particles out of the eruption column.

The volcanic eruption velocity at the vent exit (W_0) - The velocity of the volcanic ash particles as they exit the vent.

The particle shape parameter (F) - The ratio of the sum of the two minor particle axes to twice the major particle axis (assuming an ellipsoid particle shape).

The air viscosity (η_a) - The viscosity of the air to which the particle is exposed.

The air density (ψ_a) - The density of the air to which the particle is exposed.

The particle density (ψ_p) - The density of the ash particles.

The eddy diffusivity constant (C) - A constant relating the eddy diffusivity to the particle fall time.

The wind speed (u) - The speed of the prevailing wind. In Suzuki (1983) the x-axis of the x-y-z coordinate system was parallel to the prevailing wind direction.

In Suzuki (1983) it was assumed that all of the above parameters were allowed to be freely varying, i.e. their values could be selected independent of each other.

In Jarzemba (1996) distributions for the aforementioned parameters were developed using the best available Yucca Mountain site-specific and analogous data. Jarzemba (1996) also attempted to capture interrelationships between several of the volcanic parameters. For example, it was found from the

literature that empirical relationships exist between: the total mass of erupted volcanic ash, the column height, the event power and the event duration, the later two volcanic parameters being studied only for their interrelationship and for future use. It was found that by sampling the values of any two of these parameters, that all four parameter values were determined. The wind parameters (speed and direction) were sampled based on data contained in the *Site Characterization Plan* [DOE (1988)] and the following parameter values were held constant based on values found in Suzuki (1983): the volcanic particle shape factor (0.5), the eddy diffusivity constant (400 $cm^2/s^{5/2}$), the air viscosity (0.00018 g/cm-s) and the air density (0.00129 g/cm^3). Further, Jarzemba (1996) noted that radionuclide isopachs could be calculated from the volcanic ash isopachs by assuming that the radionuclides released in the event were uniformly distributed throughout the ash mass ejected in the event.

The following is a summary of the how the previously mentioned parameters and distributions were sampled in Jarzemba (1996):

The eruption duration (T) - This parameter (in s) was sampled from a loguniform distribution where the log of the duration is sampled over the range [3.25,6.83]. This range was determined from analogous data.

The eruption power (P) - This parameter was sampled from a lognormal distribution. The value of T is used to determine the mean value for the lognormal distribution from a linear least squares fit of a plot of event power vs. duration for analogous volcanoes. The standard deviation of the lognormal distribution is determined by the spread of the analogous data about the linear least squares fit. The value of P was limited to 7.0×10^{13} W, corresponding to a column height of 24 km, which is an estimate of the highest stable column height observed in the analogous events.

The total mass of erupted volcanic ash (q) - This parameter (in g) was chosen deterministically based on the values of P and T and interrelationships found in the literature.

The volcanic column height (H) - This parameter (in km) was also chosen deterministically based on the values of P and T and interrelationships found in the literature.

The distribution of volcanic ash mass with particle log-diameter $\left[f(\rho^a)\right]$ - The mean and standard deviation for this distribution were determined from logtriangular and loguniform distributions respectively. The minimum, mode and maximum values for the mean particle diameter were 0.01,0.1 and 10 cm respectively. The minimum and maximum values for the standard deviation of the particle log-diameter were -1.0 and 0.3 respectively. These ranges were determined from data given in Suzuki (1983).

Beta (β) - This parameter was sampled from a loguniform distribution over the range [0.01,0.5]. This range was chosen based on data in Suzuki (1983).

The volcanic eruption velocity at the vent exit (W_0) - This parameter (in m/s) was chosen deterministically based on the values of q and T.

The wind direction (u_{dir}) - This parameter (in degrees) was sampled in 22.5 degree increments over the range [-180,180] with zero degrees being due east. The relative probabilities of the 22.5 degree "bins" were determined from data in the *Site Characterization Plan* [DOE (1988)].

The wind speed (u) - The wind speed (in cm/s) was sampled from an exponential distribution with the mean wind speed in the prevailing wind direction being a function of that direction, i.e. different wind directions have different mean wind speeds. These directionally dependent mean wind speeds were determined from the *Site Characterization Plan* [DOE (1988)].

These same parameter sampling procedures are used for the current study.

2 DESCRIPTION OF MODELING APPROACH

2.1 EXPOSURE SCENARIO

The exposure scenario for these dose estimates is based on the assumption that the critical group is composed of an Amargosa Desert farmer/rancher residing on a plot of land at a specified point in the region (the dose point) immediately after a volcanic eruption occurs. The critical group is defined as a relatively small group of individuals (or individual) whose membership includes the maximally exposed individual, using cautious but reasonable assumptions, and other individuals whose projected dose is within an order of magnitude of the maximally exposed individual [(ICRP 1991; 1985; 1977)]. For the purposes of these analyses, the critical group is the maximally exposed individual as defined by the lifestyle characteristics in LaPlante et al., (1995). For these preliminary analyses, no other possible critical groups were considered. The Amargosa Desert farmer/rancher is selected as the critical group because of current lifestyle practices in the YM region. Figure 1 shows the dose points chosen for this report and the depth to the water table. The depth to the water table together with land slope were key parameters in deciding where this group would most likely exist. A great depth to the water table would make this scenario economically infeasible. Similarly, a high land slope would seem to limit the desirability of a sight for arid-region farming. Due to large uncertainties in predictions of parameter values over the long term, a static biosphere assumption was used that relies on current site characteristics, of the region south of YM for dose estimates (i.e., today's biosphere). Details of the farmer/ranchers lifestyle activities were based upon reasonable assumptions that would result in a reasonably maximal exposure. The resident farmer/rancher was assumed to raise (locally) half of his consumed beef, milk, fruit, grain, and vegetables and was assumed to obtain all pork, poultry, and fish products from other, uncontaminated sources. The assumption that the farmer/rancher consumes half of his beef, milk, fruit, grains, and vegetables is similar to assumptions made for low-level waste repository performance assessments where it is assumed that 50 percent of a person's diet is from contaminated, locally grown food [Yu et al., (1993)]. These assumptions are based on the best available site specific information about the lifestyle activities of this group [LaPlante et al., (1995), Wescott et al., (1995)]. A detailed description of the lifestyle characteristics of the exposure scenario and parameter selections is provided in LaPlante et al. (1995), however, the present analysis used soil concentration from volcanic ash deposition as the source of contamination rather than groundwater. In this region, no farms exist that sell food crops for export, but some raise livestock using both pasture land and feed crops irrigated with local groundwater.[1] The primary livestocks in the county encompassing the potential exposure area are

[1]Personal Communication, Las Vegas Agricultural Extension Office, Nevada, January 27, 1995.

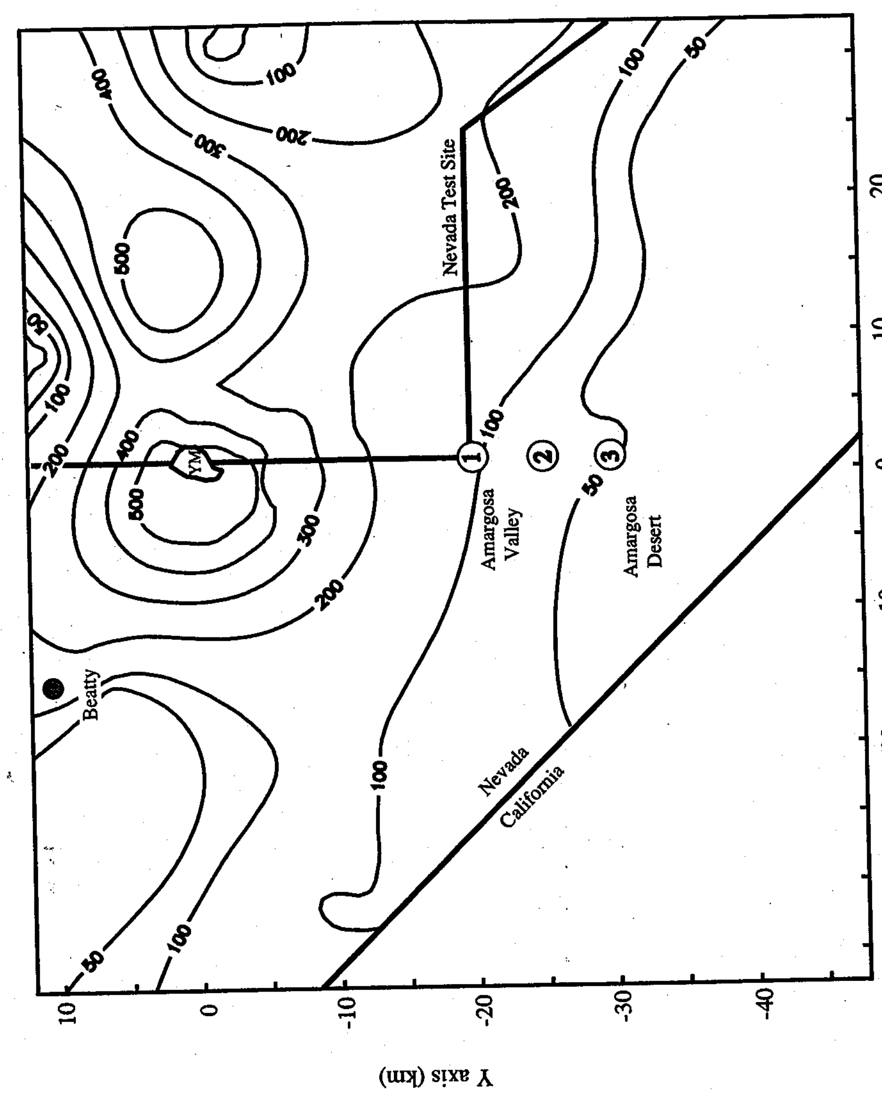

Figure 1. The dose points considered in these analyses; water table contours in meters below ground surface

beef cattle, while hogs, chickens, and milk cows are raised in lesser numbers [U.S. Department of Commerce (1989)]. Feed crops are predominantly hay (e.g., alfalfa) and limited amounts of grain. At present, alfalfa farms in particular are located in the Amargosa Desert region [Nevada Division of Water Resources (1995)].

Parameter distributions were determined from the literature or estimated from reported ranges. Agricultural information was collected for southwestern Nevada [U.S. Department of Commerce (1989); Nevada Agricultural Statistics Service (1988)]. Soil characteristics were assumed to be similar to those in the Amargosa Desert area and information on these characteristics was obtained from local and national offices of the Soil Conservation Service [LaPlante et al. (1995)]. Future analyses may include updating these soil characteristics with ones more representative of volcanic ash.

Nevada Test site studies provided information for modeling doses from resuspension [Anspaugh et al. (1975); Otis (1983); Breshears et al. (1989)] and crop interception of contaminated air [Anspaugh (1987)]. For the present analysis, a resuspension factor for soil was used, however, future analyses may be improved by using resuspension factors for volcanic ash. A range from 30 to 82 percent of animal feed for milk and beef was assumed to be from contaminated fresh forage [Breshears et al. (1992)]. Generic parameter values from prior NRC assessments [Kennedy and Strenge (1992)] were used when information was not available from local sources. Food transfer factors, while not from local sources, were from recent work [International Atomic Energy Agency (1994)] supplemented as necessary with additional data [Baes III et al. (1982); Hoffman et al. (1982)]. External dose conversion factors in the GENII-S code [Leigh et al., (1993)] were updated using recent Environmental Protection Agency (EPA) federal guidance [Eckerman and Ryman (1993)].

A diagram of this exposure scenario is presented in Figure 2. The progression of events in the exposure scenario shown in Figure 2 is as follows:

(1) Magma enters the repository and becomes contaminated with spent fuel particles.

(2) Ash forms into contaminated particulate matter. The level of contamination of the particles as a function of particle size of the volcanic ash is as given later in this report.

(3) Eruption parameters are sampled according to the procedure given in Jarzemba (1996) and summarized in the background section of this report.

(4) Eruption column and contaminant plume form and produce volcanic ash fallout at distances and directions as determined by the methods in Suzuki (1983) and Jarzemba (1996).

(5) Doses received by an Amargosa Desert farmer/rancher at the dose points were calculated. It is assumed that the farmer/rancher exists immediately after the particle plume laid down the contaminated blanket. The pathways accounted for in the calculated doses were inhalation (from resuspension), ingestion from both contaminated animal products and crops, and external dose from groundshine. Contamination of the water table from water percolating through the ash blanket and subsequent doses from the drinking water pathway have not been accounted for in these analyses.

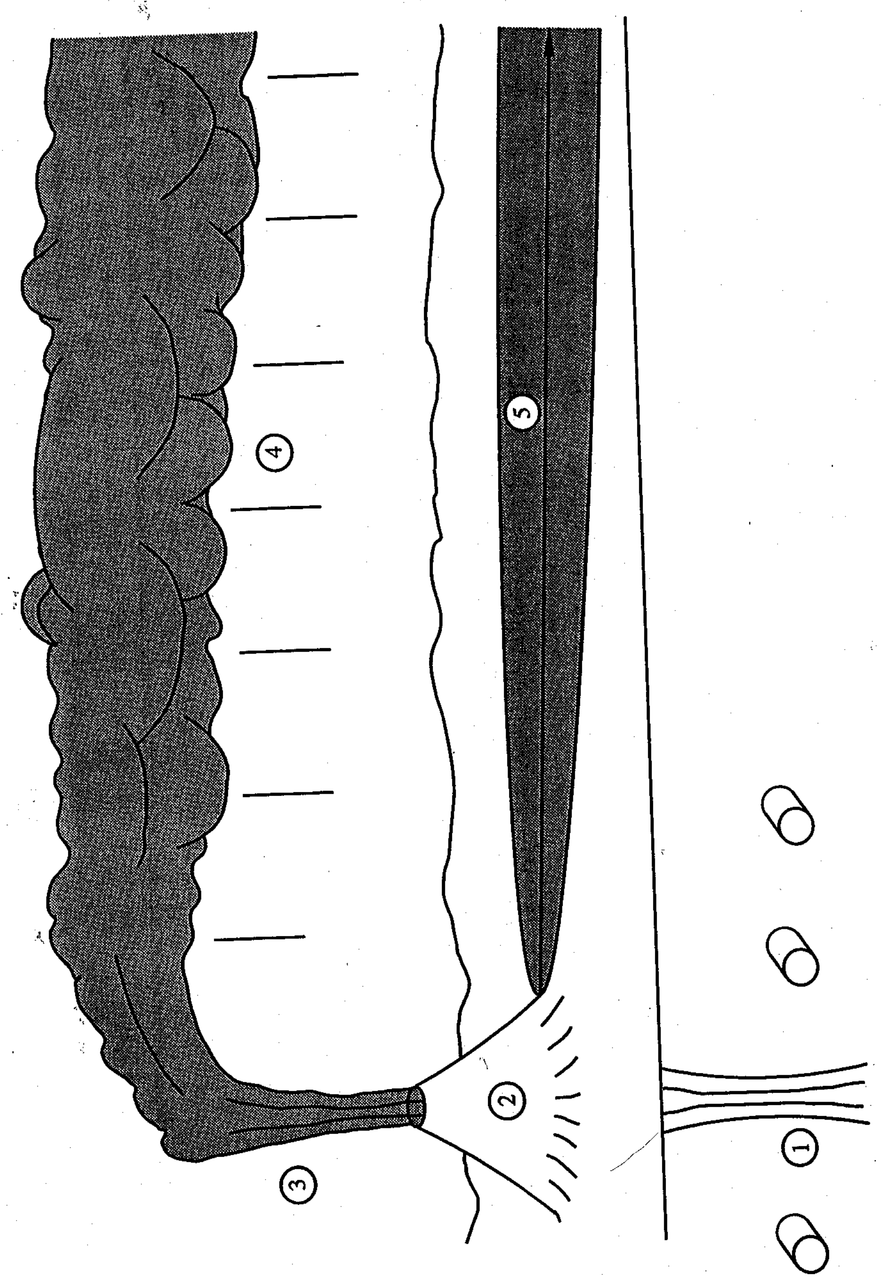

Figure 2. Diagram of the Exposure Scenario

2.2 PROBABILITY OF VOLCANIC DISRUPTION

In order to calculate the expected value of the peak dose to the critical group due to extrusive volcanism in the Time Period of Interest (TPI), the probability of volcanic disruption must be known. Connor and Hill (1995) modeled volcanism in the YM region as a spatially inhomogeneous and time homogeneous process to estimate the probability of a new cone forming in an 8 km^2 region, including the repository footprint plus a 500 m buffer zone, over the next 10,000 yr. They found that the probability ranges from about 1×10^{-4} to 5×10^{-4}. For the purposes of these analyses, a centroid value of 3×10^{-4} per 10,000 yr, leading to a recurrence rate (λ_{rr}) of 3×10^{-8} per yr was assumed.

Two TPIs were considered; 10,000 yr and 1,000,000 yr. Multiple events in the TPI were not explicitly considered, however, in determining the probability of new cone formation they were treated as a single event. If it is assumed that the above recurrence rate is constant in time (i.e., no waxing or wanning) and that volcanism occurs as a homogeneous Poisson process, then the probability of <u>no</u> volcanic disruption in the TPI is given by:

$$\overline{p(TPI)} = \exp\left(-\lambda_{rr}\cdot TPI\right) \tag{2-1}$$

Conversely, the probability of at least one disruption during the TPI is given by:

$$p(TPI) = 1 - \exp\left(-\lambda_{RR}\cdot TPI\right) \tag{2-2}$$

Explicitly, the probabilities of at least one disruption in TPIs of 10,000 yr and 1,000,000 yr are:

$$p(10{,}000\ yr) = 3.0\times10^{-4} \tag{2-3}$$

$$p(1{,}000{,}000\ yr) = 3.0\times10^{-2} \tag{2-4}$$

2.3 VOLCANIC ASH DISTRIBUTION CALCULATIONS

Volcanic ash distributions after an event were calculated using the methods and data outlined earlier. The point on the earth's surface at which volcanic ash thicknesses and subsequent radionuclide densities were calculated, (the dose point), was assumed to be at a specified location and is treated as a parameter in these calculations. Possible dose points used in these calculations were 20, 25, and 30 km directly south of the repository. These points were chosen based on: knowledge of the present day population [LaPlante et al., (1995), Wescott et al., (1995)], depth to the water table, and land slopes considered to be favorable to farming/ranching under the present condition.

2.4 RADIONUCLIDE DISTRIBUTION WITHIN THE ASH BLANKET

In Jarzemba (1996), the radionuclides released in the volcanic event were assumed to be uniformly distributed within the volcanic ash mass released in the event. In these analyses, a different distribution was used, which is thought to be more realistic even though no experimental data is available to confirm this assertion.

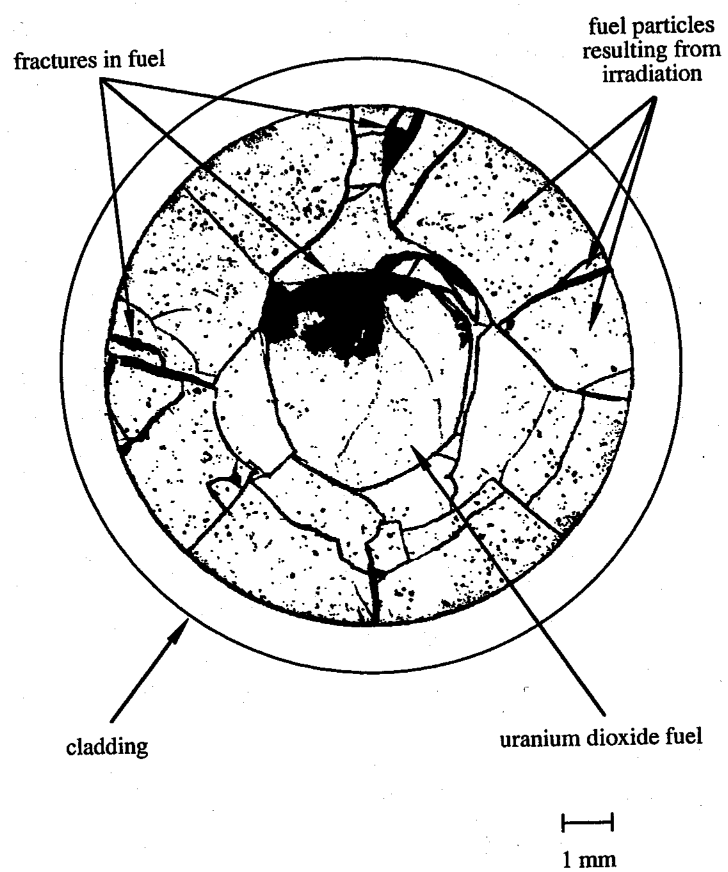

Figure 3. Cross section of a fuel pellet after irradiation and fissioning in a reactor [abstacted from Clark, et al. (1985)]

Spent nuclear fuel is highly fractured from the buildup of fission fragment gasses in its ceramic matrix during irradiation in the reactor. Figure 3, abstracted from Clark et al., (1985), shows a cross section of an irradiated spent-fuel pellet. For these analyses, it was assumed that the log of the fuel particle diameter has a triangular probability distribution. The minimum and maximum fuel particle diameters were assumed to be 0.01 cm and 1.0 cm which correspond to log-diameters of −2 and 0 respectively. The median particle diameter was assumed to be 0.1 cm corresponding to a log-diameter of −1. Figure 4 shows the probability density function for the mass of fuel of the log-diameter$[m(\rho^f)]$ using these assumptions. The upper limit of $\rho^f = 0$ was assumed because spent-fuel pellets are about 1 cm in diameter before irradiation in the reactor. The median value of $\rho^f = -1$ was assumed from the visual evidence presented in Figure 3, as the median fractured particle diameter appears to be about 1 mm. The lower limit of $\rho^f = -2$ was assumed based on this same evidence since very few particles in Figure 3 appear to have diameters smaller than 0.1 mm. This distribution of the fuel particle size was used independent of the timing of the event. Future work on this topic may include use of a time dependent distribution of the fuel mass with particle size to account for changes in fuel structure with chemical composition and age.

It was conservatively assumed in these analyses that all canister cladding and containment have been breached and are ineffective at preventing exposure of the fuel to the magma or volcanic ash particulate matter as it is being formed. This assumption will be investigated further in future work on this topic. Since the magma is typically at temperatures of about 1,000 °C, which is above the melting point of zircalloy, the conservative assumption that the cladding was also ineffective at preventing spent-fuel incorporation was made. This assumption may also be updated as further information on waste package performance under these conditions becomes available.

This scheme for partitioning fuel into an erupting magma requires the introduction of a new function into the previous analyses of Jarzemba (1996) to determine the mass of fuel per unit mass of volcanic ash as a function of the log-diameter of the ash after the ash has been contaminated with spent fuel $[FF(\rho^a)]$. As in Jarzemba (1996), the volcanic ash mass is assumed to be distributed lognormally

$$f(\rho^a) = \frac{1}{\sqrt{2\pi}\,\sigma_d}\exp\left(-\frac{(\rho^a - \rho^a_{mean})^2}{2\sigma_d^2}\right) \tag{2-5}$$

where:

- ρ^a = the log-diameter of ash particle size, with particle size in cm
- ρ^a_{mean} = the mean of the log-diameter of ash particle size, with particle size in cm
- σ_d = the standard deviation of the log particle size
- $f(\rho^a)$ = the normalized probability distribution of ash mass with ρ^a

The mass of fuel as a function of the log-diameter of the fuel $[m(\rho^f)]$ is defined as

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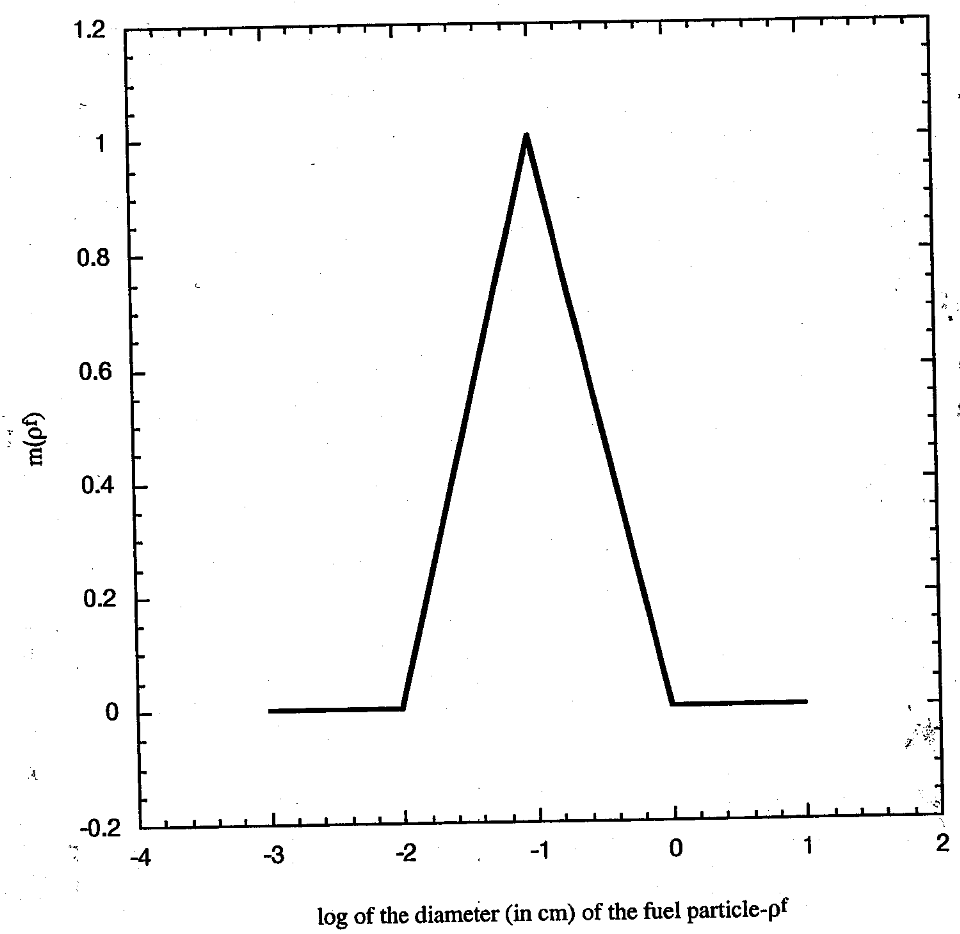

Figure 4. Assumed probability density of mass of fuel versus log-diameter of fuel particle

$$m(\rho^f) = k_1(\rho^f - \rho^f_{min}) \qquad \rho^f_{min} < \rho^f \le \rho^f_{med}$$

$$m(\rho^f) = k_2(\rho^f - \rho^f_{med}) + k_1(\rho^f_{med} - \rho^f_{min}) \qquad \rho^f_{med} < \rho^f \le \rho^f_{max} \qquad (2\text{-}6)$$

$$m(\rho^f) = 0 \qquad \text{otherwise}$$

where:

$$k_1 = \frac{2}{(\rho^f_{max} - \rho^f_{min})(\rho^f_{med} - \rho^f_{min})}$$

$$k_2 = -\frac{2}{(\rho^f_{max} - \rho^f_{min})(\rho^f_{max} - \rho^f_{med})}$$

ρ^f = the log-diameter of fuel particle size, with particle size in cm
ρ^f_{min} = the minimum log-diameter of fuel particle size, with particle size in cm
ρ^f_{max} = the maximum log-diameter of fuel particle size, with particle size in cm
ρ^f_{med} = the median log-diameter of fuel particle size, with particle size in cm
$m(\rho^f)$ = the normalized probability distribution of fuel mass with ρ^f

The motivation for limiting the amount of fuel mass available for incorporation into the volcanic ash particles of a given size is that for smaller volcanic ash particles an amount of fuel mass will be too large to be incorporated into these small particles. For example, a 1 cm fuel particle cannot be incorporated by a 0.5 cm volcanic ash particle. For the purposes of these analyses, the cutoff on the ratio of "incorporable" fuel diameter to volcanic ash diameter was assumed to be 0.1. This assumption means that the incorporable fuel mass must have a log-diameter (ρ^f) less than $\rho^a - \rho_c$ where ρ_c is equal to one. The parameter ρ_c can be revised as future information becomes available. A sensitivity analysis of ρ_c may also be conducted to determine the importance of this parameter. Another example, ρ_c equal to zero, is equivalent to allowing all fuel mass of size less than or equal to the volcanic ash particle size to be available for incorporation.

The assumption that ρ_c is equal to one was made from the authors' observations of actual particles presumably transported by volcanic convective columns and subsequent plume fallout. The observed incorporated matter (wall or other rock fragments) in these particles appears to be about one order of magnitude or less in size than the particle size itself. A search of the literature in this area found no corroborating evidence for this assumption. The value of ρ_c should be updated as future evidence on this topic becomes available.

To determine $FF(\rho^a)$ the fuel fraction (ratio of fuel mass to ash mass) as a function of ρ^a, one must consider that all fuel particles of size smaller than $(\rho^a - \rho_c)$ have the ability to simultaneously be

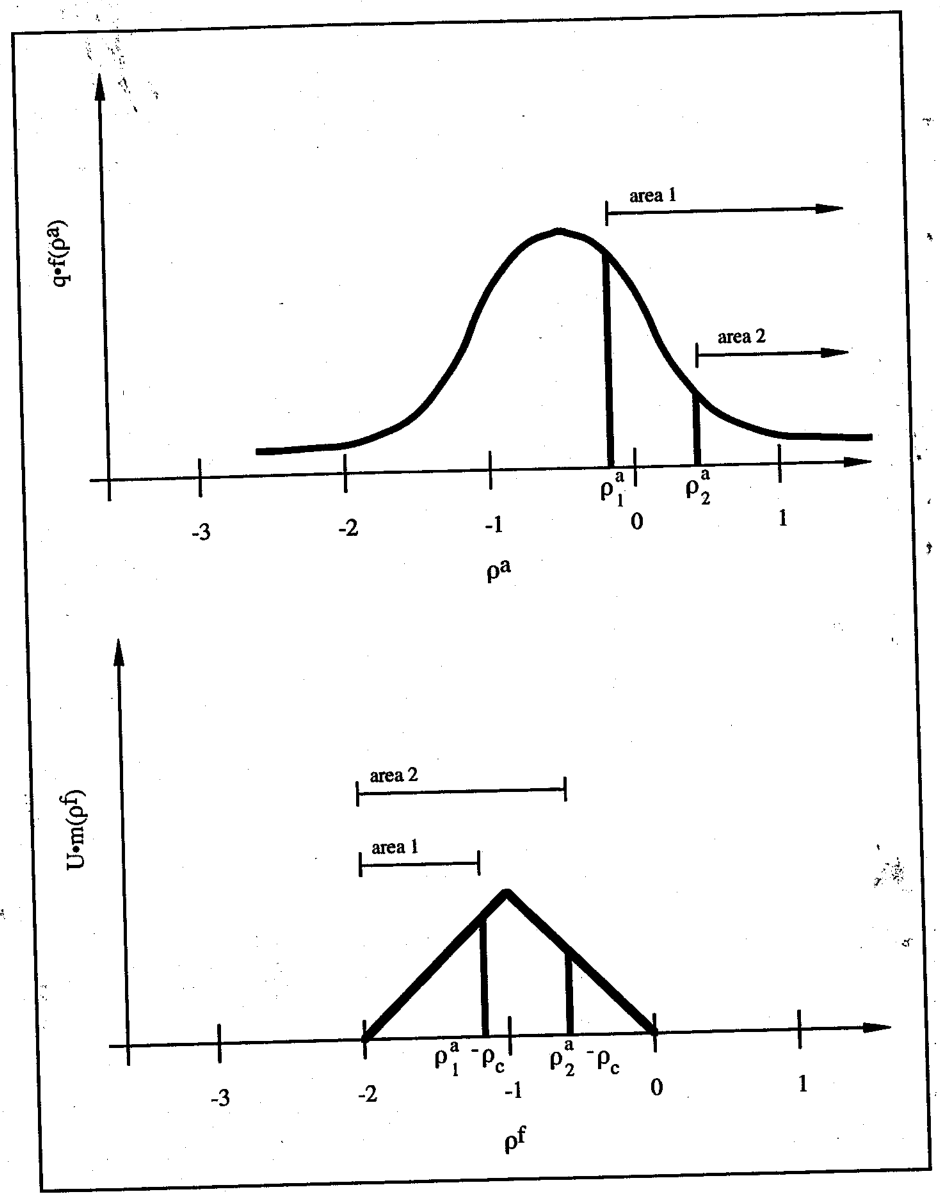

Figure 5. A diagram describing the fuel fraction as a function of ρ^a

incorporated into volcanic ash particles of size ρ^a or larger. This situation is shown in Figure 5 by considering that all the fuel mass in area 1 of the lower curve is available to all the volcanic ash mass in area 1 of the upper curve. Similarly, all the fuel mass in area 2 of the lower curve is available to all the volcanic ash mass in area 2 of the upper curve. This partitioning scheme was done to reflect the fact that larger volcanic ash has the ability to incorporate a relatively larger amount of spent-fuel. The fuel fraction as a function of ρ^a was determined by summing all the incremental contributions of fuel mass to the volcanic ash mass from fuel sizes smaller than $(\rho^a - \rho_c)$. An expression for the fuel fraction is given as

$$FF(\rho^a) = \frac{U}{q} \cdot \int_{\rho=-\infty}^{\rho=\rho^a} \frac{m(\rho - \rho_c)}{1 - F(\rho)}\, d\rho \qquad (2\text{-}7)$$

where:

q	=	the total mass of ash ejected in the event in g
U	=	the total mass of fuel ejected in the event in g
$F(\rho^a)$	=	the cumulative distribution of $f(\rho^a)$

Equation (2-7) assumes the resulting contaminated particles follow the same size distribution as the original volcanic ash particles. This seems reasonable since for most events sampled in these analyses, the total mass of volcanic ash is on the order of 10^{13} to 10^{15} g and for these preliminary analyses, each event was assumed to disrupt one waste package, or 10^7 g of fuel. The assumption that one waste package was available for incorporation was used as a baseline and will be updated by future work. For example, it may be possible to relate the number of waste packages available for incorporation to the energetics of the event.

Very dense particles cannot be transported significant distances by a convective column (from observations made with this model, "very dense" means "with density greater than about 5 g/cm^3"). In these analyses, if the fuel fraction was greater than one then it was truncated to zero (to remove the contamination that these particles carry from the transport scenario). A fuel fraction of one corresponds to a contaminated particle composed of equal masses of fuel and volcanic ash. Since the average ash density is about 1.5 g/cm^3 and spent-fuel has an initial density of about 11 g/cm^3, $FF(\rho^a)=1$ roughly corresponds to a particle with a density of 5 g/cm^3.

To clarify this procedure further, consider the following simple, albeit unrealistic, example. Assume that the total quantity of volcanic ash released in the event (q) occurs in the following way: one-third of the volcanic ash mass has $\rho^a=-1$; one-third of the volcanic ash mass has $\rho^a=0$; and one-third of the volcanic ash mass has $\rho^a=1$. Assume that the total quantity of spent-fuel released in the event (U) occurs in the following: one-third of the fuel mass has $\rho^f=-2.01$; one-third of the fuel mass has $\rho^f=-1.01$; and one-third of the fuel mass has $\rho^f=-0.01$. For reasons previously stated, it is assumed that $\rho_c=1$. For this simplistic example, it is only necessary to describe the fuel fraction at $\rho^a=-1,0$ and 1 to completely describe the system.

The fuel fraction at these three values of ρ^a is given as follows:

$$FF(\rho^a = -1)\frac{\frac{1}{3}U}{q} = \frac{1}{3}\frac{U}{q} \qquad (2\text{-}8)$$

$$FF(\rho^a = 0) = \frac{\frac{1}{3}U}{q} + \frac{\frac{1}{3}U}{\frac{2}{3}q} = \frac{5}{6}\frac{U}{q} \qquad (2\text{-}9)$$

$$FF(\rho^a = 1) = \frac{\frac{1}{3}U}{q} + \frac{\frac{1}{3}U}{\frac{2}{3}q} + \frac{\frac{1}{3}U}{\frac{1}{3}q} = \frac{11}{6}\frac{U}{q} \qquad (2\text{-}10)$$

If it is assumed that U and q are equal then $FF(\rho^a = 1)$ is greater than 1, and hence its value must be truncated to zero because these particles are too dense to be transported significant distances by a convection column. Finally, the fuel fraction becomes:

$$FF(\rho^a=-1) = \frac{1}{3}$$

$$FF(\rho^a=0) = \frac{5}{6} \qquad (2\text{-}11)$$

$$FF(\rho^a=1) = 0$$

An isopleth map of the areal density of spent fuel as a function of position for a particular realization of the spent-fuel distribution is provided in Figure 6. The realization for which the spent-fuel contours are shown in Figure 6 occurred at a time of 829 yr. The sampled time of 829 yr is an arbitrary choice and any other event time within the TPI is equally as valid. Table 1 shows the radionuclide content of the spent-fuel at that point in time (in Ci/g of spent-fuel). The important simulation parameters that were sampled in the realization shown in Figure 6 are shown in Table 2, and the fuel fraction as a function of ρ^a for this case is shown in Figure 7. The volcanic parameters (and their interrelationships) that were held constant in these analyses are described in Jarzemba (1996) and re-stated in the background section of this report. These parameters include such constants as the particle shape parameter, air viscosity and density, and the eddy diffusivity constant. In calculations presented in this report, radionuclide inventories have been determined by using the INVENT computer module described in Lozano et al., (1994). The time of event occurrence was sampled uniformly over the TPI with events occurring in the first 100 yr having zero dose to account for and active institutional controls for the first

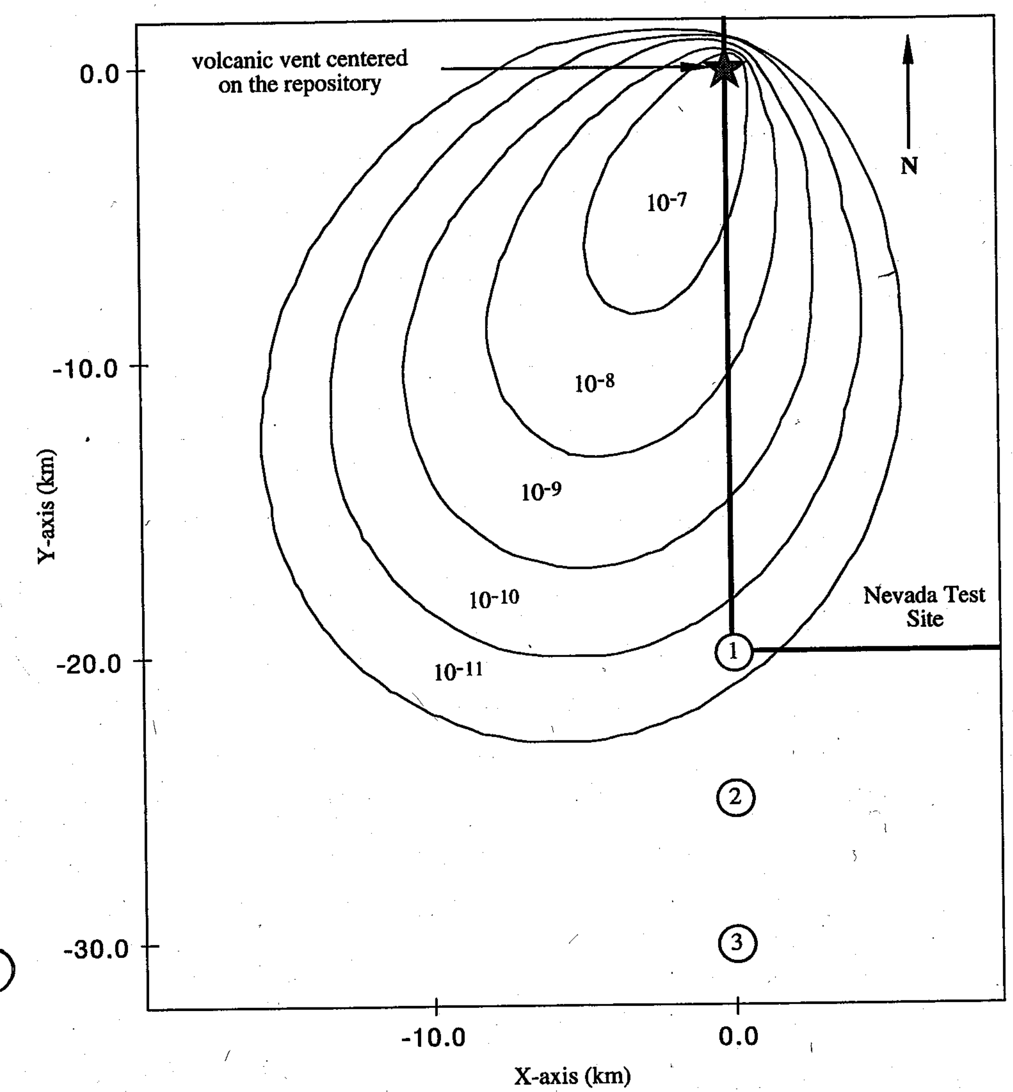

Figure 6. A spent fuel isoach map following an eruption with the parameters shown in Table 1. All densities are shown in g of spent-fuel per cm². In this particular realization, the event occurred at t=829 yr.

100 yr after closure. During this initial period, controls would presumably prevent farming on the ash blanket. It was also assumed that the fuel had been aged 100 yr by repository closure to more accurately reflect the radionuclide inventory of the fuel.

2.5 DOSE CONVERSION

Conversion from radionuclide concentrations to dose was done using the GENII-S [Leigh et al. (1993)] code. Individual annual total effective dose equivalents (TEDEs) were calculated for each of 42 radionuclides for a resident Amargosa Desert farmer/rancher based upon unit radionuclide concentrations on the soil. The 42 radionuclides modeled in these calculations are as follows:

Curium isotopes:	246, 245, 244, 243
Americium isotopes:	243, 242m, 241
Plutonium isotopes:	242, 241, 240, 239, 238
Uranium isotopes:	238, 236, 235, 234, 233, 232
Thorium isotopes:	230, 229
Cesium isotopes:	137, 135
Other isotopes:	^{237}Np, ^{231}Pa, ^{227}Ac, ^{226}Ra, ^{210}Pb, ^{151}Sm, ^{129}I, ^{126}Sn, ^{121m}Sn, ^{107}Pd, ^{99}Tc, ^{94}Nb, ^{93}Mo, ^{93}Zr, ^{90}Sr, ^{79}Se, ^{63}Ni, ^{59}Ni, ^{36}Ci, ^{14}C

This list matches the one given in the Sandia TSPA-1993 [Wilson et al., (1994)], with one exception. That exception is ^{108m}Ag, for which data to perform the dose conversion analyses was unavailable. In any case, this isotope is not expected to be a major contributor to dose. A Monte Carlo style analysis with 125 realizations is used to generate TEDE distributions. Input parameter values were sampled from distributions using Latin Hypercube Sampling. Tables 3 through 6 present the results as the expected values and standard deviations of annual TEDE distributions for each pathway calculated for each radionuclide assuming that the radionuclides were deposited on the surface of the soil with unit concentration. Table 7 gives the total pathway DCFs assuming that the individual consumes 50 percent of his food from contaminated sources.

2.6 CALCULATION OF THE EXPECTED VALUE OF THE PEAK DOSE TO THE AMARGOSA DESERT FARMER/RANCHER IN THE TIME PERIOD OF INTEREST

Values of the peak annual effective dose equivalent (hereafter called dose) to the Amargosa Desert farmer/rancher in the TPI for each realization were calculated for TPIs of 10,000 yr and 1,000,000 yr. For each TPI, 1,000 dose realizations were obtained. The dose to the farmer/rancher was calculated based on the dose conversion factors in the previous section. The expected value of the peak dose in the TPI to the farmer/rancher is given by:

$$E(\dot{D},TPI) = p(TPI) \sum_{n=1}^{N_R} \frac{1}{N_R} \cdot \dot{D}(n) \quad (2\text{-}12)$$

Table 1. Radionuclide concentration in the spent-fuel in curies per gram of spent-fuel for the realization shown in Figure 6

Radionuclide	Ci of radionuclide per g of spent fuel
Ac-227	3.00E-10
Am-241	1.10E-03
Am-242m	1.80E-07
Am-243	1.40E-05
C-14	1.20E-06
Cl-36	1.20E-08
Cm-243	3.40E-14
Cm-244	2.80E-17
Cm-245	1.20E-07
Cm-246	2.30E-08
Cs-135	3.50E-07
Cs-137	4.60E-10
I-129	2.90E-08
Mo-93	8.60E-09
Nb-94	4.90E-07
Ni-59	2.40E-06
Ni-63	6.40E-07
Np-237	8.90E-07
Pa-231	3.20E-10
Pb-210	2.00E-09
Pd-107	1.00E-07
Pu-238	3.30E-06
Pu-239	3.00E-04
Pu-240	4.70E-04
Pu-241	1.20E-07
Pu-242	1.60E-06
Ra-226	2.10E-09
Se-79	3.80E-07
Sm-151	5.80E-07
Sn-121m	9.20E-12
Sn-126	7.10E-07
Sr-90	1.80E-10
Tc-99	1.20E-05
Th-229	7.80E-11
Th-230	1.40E-08
U-232	9.30E-12
U-233	2.40E-09
U-234	1.90E-06
U-235	1.70E-08
U-236	2.50E-07
U-238	3.20E-07
Zr-93	1.80E-06

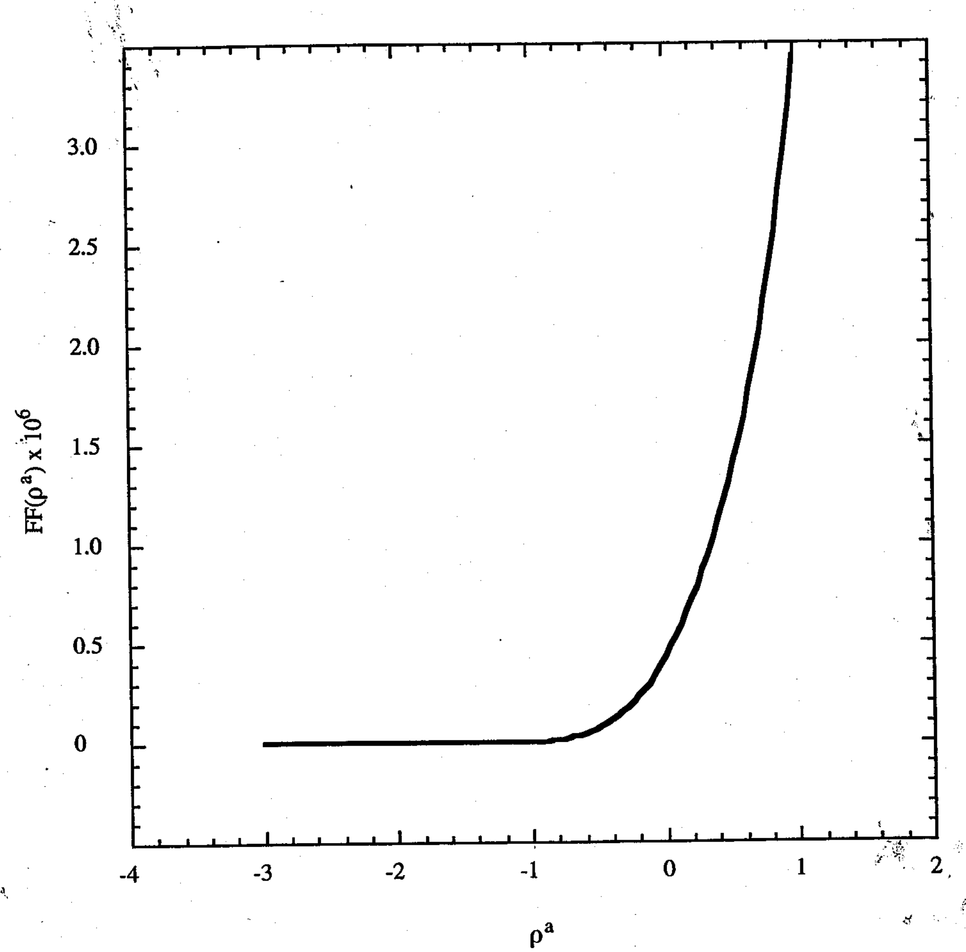

Figure 7. A plot of the normalized fuel fraction as a function of ρ^a for the realization shown in Figure 6.

Table 2. Listing of the sampled parameters for the realization shown in Figure 6

Parameter	Distribution Type	Range	Sampled Value
Total volcanic ash mass (g)	Described earlier		3.73×10^{13}
Event duration (s)	Loguniform	[3.25, 6.83]	3.3×10^{4}
Event power (W)	Lognormal	[0. 13.8]	8.23×10^{11}
Column height (km)	Function of power		7.809
Mean particle diameter (cm)	Logtriangular	[−2, 1]	0.068
Standard deviation of particle log-diameter	Loguniform	[−3, 0.3]	0.995
Beta[1]	Loguniform	[0.01, 0.5]	0.305
Wind speed (cm/s)	Exponential		832.4
Wind direction (degrees-relation to due east)	Described earlier		−112.5
Mass of fuel ejected (g)	Constant		1.0×10^{7}

1 Beta is a constant controlling particle diffusion in the eruption column.

where:

$\dot{D}(n)$ = the peak dose to the farmer/rancher in the TPI for realization n
N_R = the number of event realizations

The quantity $\dot{D}(n)$ is calculated as:

$$\dot{D}(n) = \sum_{i=1}^{42} {}^{T}DCF_i \cdot C_i \qquad (2\text{-}13)$$

where:

${}^{T}DCF_i$ = the total pathway DCF for radionuclide i (Table 7)
C_i = the radionuclide surficial concentration at the dose point

The expected doses generated by Equation (2-12) assume that the only scenario for delivering doses to the farmer/rancher is extrusive volcanism. The summation in Equation (2-12) represents the expected value of the dose given that an extrusive event occurs in the TPI within the repository zone and disrupts

Table 3. Dose Conversion Factors (DCFs) for the animal product ingestion pathway

Radionuclide	Expected value of the DCF [rem/yr/Ci/cm^2]	Standard Deviation [rem/yr/Ci/cm^2]
Ac-227	1.70E+08	1.40E+08
Am-241	3.10E+07	2.40E+07
Am-242m	3.00E+07	2.30E+07
Am-243	3.10E+07	2.40E+07
C-14	0.00E+00	0.00E+00
Cl-36	2.70E+08	2.20E+08
Cm-243	1.50E+07	1.50E+07
Cm-244	1.20E+07	1.20E+07
Cm-245	2.30E+07	2.10E+07
Cm-246	2.30E+07	2.20E+07
Cs-135	8.50E+07	6.50E+07
Cs-137	5.90E+08	4.50E+08
I-129	2.70E+09	2.10E+09
Mo-93	1.10E+06	9.50E+05
Nb-94	1.30E+03	1.10E+03
Ni-59	1.10E+06	1.00E+06
Ni-63	3.10E+06	2.70E+06
Np-237	1.10E+09	8.30E+08
Pa-231	3.60E+07	2.80E+07
Pb-210	1.00E+09	8.00E+08
Pd-107	5.40E+05	4.80E+05
Pu-238	1.10E+05	8.70E+04
Pu-239	1.20E+05	8.80E+04
Pu-240	1.20E+05	8.80E+04
Pu-241	4.40E+03	3.40E+03
Pu-242	1.10E+05	8.30E+04
Ra-226	5.00E+08	3.00E+08
Se-79	3.50E+07	2.60E+07
Sm-151	3.90E+05	3.00E+05
Sn-121m	3.60E+07	2.80E+07
Sn-126	3.40E+08	2.60E+08
Sr-90	3.60E+08	2.60E+08
Tc-99	1.50E+06	1.20E+06
Th-229	5.30E+07	4.70E+07
Th-230	1.40E+06	1.10E+06
U-232	1.30E+07	1.10E+07
U-233	4.50E+06	3.70E+06
U-234	1.10E+05	3.70E+06
U-235	4.60E+06	3.90E+06
U-236	4.10E+06	3.50E+06
U-238	4.40E+06	3.60E+06
Zr-93	6.00E+02	4.70E+02

Table 4. Dose Conversion Factors (DCFs) or the terrestrial food ingestion pathway

Radionuclide	Expected value of the DCF [rem/yr/Ci/cm^2]	Standard Deviation [rem/yr/Ci/cm^2]
Ac-227	2.70E+10	1.70E+10
Am-241	6.90E+09	4.40E+09
Am-242m	6.70E+09	4.20E+09
Am-243	6.90E+09	4.40E+09
C-14	0.00E+00	0.00E+00
Cl-36	4.10E+08	2.50E+08
Cm-243	4.80E+09	3.00E+09
Cm-244	3.80E+09	2.40E+09
Cm-245	7.10E+09	4.50E+09
Cm-246	7.20E+09	4.50E+09
Cs-135	1.40E+07	8.30E+06
Cs-137	9.50E+07	5.80E+07
I-129	4.90E+08	3.00E+08
Mo-93	4.80E+06	2.20E+06
Nb-94	1.40E+07	8.80E+06
Ni-59	4.00E+05	2.50E+05
Ni-63	1.10E+06	6.70E+05
Np-237	1.00E+10	6.40E+09
Pa-231	2.10E+10	1.30E+10
Pb-210	1.10E+10	6.70E+09
Pd-107	3.30E+05	1.90E+05
Pu-238	8.34E+07	5.28E+07
Pu-239	9.50E+07	6.00E+07
Pu-240	9.60E+07	6.00E+07
Pu-241	2.30E+06	1.50E+06
Pu-242	9.00E+07	5.70E+07
Ra-226	1.90E+09	1.20E+09
Se-79	1.60E+07	1.00E+07
Sm-151	7.30E+05	4.60E+05
Sn-121m	4.30E+06	2.70E+06
Sn-126	4.00E+07	2.50E+07
Sr-90	3.70E+08	1.90E+08
Tc-99	4.40E+07	2.60E+07
Th-229	7.10E+09	4.50E+09
Th-230	1.00E+09	6.50E+08
U-232	1.60E+08	1.00E+08
U-233	5.10E+07	3.20E+07
U-234	5.00E+07	3.10E+07
U-235	5.40E+07	3.40E+07
U-236	4.70E+07	2.90E+07
U-238	5.90E+07	3.70E+07
Zr-93	3.10E+06	2.00E+06

Table 5. Dose Conversion Factors (DCFs) for the external radiation pathway

Radionuclide	Expected value of the DCF [rem/yr/Ci/cm^2]	Standard Deviation [rem/yr/Ci/cm^2]
Ac-227	1.40E+05	7.70E+03
Am-241	4.60E+07	2.60E+06
Am-242m	2.60E+06	1.50E+05
Am-243	4.60E+07	2.60E+06
C-14	1.40E+04	7.90E+02
Cl-36	5.90E+05	3.30E+04
Cm-243	1.10E+08	6.20E+06
Cm-244	7.80E+05	4.40E+04
Cm-245	7.60E+07	4.30E+06
Cm-246	6.90E+05	3.90E+04
Cs-135	3.00E+04	1.70E+03
Cs-137	4.80E+08	2.70E+07
I-129	2.20E+07	1.30E+06
Mo-93	4.60E+06	2.60E+05
Nb-94	1.30E+09	7.50E+07
Ni-59	0.00E+00	0.00E+00
Ni-63	0.00E+00	0.00E+00
Np-237	2.60E+07	1.50E+06
Pa-231	3.50E+07	2.00E+06
Pb-210	2.20E+06	1.30E+05
Pd-107	0.00E+00	0.00E+00
Pu-238	5.47E+05	3.06E+04
Pu-239	3.20E+05	1.80E+04
Pu-240	7.00E+05	4.00E+04
Pu-241	1.70E+03	1.10E+04
Pu-242	5.90E+05	3.30E+04
Ra-226	5.60E+06	3.10E+05
Se-79	1.80E+04	1.00E+03
Sm-151	4.40E+03	2.50E+02
Sn-121m	4.30E+06	2.40E+05
Sn-126	4.80E+07	2.70E+06
Sr-90	2.40E+05	1.40E+04
Tc-99	6.90E+04	3.90E+03
Th-229	7.40E+07	4.20E+06
Th-230	6.50E+05	3.70E+04
U-232	8.90E+05	5.50E+04
U-233	6.30E+05	3.50E+04
U-234	6.50E+05	3.70E+04
U-235	1.30E+08	7.30E+06
U-236	5.70E+05	3.20E+04
U-238	4.80E+05	2.70E+04
Zr-93	0.00E+00	0.00E+00

Table 6. Dose Conversion Factors (DCFs) for the inhalation from resuspension pathway

Radionuclide	Expected value of the DCF [rem/yr/Ci/cm^2]	Standard Deviation [rem/yr/Ci/cm^2]
Ac-227	2.10E+07	2.70E+06
Am-241	7.00E+06	9.10E+05
Am-242m	6.70E+06	8.60E+05
Am-243	7.00E+06	9.10E+05
C-14	3.30E+01	4.20E+00
Cl-36	3.50E+01	4.50E+00
Cm-243	4.90E+06	6.30E+05
Cm-244	3.90E+06	5.10E+05
Cm-245	7.10E+06	9.30E+05
Cm-246	7.20E+06	9.30E+05
Cs-135	7.10E+01	9.20E+00
Cs-137	4.70E+02	6.20E+01
I-129	2.40E+03	3.10E+02
Mo-93	1.60E+01	2.10E+00
Nb-94	6.00E+03	7.80E+02
Ni-59	1.40E+01	1.80E+00
Ni-63	3.50E+01	4.60E+00
Np-237	1.00E+07	1.30E+06
Pa-231	1.40E+07	1.80E+06
Pb-210	2.10E+05	2.80E+04
Pd-107	2.20E+02	2.60E+01
Pu-238	4.26E+06	5.56E+05
Pu-239	4.80E+06	6.20E+05
Pu-240	4.80E+06	6.20E+05
Pu-241	7.80E+04	1.00E+04
Pu-242	4.60E+06	6.00E+05
Ra-226	1.30E+05	1.70E+04
Se-79	1.50E+02	2.00E+01
Sm-151	4.70E+02	6.20E+01
Sn-121m	1.80E+02	2.30E+01
Sn-126	1.50E+03	2.00E+02
Sr-90	3.20E+03	4.20E+02
Tc-99	1.40E+02	1.80E+01
Th-229	2.70E+07	3.50E+06
Th-230	4.10E+06	5.30E+05
U-232	1.00E+07	1.40E+06
U-233	2.10E+06	2.80E+05
U-234	2.10E+06	2.70E+05
U-235	2.00E+06	2.50E+05
U-236	2.00E+06	2.60E+05
U-238	1.90E+06	2.40E+05
Zr-93	1.30E+03	1.70E+02

Table 7. Total pathway Dose Conversion Factors (DCFs)

Radionuclide	Expected value of the DCF [rem/yr/Ci/cm²]	Standard Deviation [rem/yr/Ci/cm²]
Ac-227	1.36E+10	1.70E+10
Am-241	3.52E+09	4.40E+09
Am-242m	3.37E+09	4.20E+09
Am-243	3.52E+09	4.40E+09
C-14	1.40E+04	7.90E+02
Cl-36	3.41E+08	3.33E+08
Cm-243	2.52E+09	3.00E+09
Cm-244	1.91E+09	2.40E+09
Cm-245	3.64E+09	4.50E+09
Cm-246	3.62E+09	4.50E+09
Cs-135	4.95E+07	6.55E+07
Cs-137	8.23E+08	4.55E+08
I-129	1.62E+09	2.12E+09
Mo-93	7.55E+06	2.41E+06
Nb-94	1.31E+09	7.55E+07
Ni-59	7.50E+05	1.03E+06
Ni-63	2.10E+06	2.78E+06
Np-237	5.59E+09	6.45E+09
Pa-231	1.06E+10	1.30E+10
Pb-210	6.00E+09	6.75E+09
Pd-107	4.35E+05	5.16E+05
Pu-238	4.66E+07	5.28E+07
Pu-239	5.27E+07	6.00E+07
Pu-240	5.36E+07	6.00E+07
Pu-241	1.23E+06	1.50E+06
Pu-242	5.02E+07	5.70E+07
Ra-226	1.21E+09	1.24E+09
Se-79	2.55E+07	2.79E+07
Sm-151	5.65E+05	5.49E+05
Sn-121m	2.45E+07	2.81E+07
Sn-126	2.38E+08	2.61E+08
Sr-90	3.65E+08	3.22E+08
Tc-99	2.28E+07	2.60E+07
Th-229	3.68E+09	4.50E+09
Th-230	5.05E+08	6.50E+08
U-232	9.74E+07	1.01E+08
U-233	3.05E+07	3.22E+07
U-234	2.78E+07	3.12E+07
U-235	1.61E+08	3.50E+07
U-236	2.81E+07	2.92E+07
U-238	3.41E+07	3.72E+07
Zr-93	1.55E+06	2.00E+06

one waste package containing 10 Metric Tonnes of Uranium (MTU) of spent-fuel. By multiplying the summation by the probability of the event occurring in the TPI, the overall expected value was obtained.

Table 8 shows the expected value of the peak annual effective dose equivalent in the TPI as a function of position of the dose point on the earth's surface. The x–y coordinate axis is oriented with positive x in the due east direction, the positive y in the due north direction and is centered on the repository. Appendix A shows the Complementary Cumulative Distribution Functions (CCDFs) and the stack histograms of the common logarithm of the doses for the 1,000 realizations for each of the positions and TPIs shown in Table 8. Table 9 shows the most important radionuclides along with their percent contribution for calculating the expected dose valuse shown in Table 8. For a TPI of 10,000 yr the most important radionuclide was ^{241}Am, with lesser contributions from ^{243}Am, ^{240}Pu, ^{239}Pu and ^{237}Np. For a TPI of 1,000,000 yr the most important radionuclide was ^{237}Np, with significant contributions made from a large number of radionuclides.

2.7 RESULTS

The results show a generally decreasing dose with distance from the event (Table 8). The CCDFs and the stack histogram of doses for the three dose points and two TPIs are given in Appendix A. These results indicate that increasing the TPI from 10,000 yr to 1,000,000 yr generally increases the expected value of the peak doses in the TPI by a factor of two to four, although the magnitude of this increase is somewhat uncertain due to the large standard deviation on the estimates. Increase in the importance of volcanism is more pronounced when one compares the low dose rate ranges of the CCDFs for the two TPIs for the same dose point, as shown in Appendix A. The differences in the high dose rate ranges in the CCDFs are an artifact of the sampling scheme. Since 1,000 realizations were achieved for each TPI, the 10,000 yr TPI case has proportionately more realizations at times when the waste is more hazardous, thus a more accurate estimate of the "maximum hazard" of the exposure scenario is achieved. Results affirm that by merely increasing the TPI, the importance of low probability, high consequence events such as volcanism has significantly increased when compared with scenarios that are certain to occur such as an undisturbed repository leaching small amounts of radionuclides to the water table with subsequent drinking water pathway doses. These analyses assumed that 10 MTU (one waste package) of spent-fuel is incorporated in the volcanic ash ejected during the event. This assumption can be updated as more information becomes available. Future models may couple the amount of spent-fuel ejected with the energetics of the event.

3 ASSUMPTIONS AND LIMITATIONS

3.1 ASSUMPTIONS

The following assumptions have been made in the calculations described in this report:

- The volcanic ash dispersal model and parameter ranges are valid for modeling volcanic ash dispersals at YM
- The doses are calculated for an Amargosa Desert farmer/rancher as described in LaPlante et al. (1995) with all of the associated assumptions and limitations
- The selected dose points describe the possible locations of the critical group

Table 8. Expected values and standard deviations as a function of position and the time period of interest

Dose Point Number	Period of Interest (yr)	Dose Point Location		Expected Annual Effective Dose Equivalent (rem/yr)	Standard Deviation (rem/yr)
		x (km)	y (km)		
1	10,000	0	−20	2.7×10^{-6}	2.2×10^{-3}
2	10,000	0	−25	7.5×10^{-7}	7.6×10^{-4}
3	10,000	0	−30	2.5×10^{-7}	3.4×10^{-4}
1	1,000,000	0	−20	7.7×10^{-6}	6.1×10^{-4}
2	1,000,000	0	−25	1.8×10^{-6}	1.4×10^{-4}
3	1,000,000	0	−30	4.4×10^{-7}	4.1×10^{-5}

- Variances in the DCF are small compared with other parameter variances in the calculation, hence the mean values for DCFs can be used without greatly affecting the expected doses
- Volcanic ash particles carry only spent-fuel particles less than or equal to one-tenth of the volcanic ash particle diameter
- Consistent with the above assumption, a contaminated particle can have no more than one-half its mass comprised of spent-fuel
- One waste package container (10 MTU of fuel) is available for incorporation in each event
- The farmer/rancher receives 50 percent of beef, milk, fruit, grains, and vegetables from contaminated sources.

3.2 SUGGESTIONS FOR FUTURE WORK

- Incorporate resuspension factors and "soil" properties of volcanic ash into the analyses
- Incorporate time dependent spent-fuel particle size distributions into the analyses
- Investigate waste package performance under exposure to magma at the aforementioned conditions
- Investigate the relationship between the volcanic event magnitude and the number of waste packages available for incorporation

Table 9. The most important radionuclides along with their percent contribution to the expected dose values

Dose Point Number	Period of Interest (yr)	Dose Point Location		Important Nuclides [% contribution]
		x (km)	y (km)	
1	10,000	0	-20	^{241}Am [88.9] ^{243}Am [5.4] ^{240}Pu [2.6] ^{239}Pu [2.0] ^{237}Np [0.8] others [0.3]
2	10,000	0	-25	^{241}Am [87.8] ^{243}Am [5.9] ^{240}Pu [2.9] ^{239}Pu [2.2] ^{237}Np [0.9] others [0.3]
3	10,000	0	-30	^{241}Am [90.9] ^{243}Am [4.5] ^{240}Pu [2.1] ^{239}Pu [1.6] ^{237}Np [0.7] others [0.2]
1	1,000,000	0	-20	^{237}Np [36.3] ^{239}Pu [0.8] ^{210}Pb [26.6] ^{129}I [0.3] ^{229}Th [22.4] ^{99}Tc [0.3] ^{226}Ra [5.3] ^{233}U [0.2] ^{227}Ac [2.7] ^{242}Pu [0.2] ^{230}Th [2.2] ^{234}U [0.1] ^{231}Pa [2.1] others [0.5]
2	1,000,000	0	-25	^{237}Np [34.3] ^{239}Pu [0.5] ^{210}Pb [30.1] ^{129}I [0.3] ^{229}Th [20.7] ^{99}Tc [0.3] ^{226}Ra [6.0] ^{233}U [0.2] ^{230}Th [2.5] ^{242}Pu [0.2] ^{227}Ac [2.4] ^{234}U [0.1] ^{231}Pa [1.9] others [0.5]
3	1,000,000	0	-30	^{237}Np [34.9] ^{239}Pu [0.6] ^{210}Pb [29.1] ^{129}I [0.3] ^{229}Th [21.2] ^{99}Tc [0.3] ^{226}Ra [5.8] ^{233}U [0.2] ^{227}Ac [2.5] ^{242}Pu [0.2] ^{230}Th [2.4] ^{234}U [0.1] ^{231}Pa [1.9] others [0.5]

- Investigate the sensitivity of the analyses to the parameter ρ_c.

4 SUMMARY/CONCLUSIONS

The annual effective dose equivalents calculated from the analyses described in this report were based in part on the volcanic ash dispersion model described in Jarzemba (1996) and outlined in this report. In addition, improvements to this model have been made to more realistically model the distribution of spent-fuel within the extruded particulate matter. Expected peak dose calculations to an Amargosa Desert farmer/rancher were made assuming a lifestyle as described by LaPlante et al. (1995) and for different locations of this individual on the earth's surface after the event. The analyses in this report show that increasing the TPI has the effect of increasing the importance of low probability, high consequence events, such as extrusive volcanism, when compared with scenarios that are certain to occur regardless of the TPI (e.g., undisturbed repository).

5 REFERENCES

Anspaugh, L.R., J.H. Shinn, P.L. Phelps, and N.C. Kennedy. 1975. Resuspension and redistribution of plutonium in soils. *Health Physics* 29: 571–582.

Anspaugh, L.R. 1987. *Retention by Vegetation of Radionuclides Deposited in Rainfall—A Literature Summary*. UCRL-53810. Livermore, CA: Lawrence Livermore National Laboratory.

Baes, C.F. III, R.D. Sharp, A.L. Sjoreen, and R.W. Shor. 1982. *A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture*. ORNL-5786. Oak Ridge, TN: Oak Ridge National Laboratories.

Breshears, D.D., T.B. Kirchner, M.D. Otis, and F.W. Whicker. 1989. Uncertainty in predictions of fallout radionuclides in foods and of subsequent ingestion. *Health Physics* 57(6): 943–953.

Breshears, D.D., T.B. Kirchner, and F.W. Whicker. 1992. Contaminant transport through agroecosystems: Assessing relative importance of environmental, physiological, and management factors. *Ecological Applications* 2(3): 285–297.

Cember, H. 1983. *Introduction to Health Physics—Second Edition*. Permacon Press: New York, NY.

Clark, P.A.E., et al. 1985. *Post Irradiation Examination of Two High Burnup Fuel Rods Irradiated in the Halden BWR*. AEREG 3207. AERE Harwell Report.

Connor, C.B., and B.E. Hill. 1995. Three Nonhomogeneous Poisson Models for the Probability of Basaltic Volcanism. *Journal of Geophysical Research* 100(10): 10,107–10,125.

Eckerman, K.F., and J.C. Ryman. 1993. *External Exposure to Radionuclides in Air, Water, and Soil: Exposure-to-Dose Coefficients for General Application, Based on the 1987 Federal Radiation Protection Guidance*. Federal Guidance Report No. 12. Oak Ridge, TN: Oak Ridge National Laboratory.

Hoffman, F.O., R.H. Gardner, and K.F. Eckerman. 1982. *Variability in Dose Estimates Associated with the Food Chain Transport and Ingestion of Selected Radionuclides*. NUREG/CR-2612. Oak Ridge, TN: Oak Ridge National Laboratory.

ICRP [International Council for Radiation Protection]. 1977. *Recommendations of the ICRP*. ICRP Publication 26: 1(3): Permagon Press. Oxford, UK.

ICRP [International Council for Radiation Protection]. 1985. *Principles of Monitoring for the Radiation Protection of the Population*. ICRP Publication 43: 15(1): Permagon Press. Oxford, UK.

ICRP [International Council for Radiation Protection]. 1991. *Radiation Protection, 1990 Recommendations of International Commission on Radiological Protection*. ICRP Publication 60. Annuls of the ICRP. Oxford, UK.

International Atomic Energy Agency. 1994. *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments*. Technical Report Series No. 364. Vienna, Austria: International Atomic Energy Agency.

Jarzemba, M.S. 1996. Stochastic Radionuclide Distributions after a Basaltic Eruption for Performance Assessments of Yucca Mountain. Submitted for publication in *Nuclear Technology*.

Kennedy, W.E., and D.L. Strenge. 1992. *Residual Radioactive Contamination from Decommissioning: Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent*. NUREG/CR-5512, Vol. 1. Richland, WA: Pacific Northwest Laboratory.

LaPlante, P.A., S.J. Maheras, and M.S. Jarzemba. 1995. *Initial Analyses of Site-Specific Dose Assessment Parameters and Exposure Pathways Applicable to a Groundwater Release Scenario at Yucca Mountain*. CNWRA 95-018. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Leigh, C.D., B.M. Thompson, J.E. Campbell, D.E. Longsine, R.A. Kennedy, et al. 1993. *User's Guide for GENII-S: A Code for Statistical and Deterministic Simulation of Radiation Doses to Humans from Radionuclides in the Environment*. SAND 91-0561. Albuquerque, NM: Sandia National Laboratories.

Lozano, A.S., H. Karimi, J.P. Cornelius, R.D. Manteufel, and R.W. Janetzke. 1994. *INVENT: A Module for the Calculation of Radionuclide Inventories, Software Description, and User's Guide*. CNWRA 94-016. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Nevada Division of Water Resources. 1995. *Preliminary Summary of Ground Water Pumpage Inventory for Amargosa Valley Basin No. 230 from 1989 through 1993*. Carson City, NV: Nevada Division of Water Resources. Unpublished.

Nevada Agricultural Statistics Service. 1988. *Nevada Agricultural Statistics: 1, 1987-88*. Reno, NV: Nevada Agricultural Statistics Service.

Otis, M.D. 1983. *Sensitivity and Uncertainty Analysis of the PATHWAY Radionuclide Transport Model*. Ph.D. Dissertation. Fort Collins, CO: Colorado State University.

Suzuki, T. 1983. A theoretical model for dispersion of tephra. *Arc Volcanism: Physics and Tectonics*. Tokyo: Terra Scientific Publishing: 95–113.

U.S. Department of Commerce. 1989. *Census of Agriculture, Volume 1: Geographic Area Series, Part 28: Nevada State and County Data*. AC87-A-28. Washington DC: U.S. Department of Commerce.

Walker, G.P.L., L. Wilson, and E.L.G. Bowell. 1970. Explosive Volcanic Eruptions-I: The Rate of Fall of Pyroclasts. *Geophysical Journal of the Royal Astrological Society* 22: 377–383.

Wescott, R.G., M.P. Lee, N.A. Eisenberg, and R.G. Baca (Eds.). 1995. *NRC Iterative Performance Assessment, Phase 2*. NUREG 1464. Washington, DC: Nuclear Regulatory Commission.

Wilson, M., J.H. Gauthier, R.W. Barnard, G.E. Barr et al. 1994. *Total System Performance Assessment for Yucca Mountain SNL Second Iteration (TSPA-1993)*. SAND 93-2675. Albuquerque, NM: Sandia National Laboratories.

Yu, C., A.J. Zielen, J.J. Cheng, and Y.C. Yuan. 1993. *Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0*. ANAL/EAD/LD-2. Argonne, IL: Argonne National Laboratory

MSJ

APPENDIX A

MSJ

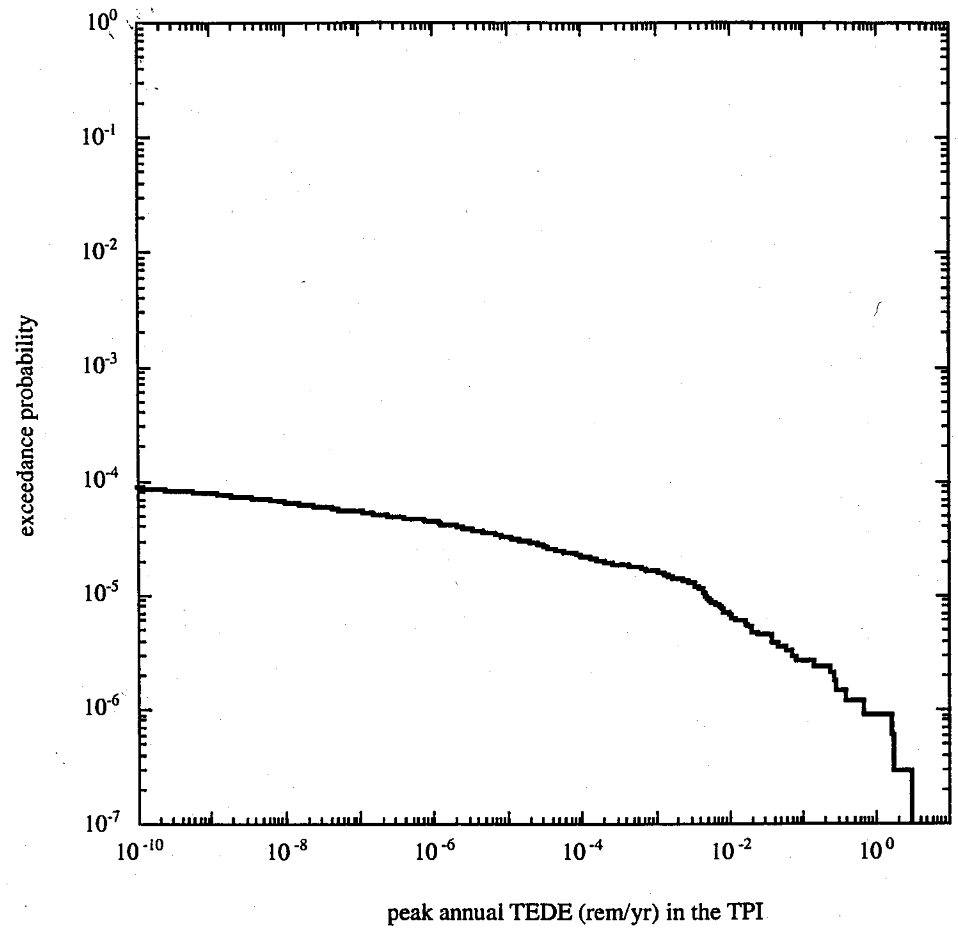

Figure A-1. The CCDF of the peak annual TEDE (rem/yr) at dose point 1 for a TPI of 10,000 yr

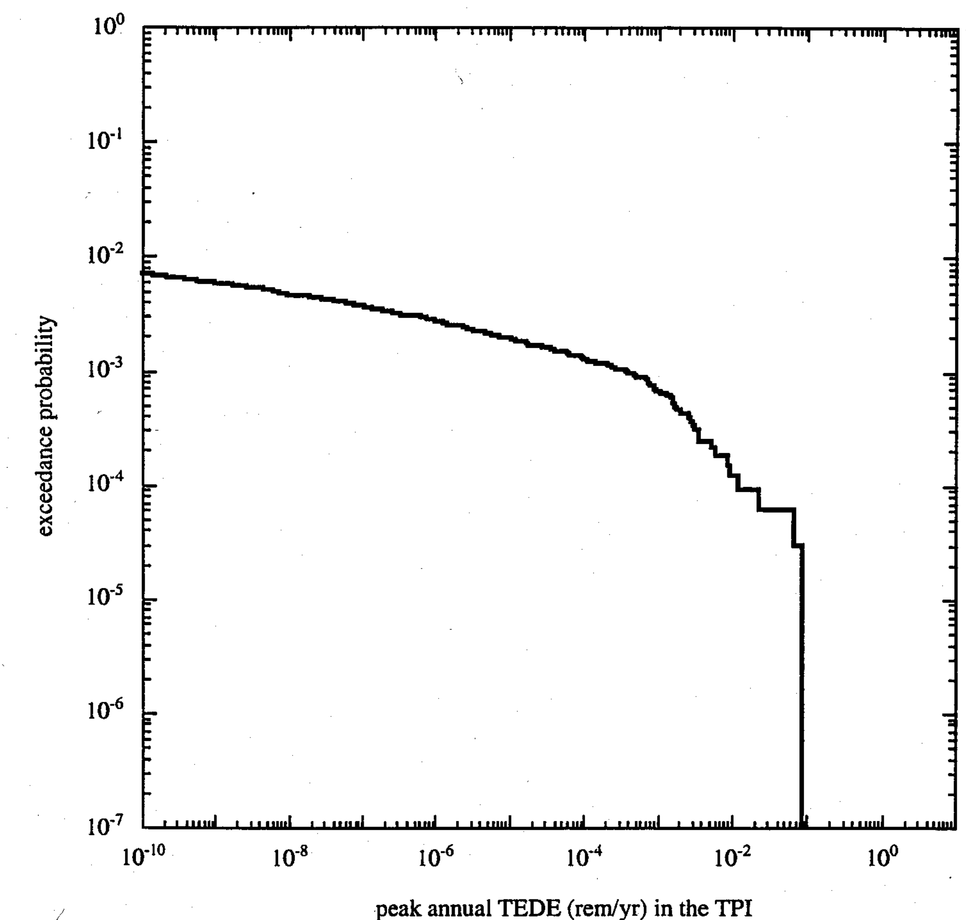

Figure A-2. The CCDF of the peak annual TEDE (rem/yr) at dose point 1 for a TPI of 1,000,000 yr

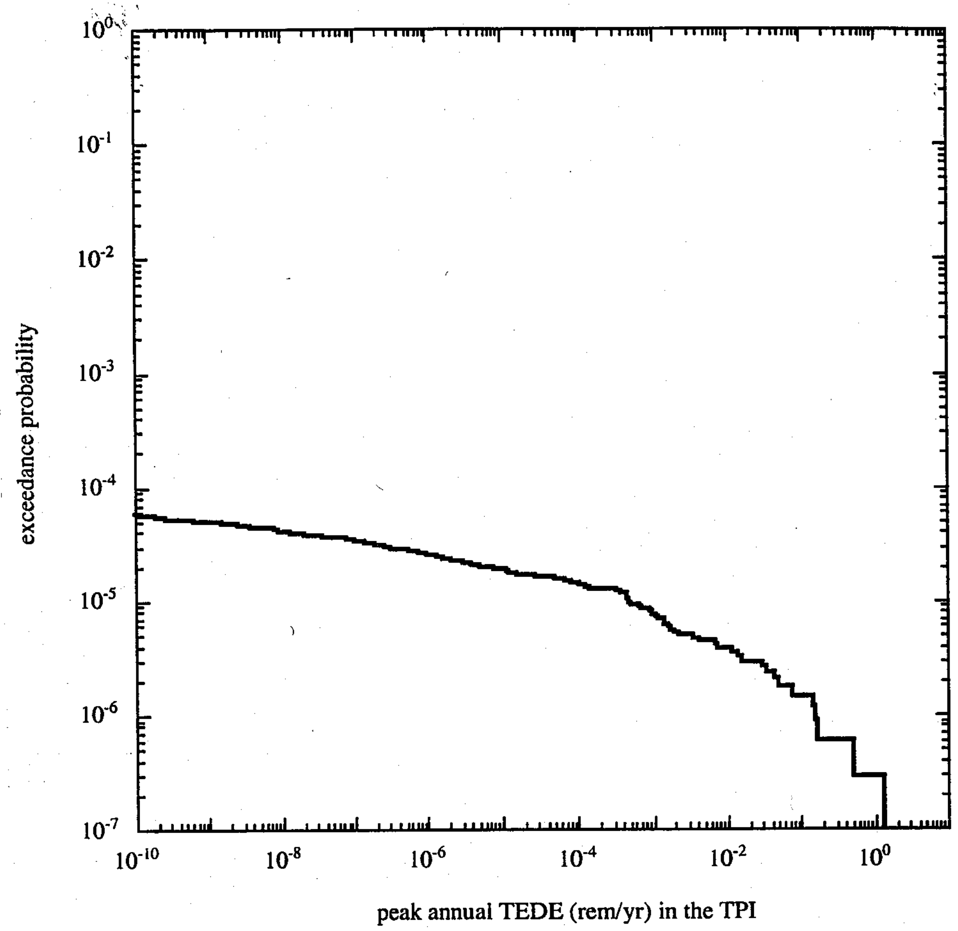

Figure A-3. The CCDF of the peak annual TEDE (rem/yr) at dose point 2 for a TPI of 10,000 yr

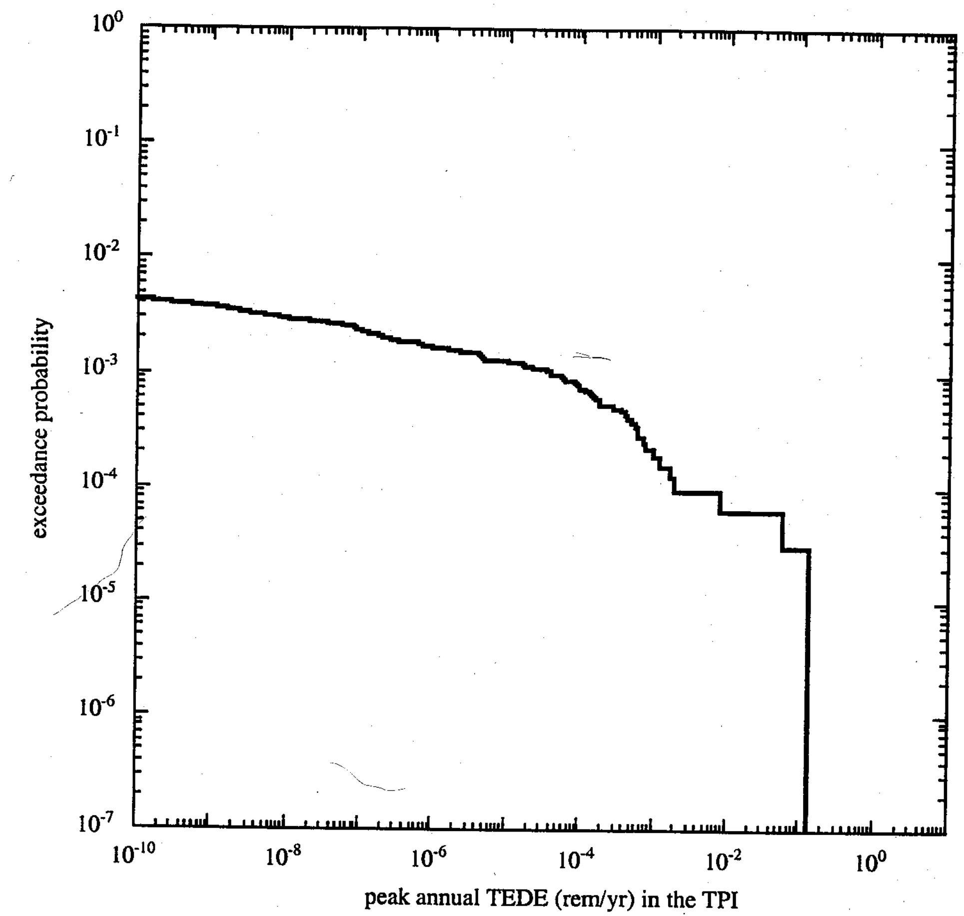

Figure A-4. The CCDF of the peak annual TEDE (rem/yr) at dose point 2 for a TPI of 1,000,000 yr

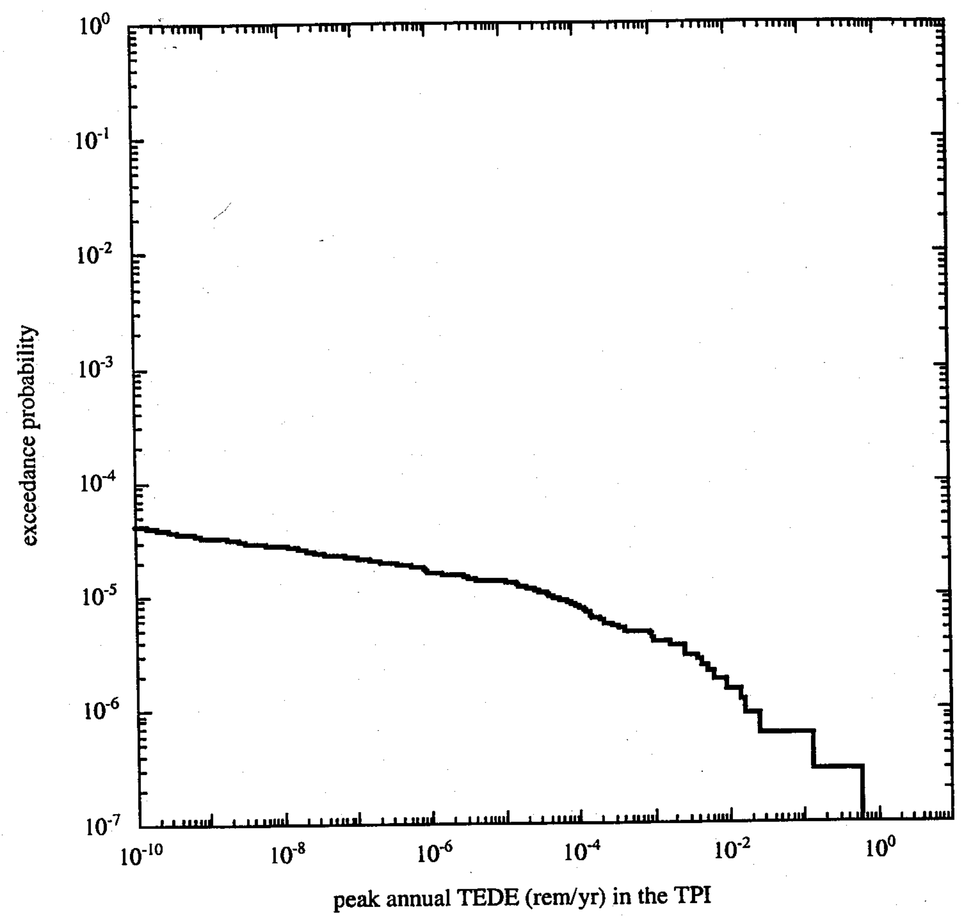

Figure A-5. The CCDF of the peak annual TEDE (rem/yr) at dose point 3 for a TPI of 10,000 yr

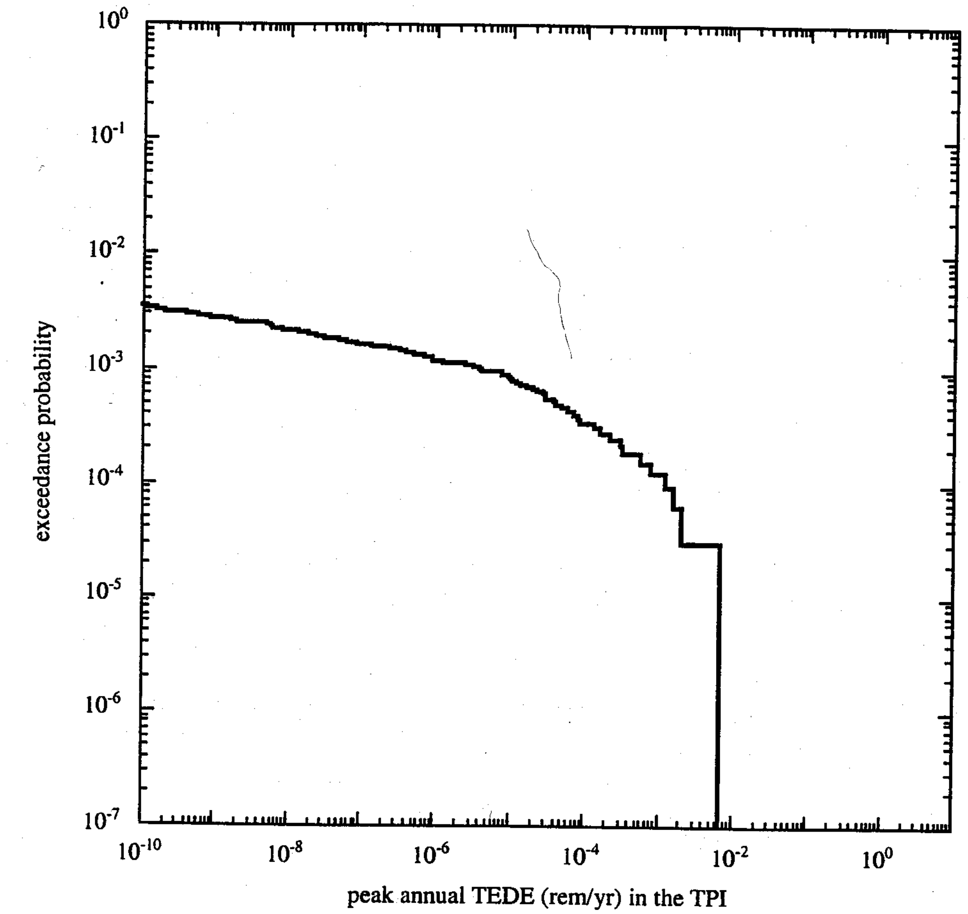

Figure A-6. The CCDF of the peak annual TEDE (rem/yr) at dose point 3 for a TPI of 1,000,000 yr

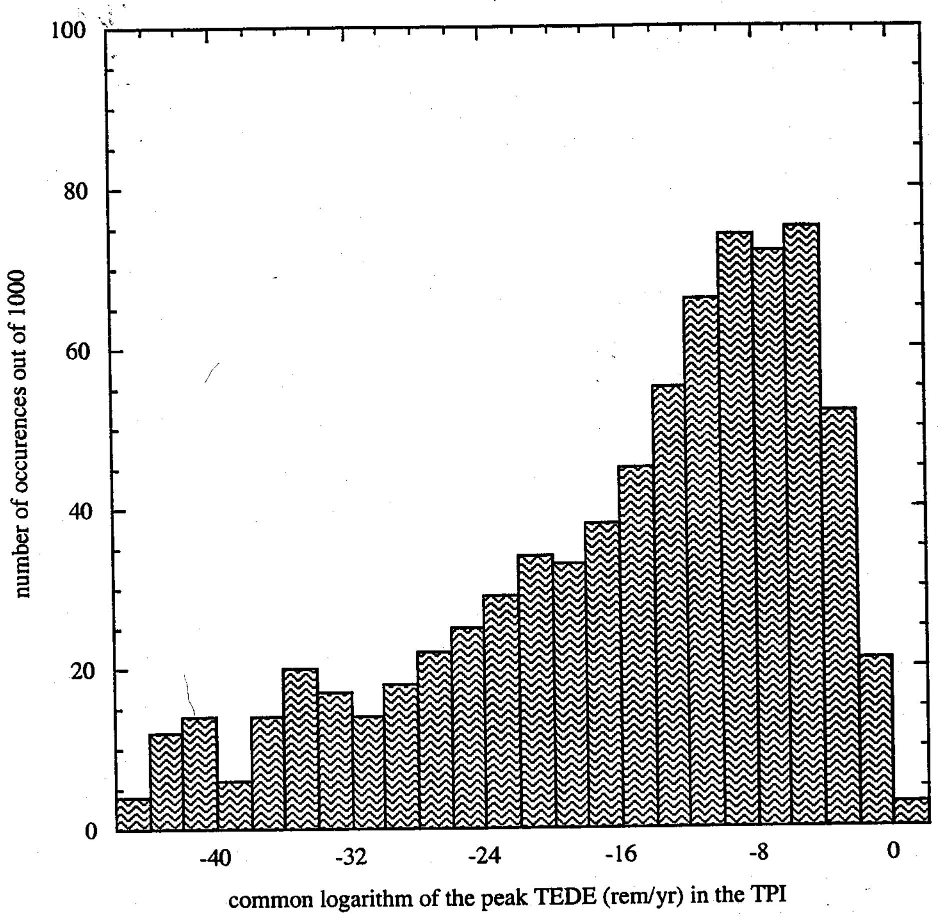

Figure A-7. A stack histogram of the common logarithm of the peak TEDE (rem/yr) at dose point 1 for a TPI of 10,000 yr

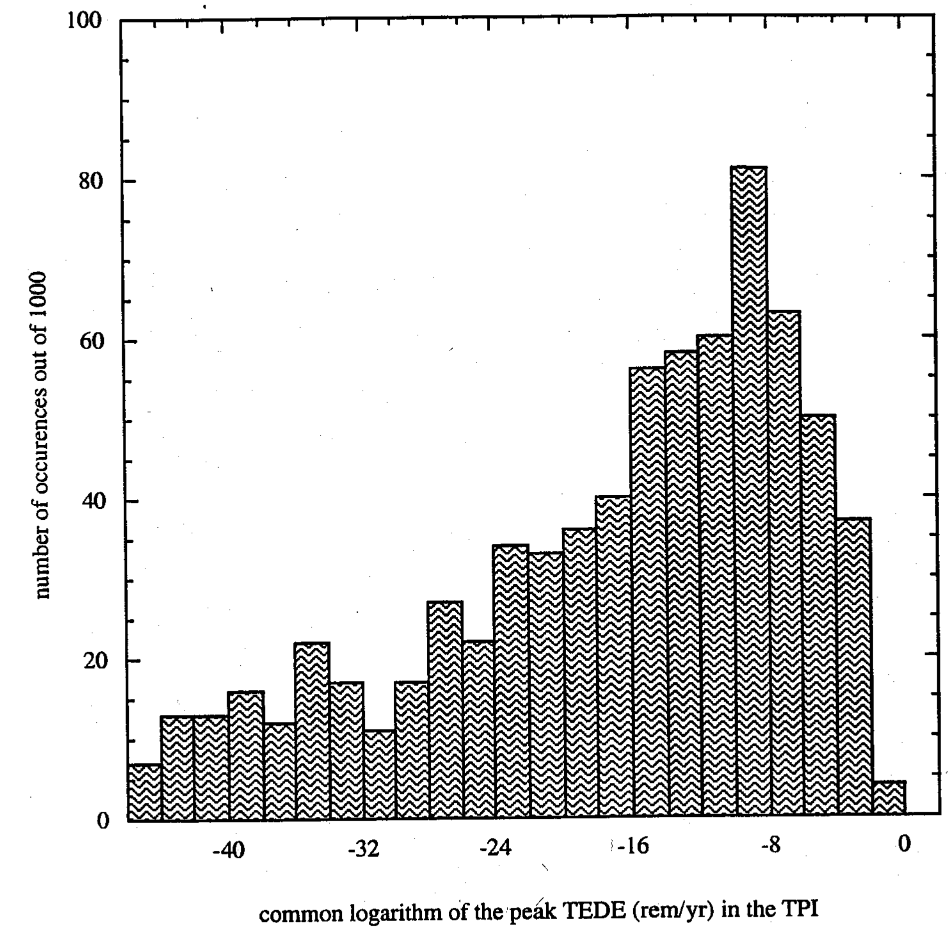

Figure A-8. A stack histogram of the common logarithm of the peak TEDE (rem/yr) at dose point 1 for a TPI of 1,000,000 yr

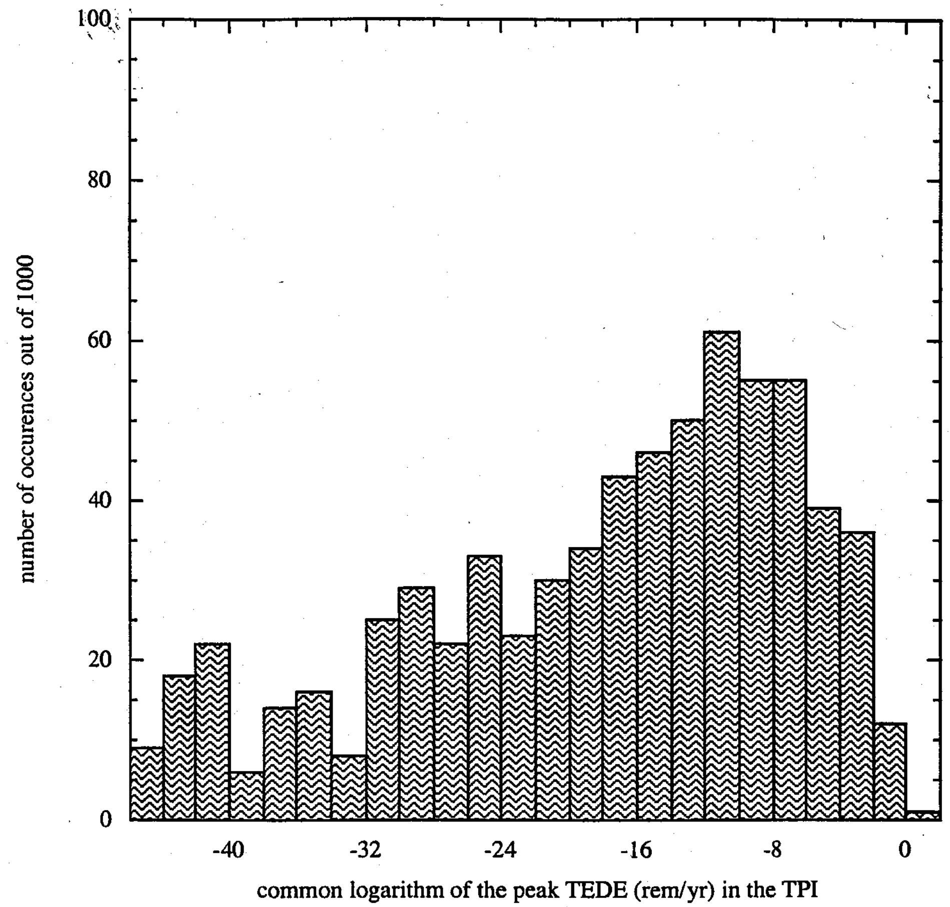

Figure A-9. A stack histogram of the common logarithm of the peak TEDE (rem/yr) at dose point 2 for a TPI of 10,000 yr

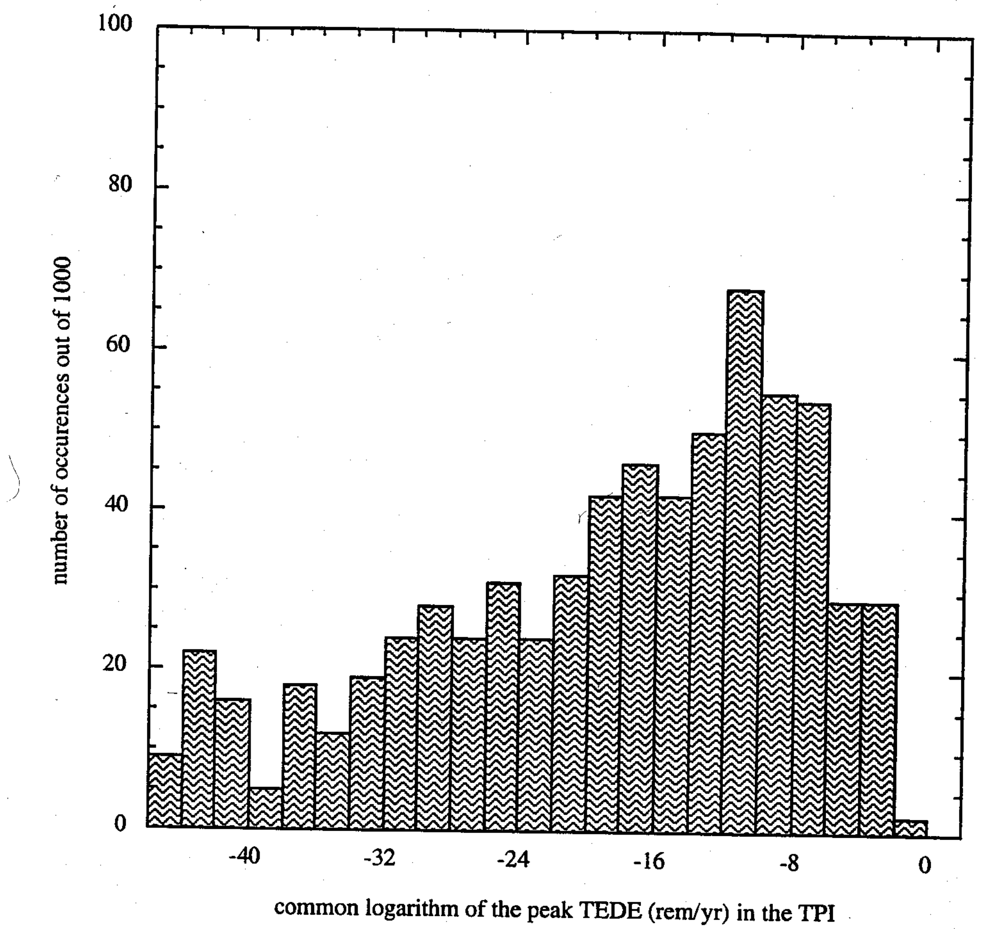

Figure A-10. A stack histogram of the common logarithm of the peak TEDE (rem/yr) at dose point 2 for a TPI of 1,000,000 yr

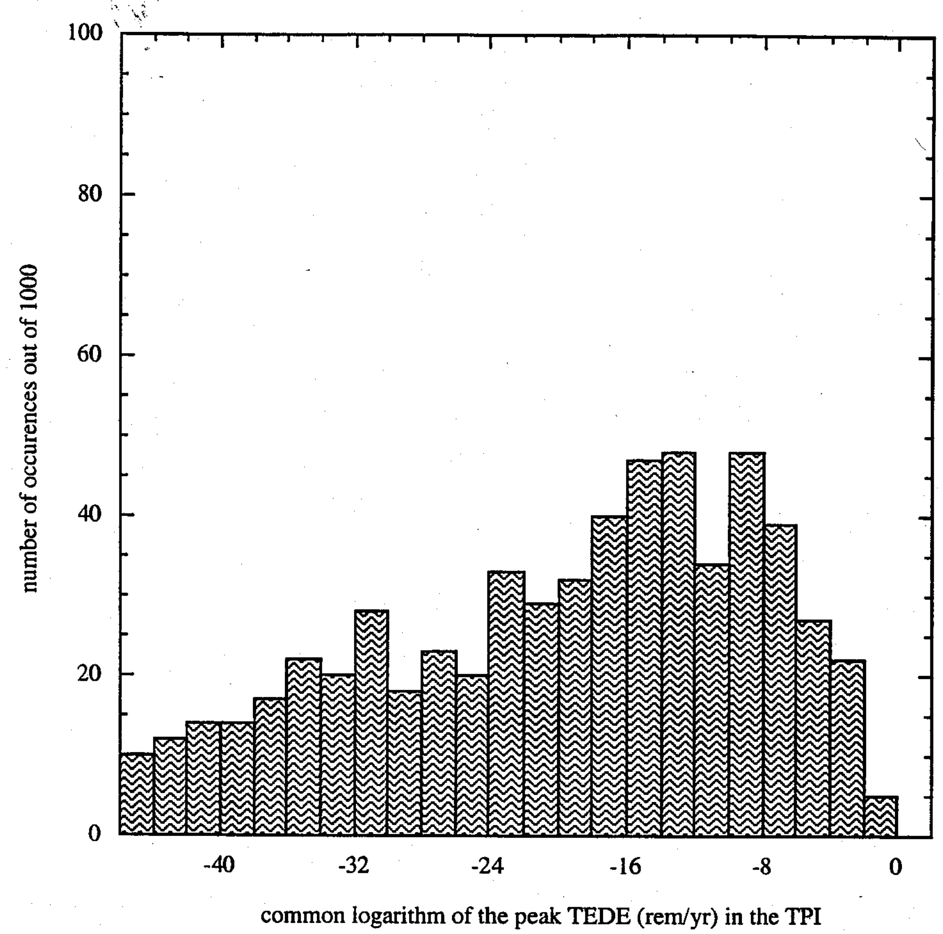

Figure A-11. A stack histogram of the common logarithm of the peak TEDE (rem/yr) at dose point 3 for a TPI of 10,000 yr

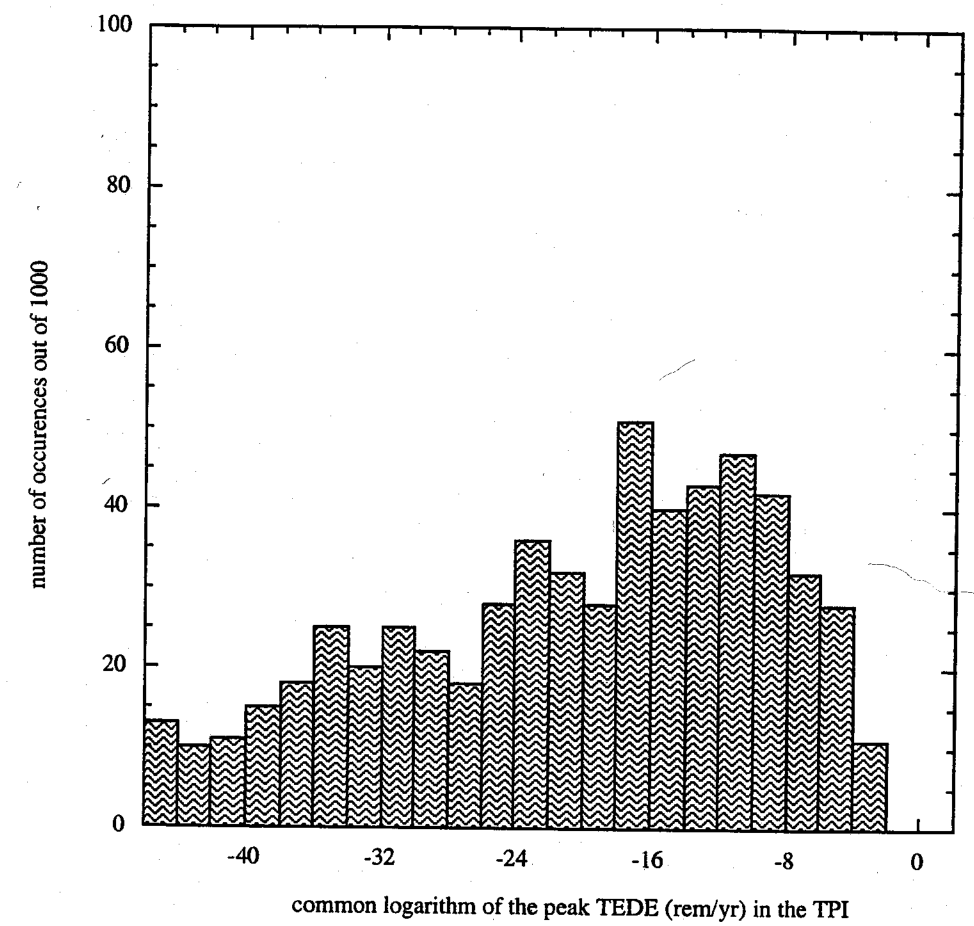

Figure A-12. A stack histogram of the common logarithm of the peak TEDE (rem/yr) at dose point 3 for a TPI of 1,000,000 yr

7-19-96 "Ashplume" Program Output.
MSJ

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```
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c
      Program Ashplume
c
c     This program calculates the mass per unit area of ash and
c     spent fuel distributed around a volcancic vent after an eruption.
c     Ashplume is based the dispersion model in Suzuki, 1983, and the
c     parameter sampling "philosophy" in Jarzemba, 1996
c
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      parameter (maxd=500)
      parameter (number=6)
      parameter (nmy=1000)
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      common /one/ beta,q,ashdenmin,ashdenmax,dmean,dsigma,fshape
      common /two/ h,werupt0,airden,airvis,c,u
      common /three/ fdmin,fdmax,fdmean,hmin,hmax,xmin,xmax
      common /threel/ dmin,dmax,rhomin,rhomax,rhomean
      common /four/ ymin,ymax,acutoff
      common /five/ x,y,udir,frhomin,frhomax,frhomean,rhosigma,drho
      common /six/ numptsx,numptsy
      common /seven/ Uran
      common /eight/ rhocut
      common /nine/ v,icount
      common /eleven/ ashrholow,ashrhohi
      common /twelve/ power,tdur
      dimension v(10000),xash(maxd,maxd),xfuel(maxd,maxd)
      open(unit=10,file="multiromb.out",status="unknown")
c
c     Uran is the amount of extruded waste in g
c     icount is a counter for the string of random numbers stored in v
c     iseed is the random number seed
c     max is the number of random numbers to get- eight random numbers
c     per realization
c
      icount=1
      iseed=3
      write (10,*)"iseed= ",iseed
      write (6,*)"iseed= ",iseed
      write (6,*)
      write (10,*)
      max=10000
      pi=dacos(-1.d0)
      call rand(iseed,v,max)
      ichoice=0
      while (ichoice.eq.0)
        write (6,*) "Do you  want stochastic  sampling of  numerous
     & volcanoes (ENTER 1)"
        write (6,*)
        write (6,*) " OR "
        write (6,*)
        write (6,*) "one  volcano  for  a  specific  input  parameter
     &  set   (ENTER 2)?"
        write (6,*)
        write (6,*) "For the stochastic sampling routine, the code
     & will take input data"
        write (6,*) "from the file -multiromb.in-; else you will be
     & asked to input some"
        write (6,*) "of the parameters from the keyboard"
        write (6,*)
```

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```
        read (5,*) ichoice
        if (ichoice.ne.1.and.ichoice.ne.2) then
          write (6,*)
          write (6,*)"*** TRY AGAIN- must  enter a 1 or a 2 ***"
          write (6,*)
          ichoice=0
        end if
      end do
      if (ichoice.eq.1) then
        write (6,*) "Number of volcanoes to evaluate? (max=1000)"
        read (5,*) num
      else
        num=1
      end if
c
c     xash, xfuel in g/cm**2
c
        do k=1,num
          write (6,*)
          write (10,*)
          write (6,*) "Volcano Number ",k
          write (10,*) "Volcano Number ",k
          write (6,*)
          write (10,*)
c
c     inputdata selects the parameters for the realization
c
          call inputdata
          if (ichoice.eq.2) then
            call userinput
          end if
          call outheader
          write (6,*)
          write (10,*)
          write (6,50)"x (km)","y (km)","xash (g/cm^2)",
     &       "xfuel (g/cm^2)"
          write (10,50)"x (km)","y (km)","xash (g/cm^2)",
     &       "xfuel (g/cm^2)"
 50       format(2a12,2a18)
          write (6,*)
          write (10,*)
c
c     determine the grid spacing
c
          if (numptsx.ne.1) then
            deltax=(xmax-xmin)/(numptsx-1)
          end if
          if (numptsy.ne.1) then
            deltay=(ymax-ymin)/(numptsy-1)
          end if
          x=xmin
          itemp1=0
c
c     start scrolling through x starting at xmin
c
          do i=1,numptsx
            y=ymin
            temp2=0.d0
            blahold=0.d0
c
c     start scrolling through y starting at ymin
c
            do j=1,numptsy
```

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```
c
c       don't calculate if x=y=0 invalid at volcano vent.
c       temp variables to determine when the balnket has
c       been "scrolled through" for this realization.
c
                if (x.ne.0.d0.or.y.ne.0.d0) then
                  call ashcalca(xash(i,j))
c                 call ashcalcf(xfuel(i,j))
                  blah=xash(i,j)
                  if (blah.lt.acutoff) then
                    blah=0.d0
                  end if
                  temp2=temp2+blah
                  if (temp2.ne.0.d0) then
                    itempl=1
                  end if
                  write (6,100) x,y,xash(i,j),xfuel(i,j)
                  write (10,100) x,y,xash(i,j),xfuel(i,j)
100               format (2f12.3,2e18.4)
                end if
                if (blahold.gt.0.d0.and.blah.eq.0.d0) then
                  go to 20
                end if
                blahold=blah
                y=y+deltay
              end do
20            continue
              if (temp2.eq.0.d0.and.itempl.eq.1) then
                go to 10
              end if
              x=x+deltax
              write (6,*)
              write (10,*)
            end do
10          continue
          end do
        close(unit=10)
        end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
        subroutine outheader
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        parameter (nmx=200, nmy=200)
        parameter (maxd= 200)
        implicit double precision (a-h,o-z)
        implicit integer (i-n)
        common /one/ beta,q,ashdenmin,ashdenmax,dmean,dsigma,fshape
        common /two/ h,werupt0,airden,airvis,c,u
        common /three/ fdmin,fdmax,fdmean,hmin,hmax,xmin,xmax
        common /threel/ dmin,dmax,rhomin,rhomax,rhomean
        common /four/ ymin,ymax,acutoff
        common /five/ x,y,udir,frhomin,frhomax,frhomean,rhosigma,drho
        common /six/ numptsx,numptsy
        common /seven/ Uran
        common /eight/ rhocut
        common /twelve/ power,tdur

        write (6,100) "wind speed (cm/s) =",u
        write (6,100) "wind direction (deg) =",udir
        write (6,100) "mean particle diameter (cm)=",dmean
        write (6,100) "log- std dev=",dsigma
        write (6,100) "column ht (km)=",hmax
```

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```
        write (6,110) "event duration (s)=",tdur
        write (6,110) "ash mass (g)=",q
        write (6,110) "event power (W)=",power
        write (6,100) "beta=",beta
        write (6,100) "vent exit velocity (cm/s)=",werupt0

        write (10,100) "wind speed (cm/s) =",u
        write (10,100) "wind direction (deg) =",udir
        write (10,100) "mean particle diameter (cm)=",dmean
        write (10,100) "log- std dev=",dsigma
        write (10,100) "column ht (km)=",hmax
        write (10,110) "event duration (s)=",tdur
        write (10,110) "ash mass (g)=",q
        write (10,110) "event power (W)=",power
        write (10,100) "beta=",beta
        write (10,100) "vent exit velocity (cm/s)=",werupt0

100     format(a30,f15.4)
110     format(a30,e15.4)
        return
        end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
        subroutine userinput
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        parameter (nmx=200, nmy=200)
        parameter (maxd= 200)
        implicit double precision (a-h,o-z)
        implicit integer (i-n)
        common /one/ beta,q,ashdenmin,ashdenmax,dmean,dsigma,fshape
        common /two/ h,werupt0,airden,airvis,c,u
        common /three/ fdmin,fdmax,fdmean,hmin,hmax,xmin,xmax
        common /threel/ dmin,dmax,rhomin,rhomax,rhomean
        common /four/ ymin,ymax,acutoff
        common /five/ x,y,udir,frhomin,frhomax,frhomean,rhosigma,drho
        common /six/ numptsx,numptsy
        common /seven/ Uran
        common /eight/ rhocut
        common /twelve/ power,tdur
        write (6,*) "NOTE: the folowing parameters are still input"
        write (6,*) "from the input data file -multiromb.in-"
        write (6,*)
        write (6,*) " . grid parameteres"
        write (6,*) "  air properties (viscocity,density)"
        write (6,*) "  fuel particle size characteristics:"
        write (6,*) "       (min,med,max diameters)"
        write (6,*) "  ash particle shape parameter"
        write (6,*) "  eddy difusivity constant"
        write (6,*) " .max ash particle diameter for transport"
        write (6,*) "  cutoff ash blanket density"
        write (6,*)
        write (6,*) "please input the following parameters"
        write (6,*)

        write (6,*) "the event duration (in sec)"
        read (5,*) tdur
        write (6,*) "the column height (in km)"
        read (5,*) hmax
        write (6,*) "the magical constant beta"
        read (5,*) beta
        write (6,*) "the mean ash particle diameter (in cm)"
        read (5,*) dmean
```

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```
      write (6,*) "sigma for the ash lognormal dist. (unitless)"
      read (5,*) dsigma
      write (6,*) "the incorporable fuel diameter cutoff ratio"
      read (5,*) rhocut
      write (6,*) "the mass of fuel to incorporate"
      read (5,*) Uran
      write (6,*) "the wind direction- relation to due east (deg)"
      read (5,*) udir
      write (6,*) "the wind speed (cm/s)"
      read (5,*) u

      rhomean=dlog10(dmean)
      rhomin=rhomean-7.d0*dsigma
      rhomax=rhomean+7.d0*dsigma
      power=(hmax/0.0082d0)**4
      qdot=(hmax/0.24)**4.d0
      q=qdot*tdur*1.0d3
      rlog=-2.069d0+2.d0*dlog10(ashden(rhomean))+0.27435d0*
     &        dlog10(qdot*1.d3)
      vrad=10.d0**rlog
      werupt0=qdot*1.d3/(ashden(rhomean)*3.141592d0*(vrad*1.d2)**2)
      write (6,*) vrad,werupt0,rhomean,ashden(rhomean)
      return
      end
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      subroutine ashcalca(ash)
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c     This subroutine calls the integrator for the outer integral
c     to calculate the ash deposition at the current x-y point as
c     per equation (1) of Jarzemba 1996
c
c

      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      external dinnerf,dinnera
      common /threel/ dmin,dmax,rhomin,rhomax,rhomean
c
c     do integration up to rhomax or a max corresponding to the user
c     input depending on which is greater
c
      cmax=rhomax
      blah=dlog10(dmax)
      if (cmax.ge.blah) then
        cmax=blah
      end if
      call qromb1(dinnera,rhomin,cmax,ash)
      return
      end
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      subroutine ashcalcf(fuel)
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c     This subroutine calls the integrator for the outer integral
c     to calculate the fuel deposition at the current x-y point as
c     per equation (1) of Jarzemba 1996 and the adjustments for mass
c     of fuel per unit mass of ash
c
c
```

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```
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      external dinnerf,dinnera
      common /threel/ dmin,dmax,rhomin,rhomax,rhomean
c
c     do integration up to rhomax or a max corresponding to the user
c     input depending on which is greater
c
      cmax=rhomax
      blah=dlog10(dmax)
      if (cmax.ge.blah) then
        cmax=blah
      end if
      call qromb1(dinnerf,rhomin,cmax,fuel)
      return
      end
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      function dinnerf(rho)
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c     This subroutine does the inner integration of equation (1) of
c     Jarzemba 1996 while accounting for fuel mass/ash mass to calculate
c     the fuel depostion
c
c

      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      common /three/ fdmin,fdmax,fdmean,hmin,hmax,xmin,xmax
      external dintegrandf
c
c     dintegrandf is the integrand of Eq 1 of Jarzemba (1996)
c     including the fuel fraction
c
      call qromb(dintegrandf,hmin,hmax,s,rho)
      dinnerf=s
      return
      end
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      function dinnera(rho)
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c     This subroutine does the inner integration of equation (1) of
c     Jarzemba 1996 to calculate the ash deposition
c
c

      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      common /three/ fdmin,fdmax,fdmean,hmin,hmax,xmin,xmax
      external dintegranda
c
c     dintegranda is the integrand of Eq 1 of Jarzemba (1996)
c
      call qromb(dintegranda,hmin,hmax,s,rho)
      dinnera=s
      return
      end
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      function dintegrandf(z,rho)
```

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```
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c      This subroutine is the integrand for fuel deposition- the coordinate
c      system has to be adjusted to match the main coordinate system
c
       implicit double precision (a-h,o-z)
       implicit integer (i-n)
       common /one/ beta,q,ashdenmin,ashdenmax,dmean,dsigma,fshape
       common /two/ h,werupt0,airden,airvis,c,u
       common /five/ x,y,udir,frhomin,frhomax,frhomean,rhosigma,drho
       pi=dacos(-1.d0)
c
c      must perfrom a coordinate transformation from the main system [x,y]
c      to the plume calculation system [xp,yp] that has x direction
c      aligned with the wind
c
       if (x.ne.0.d0) then
         theta=datan(y/x)
       else if (x.eq.0.d0 .and. y.lt.0.d0) then
         theta=-pi/2.d0
       else if (x.eq.0.d0 .and. y.gt.0.d0) then
         theta=pi/2.d0
       end if
       theta=theta*180.d0/pi
       if (y.lt.0.d0 .and. x.lt.0.d0) then
         theta=theta-180.d0
       else if (y.gt.0.d0 .and. x.lt.0.d0) then
         theta=theta+180.d0
       else if (y.eq.0.d0 .and. x.lt.0.d0) then
         theta=-180.d0
       else if (y.eq.0.d0 .and. x.gt.0.d0) then
         theta=0.d0
       end if
       thetap=theta-udir
       if (thetap.ge.-360.d0 .and. thetap.le.-180.d0) then
         thetap=thetap+360.d0
       else if (thetap.gt.180.d0 .and. thetap.le.360.d0) then
         thetap=thetap-360.d0
       end if
       thetapr=thetap*pi/180.d0
       if (thetap.ge.0.d0 .and. thetap.lt.90.d0) then
         xp=dsqrt((x**2+y**2)/(1+(dtan(thetapr))**2))
         yp=dsqrt((x**2+y**2)/(1+(1/(dtan(thetapr))**2)))
       else if (thetap.ge.90.d0 .and. thetap.le.180.d0) then
         xp=-dsqrt((x**2+y**2)/(1+(dtan(thetapr))**2))
         yp=dsqrt((x**2+y**2)/(1+(1/(dtan(thetapr))**2)))
       else if (thetap.ge.-90.d0 .and. thetap.lt.0.d0) then
         xp=dsqrt((x**2+y**2)/(1+(dtan(thetapr))**2))
         yp=-dsqrt((x**2+y**2)/(1+(1/(dtan(thetapr))**2)))
       else if (thetap.ge.-180.d0 .and. thetap.lt.-90.d0) then
         xp=-dsqrt((x**2+y**2)/(1+(dtan(thetapr))**2))
         yp=-dsqrt((x**2+y**2)/(1+(1/(dtan(thetapr))**2)))
       end if
       xpcm=1.0d5*xp
       ypcm=1.0d5*yp
       arg=-5.d0*((xpcm-u*tf(z,rho))**2+ypcm**2)/
     &        (8.d0*c*(tf(z,rho)+ts(z))**(2.5d0))
       dintegrandf=FF(rho)*(5.d0*P(z,rho)*q*f(rho))/
     &        (8.d0*pi*c*(tf(z,rho)+ts(z))**(2.5d0))*
     &                 dexp(arg)
       return
       end
```

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```
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
       function dintegranda(z,rho)
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
       implicit double precision (a-h,o-z)
       implicit integer (i-n)
       common /one/ beta,q,ashdenmin,ashdenmax,dmean,dsigma,fshape
       common /two/ h,werupt0,airden,airvis,c,u
       common /five/ x,y,udir,frhomin,frhomax,frhomean,rhosigma,drho
       pi=dacos(-1.d0)
c
c      must perfrom a coordinate transformation from the main system [x,y]
c      to the plume calculation system [xp,yp] that has x direction
c      aligned with the wind
c
       if (x.ne.0.d0) then
         theta=datan(y/x)
       else if (x.eq.0.d0 .and. y.lt.0.d0) then
         theta=-pi/2.d0
       else if (x.eq.0.d0 .and. y.gt.0.d0) then
         theta=pi/2.d0
       end if
       theta=theta*180.d0/pi
       if (y.lt.0.d0 .and. x.lt.0.d0) then
         theta=theta-180.d0
       else if (y.gt.0.d0 .and. x.lt.0.d0) then
         theta=theta+180.d0
       else if (y.eq.0.d0 .and. x.lt.0.d0) then
         theta=-180.d0
       else if (y.eq.0.d0 .and. x.gt.0.d0) then
         theta=0.d0
       end if
       thetap=theta-udir
       if (thetap.ge.-360.d0 .and. thetap.le.-180.d0) then
         thetap=thetap+360.d0
       else if (thetap.gt.180.d0 .and. thetap.le.360.d0) then
         thetap=thetap-360.d0
       end if
       thetapr=thetap*pi/180.d0
       if (thetap.ge.0.d0 .and. thetap.lt.90.d0) then
         xp=dsqrt((x**2+y**2)/(1+(dtan(thetapr))**2))
         yp=dsqrt((x**2+y**2)/(1+(1/(dtan(thetapr))**2)))
       else if (thetap.ge.90.d0 .and. thetap.le.180.d0) then
         xp=-dsqrt((x**2+y**2)/(1+(dtan(thetapr))**2))
         yp=dsqrt((x**2+y**2)/(1+(1/(dtan(thetapr))**2)))
       else if (thetap.ge.-90.d0 .and. thetap.lt.0.d0) then
         xp=dsqrt((x**2+y**2)/(1+(dtan(thetapr))**2))
         yp=-dsqrt((x**2+y**2)/(1+(1/(dtan(thetapr))**2)))
       else if (thetap.ge.-180.d0 .and. thetap.lt.-90.d0) then
         xp=-dsqrt((x**2+y**2)/(1+(dtan(thetapr))**2))
         yp=-dsqrt((x**2+y**2)/(1+(1/(dtan(thetapr))**2)))
       end if
       xpcm=1.0d5*xp
       ypcm=1.0d5*yp
       arg=-5.d0*((xpcm-u*tf(z,rho))**2+ypcm**2)/
     &        (8.d0*c*(tf(z,rho)+ts(z))**(2.5d0))
       dintegranda=(5.d0*P(z,rho)*q*f(rho))/
     &        (8.d0*pi*c*(tf(z,rho)+ts(z))**(2.5d0))*
     &                 dexp(arg)
       return
       end
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
```

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```
c
        function tf(z,rho)
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        implicit double precision (a-h,o-z)
        implicit integer (i-n)
        tf=0.752d06*((1-dexp(-0.0625d0*z))/v0(rho))**0.926d0
        return
        end
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
        function ts(z)
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        implicit double precision (a-h,o-z)
        implicit integer (i-n)
        common /two/ h,werupt0,airden,airvis,c,u
        zcm=z*1.0d5
        ts=((5.0d0*zcm**2)/(288.d0*c))**(0.4d0)
        return
        end
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
        function f(rho)
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c       This function in the pdf of ash mass with the log-particle diameter
c
        implicit double precision (a-h,o-z)
        implicit integer (i-n)
        common /one/ beta,q,ashdenmin,ashdenmax,dmean,dsigma,fshape
        common /threel/ dmin,dmax,rhomin,rhomax,rhomean
        pi=dacos(-1.d0)
        arg=-((rho-rhomean)**2)/(2*dsigma**2)
        f=1/(dsqrt(2*pi)*dsigma)*dexp(arg)
        return
        end
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
        function dm(rho)
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c       This function is the pdf for fuel mass as a function
c       of the log-particle diameter
c
        implicit double precision (a-h,o-z)
        implicit integer (i-n)
        common /five/ x,y,udir,frhomin,frhomax,frhomean,rhosigma,drho
        dk1=2.d0/((frhomax-frhomin)*(frhomean-frhomin))
        dk2=-2.d0/((frhomax-frhomin)*(frhomax-frhomean))
        if (rho.le.frhomin.or.rho.ge.frhomax) then
          dm=0.d0
        end if
        if (rho.gt.frhomin.and.rho.lt.frhomean) then
          dm=dk1*(rho-frhomin)
        end if
        if (rho.ge.frhomean.and.rho.lt.frhomax) then
          dm=dk2*(rho-frhomean)+dk1*(frhomean-frhomin)
        end if
        return
        end
```



```
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
        function FF(rho)
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c       This function calculates the fuel fraction as a function of log-diameter
c
        implicit double precision (a-h,o-z)
        implicit integer (i-n)
        external Fcumm,FFintegrand
        common /five/ x,y,udir,frhomin,frhomax,frhomean,rhosigma,drho
        common /seven/ Uran
        common /eight/ rhocut
        cmin=frhomin+rhocut
        call qromb3(FFintegrand,cmin,rho,s)
        FF=s
        if (FF.ge.1.d0) then
          FF=0.d0
        end if
        return
        end
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
        function FFintegrand(rho)
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        implicit double precision (a-h,o-z)
        implicit integer (i-n)
        external Fcumm
        common /one/ beta,q,ashdenmin,ashdenmax,dmean,dsigma,fshape
        common /seven/ Uran
        common /eight/ rhocut
        FFintegrand=Uran/q*dm(rho-rhocut)/(1.d0-Fcumm(rho))
        return
        end
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
        function Fcumm(rho)
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        implicit double precision (a-h,o-z)
        implicit integer (i-n)
        common /one/ beta,q,ashdenmin,ashdenmax,dmean,dsigma,fshape
        common /threel/ dmin,dmax,rhomin,rhomax,rhomean
        external f
        Fmax=1.d0
        Fmin=0.d0
        call qromb2(f,rhomin,rho,s)
        Fcumm=s
        if (Fcumm.ge.Fmax) then
          Fcumm=Fmax
        end if
        if (Fcumm.le.Fmin) then
          Fcumm=Fmin
        end if
        return
        end
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
        function P(z,rho)
c
ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
```

```
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      common /one/ beta,q,ashdenmin,ashdenmax,dmean,dsigma,fshape
      common /two/ h,werupt0,airden,airvis,c,u
      common /three/ fdmin,fdmax,fdmean,hmin,hmax,xmin,xmax
      wz=werupt0*(1-z/hmax)
      yz=beta*(wz-v0(rho))/v0(rho)
      y0=beta*(werupt0-v0(rho))/v0(rho)
      anum= beta*werupt0*yz*dexp(-yz)
      denom= v0(rho)*hmax*(1.d0-(1.d0+y0)*
     &       dexp(-y0))
      P=anum/denom
      if (P.le.0.d0) then
             P=0.d0
      end if
      return
      end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      function v0(rho)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c     the argument d is the diameter of particles
c     velsea is the terminal fall velocity of particles at sea-level
c     the equation of the terminal velocity at sea level is given in
c     Suzuki, 1983.
c     g : gravitational accelleration in cm/s**2
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      common /one/ beta,q,ashdenmin,ashdenmax,dmean,dsigma,fshape
      common /two/ h,werupt0,airden,airvis,c,u
      g=980.d0
      d=10.d0**rho
      term1=9.d0*airvis*fshape**(-0.32d0)
      term2=81.d0*airvis**2*fshape**(-.64d0)
      term3=1.5d0*airden*ashden(rho)*d**3*g*dsqrt(1.07d0-fshape)
      anum = ashden(rho)*g*d**2
      denom = term1+dsqrt(term2 + term3)
      v0 = anum/denom
      return
      end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      function ashden(rho)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      external f,FF
      common /one/ beta,q,ashdenmin,ashdenmax,dmean,dsigma,fshape
      common /eleven/ ashrholow,ashrhohi
      if (rho.ge.ashrhohi) then
        ashden=ashdenmin
      else if (rho.le.ashrholow) then
        ashden=ashdenmax
      else
        slope=(ashdenmin-ashdenmax)/(ashrhohi-ashrholow)
        yint=ashdenmax
        ashden=slope*(rho-ashrholow)+yint
      end if
c     ashden=ashden*(1.d0+FF(rho))
```



```
      return
      end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      subroutine inputdata
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      parameter (nmx=200, nmy=200)
      parameter (maxd= 200)
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      common /one/ beta,q,ashdenmin,ashdenmax,dmean,dsigma,fshape
      common /two/ h,werupt0,airden,airvis,c,u
      common /three/ fdmin,fdmax,fdmean,hmin,hmax,xmin,xmax
      common /three1/ dmin,dmax,rhomin,rhomax,rhomean
      common /four/ ymin,ymax,acutoff
      common /five/ x,y,udir,frhomin,frhomax,frhomean,rhosigma,drho
      common /six/ numptsx,numptsy
      common /seven/ Uran
      common /eight/ rhocut
      common /nine/ v,icount
      common /eleven/ ashrholow,ashrhohi
      common /twelve/ power,tdur
      dimension v(10000)

c
c     get input parameters from data file
c
      open (unit=8,file="multiromb.in",status="old")
        read (8,*)    xmin,xmax
        read (8,*)    ymin,ymax
        read (8,*)    numptsx
        read (8,*)    numptsy

        read (8,*)    tlogmin,tlogmax
        read (8,*)    powvar
        read (8,*)    betalogmin,betalogmax
        read (8,*)    dmeanmin,dmeanmed,dmeanmax
        read (8,*)    dsigmamin,dsigmamax

        read (8,*)    ashdenmin,ashdenmax
        read (8,*)    ashrholow,ashrhohi
        read (8,*)    fshape
        read (8,*)    airden,airvis
        read (8,*)    c
        read (8,*)    dmax

        read (8,*)    fdmin, fdmean, fdmax
        read (8,*)    hmin
        read (8,*)    acutoff
        read (8,*)    rhocut
        read (8,*)    Uran

      frhomin=dlog10(fdmin)
      frhomax=dlog10(fdmax)
      frhomean=dlog10(fdmean)
      close (unit=8)

      s=1100.d0
c
c     Distributions
c
c     Power: lognormal
```

```
c        Duration:loguniform
c        beta:    loguniform
c        vrad:    deterministic
c        dmean:   logtriangular
c        dsigma:  loguniform
c        u:       exponential with directionally varying lambda
c        udir:    quasi-uniform
c
c
c

c
c        volcanic duration-logtriangular
c
         rnd2=v(icount)
         icount=icount+1
         tlog=tlogmin+(tlogmax-tlogmin)*rnd2
         tdur=10.d0**tlog
c        tdur in sec

         gauss=gasdev()
         plog=gauss*powvar**0.5d0+16.73-0.962d0*tlog
         power=10.d0**plog
         if (power.gt.7.d13) then
           power=7.d13
         end if


         hmax=(8.2d0*power**0.25)/1000.d0
         qdot=(hmax/0.24)**4.d0
         q=qdot*tdur*1.0d3


c
c        wind direction-quasi-uniform using SCP 5,000 ft data
c
         call winddirect(udir)
c
c        wind speed-exponential with direction dependent lambda
c
         call windspeed (udir,u)
c
c        dmean, dsigma-logtriangular
c
         rnd4=v(icount)
         icount=icount+1
         rnd5=v(icount)
         icount=icount+1
         rhomean=dmeanmax-dsqrt((1-rnd4)*(dmeanmax-dmeanmin)*
     &           (dmeanmax-dmeanmed))
         dmean=10.d0**rhomean
         dsigma= dsigmamin+rnd5*(dsigmamax-dsigmamin)
c
c        beta-loguniform
c
         rnd6=v(icount)
         icount=icount+1
         betalog=betalogmin+(betalogmax-betalogmin)*rnd6
         beta=10.d0**betalog

         rhomin=rhomean-7.d0*dsigma
         rhomax=rhomean+7.d0*dsigma
```



```
         rlog=-2.069d0+2.d0*dlog10(ashden(rhomean))+0.27435d0*
     &           dlog10(qdot*1.d3)
         vrad=10.d0**rlog
         werupt0=qdot*1.d3/(ashden(rhomean)*3.141592d0*(vrad*1.d2)**2)


         return
         end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
         subroutine winddirect(udir)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
         implicit double precision (a-h,o-z)
         implicit integer (i-n)
         common /nine/ v,icount
         dimension cutoff(17),angle(17),v(10000)
         data cutoff/0.017804d0,0.053412d0,0.136498d0,0.267058d0,
     &           0.376848d0,0.430260d0,0.460923d0,0.482684d0,
     &           0.496532d0,0.523238d0,0.563792d0,0.635998d0,
     &           0.776448d0,0.887228d0,0.953499d0,0.985151d0,
     &           1.000000/
         data angle/0.d0,22.5d0,45.d0,67.5d0,90.d0,112.5d0,135.d0,
     &           157.5d0,180.d0,-22.5d0,-45.d0,-67.5d0,-90.d0,
     &           -112.5d0,-135.d0,-157.5d0,1000.d0/
         rnd=v(icount)
         icount=icount+1
         do i=1,17
                 if (rnd.le.cutoff(i)) then
                         udir=angle(i)
                         go to 10
                 end if
         end do
10       return
         end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
         subroutine windspeed(udir,u)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
         implicit double precision (a-h,o-z)
         implicit integer (i-n)
         common /nine/ v,icount
         dimension angle(17),ula(17),v(10000)
         data angle/0.d0,22.5d0,45.d0,67.5d0,90.d0,112.5d0,135.d0,
     &           157.5d0,180.d0,-22.5d0,-45.d0,-67.5d0,-90.d0,
     &           -112.5d0,-135.d0,-157.5d0,1000.d0/
         data ula/0.313d0,0.222d0,0.149d0,0.139d0,0.156d0,
     &           0.217d0,0.323d0,0.4d0,0.417d0,0.244d0,
     &           0.213d0,0.189d0,0.172d0,0.185d0,0.208d0,
     &           0.294d0,99999.d0/
         do i=1,17
                 if (udir.eq.angle(i)) then
                         ulambda=ula(i)
                 end if
         end do
         if (udir.eq.1000.d0) then
                 udir=0.d0
                 u=0.d0
         end if
         rnd=v(icount)
         icount=icount+1
         u=-dlog(1-rnd)/ulambda
```

```
        u=u*100.d0
        return
        end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
        subroutine qromb3(func,a,b,s)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        implicit double precision (a-h,o-z)
        implicit integer (i-n)
        parameter (eps=5.d-5,jmax=20,jmaxp=jmax+1,k=5,km=k-1)
        external func
        dimension ss(jmaxp),h(jmaxp)
        h(1)=1.d0
        it=0
        do j=1,jmax
          call trapzd3(func,a,b,ss(j),j,it)
          if (j.ge.k) then
            call polint3(h(j-km),ss(j-km),k,0.d0,s,dss)
            if (dabs(dss).le.eps*dabs(s)) then
              return
            end if
          end if
          ss(j+1)=ss(j)
          h(j+1)=0.25d0*h(j)
        end do
        write(6,*) "integration has too many steps 3"
        write(10,*) "integration has too many steps 3"
        return
        end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
        subroutine trapzd3(func,a,b,s,n,it)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        implicit double precision (a-h,o-z)
        implicit integer (i-n)
        external func
        if (n.eq.1) then
                s=0.5d0*(b-a)*(func(a)+func(b))
                it=1
        else
                itnm=it
                del=(b-a)/itnm
                xx=a+0.5d0*del
                sum=0.d0
                do j=1,it
                        sum=sum+func(xx)
                        xx=xx+del
                end do
                s=0.5d0*(s+(b-a)*sum/itnm)
                it=2*it
        end if
        return
        end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
        subroutine polint3(xa,ya,n,x,y,dy)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        implicit double precision (a-h,o-z)
        implicit integer (i-n)
        parameter (nmax=10)
```

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```
        dimension xa(n),ya(n),c(nmax),d(nmax)
        ns=1
        dif=dabs(x-xa(1))
        do i=1,n
          dift=dabs(x-xa(i))
          if (dift.lt.dif)then
            ns=i
            dif=dift
          end if
          c(i)=ya(i)
          d(i)=ya(i)
        end do
        y=ya(ns)
        ns=ns-1
        do m=1,n-1
          do i=1,n-m
            ho=xa(i)-x
            hp=xa(i+m)-x
            w=c(i+1)-d(i)
            den=ho-hp
            if (den.eq.0.d0) then
              write(6,*) "error in polint3"
              return
            end if
            den=w/den
            d(i)=hp*den
            c(i)=ho*den
          end do
          if (2*ns.lt.n-m) then
            dy=c(ns+1)
          else
            dy=d(ns)
            ns=ns-1
          end if
          y=y+dy
        end do
        return
        end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
        subroutine qromb2(func,a,b,s)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
        implicit double precision (a-h,o-z)
        implicit integer (i-n)
        parameter (eps=5.d-5,jmax=20,jmaxp=jmax+1,k=5,km=k-1)
        external func
        dimension ss(jmaxp),h(jmaxp)
        h(1)=1.d0
        it=0
        do j=1,jmax
          call trapzd2(func,a,b,ss(j),j,it)
          if (j.ge.k) then
            call polint2(h(j-km),ss(j-km),k,0.d0,s,dss)
            if (dabs(dss).le.eps*dabs(s)) then
              return
            end if
          end if
          ss(j+1)=ss(j)
          h(j+1)=0.25d0*h(j)
        end do
        write(6,*) "integration has too many steps 2"
        write(10,*) "integration has too many steps 2"
```

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```
      return
      end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      subroutine trapzd2(func,a,b,s,n,it)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      external func
      if (n.eq.1) then
              s=0.5d0*(b-a)*(func(a)+func(b))
              it=1
      else
              itnm=it
              del=(b-a)/itnm
              xx=a+0.5d0*del
              sum=0.d0
              do j=1,it
                      sum=sum+func(xx)
                      xx=xx+del
              end do
              s=0.5d0*(s+(b-a)*sum/itnm)
              it=2*it
      end if
      return
      end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      subroutine polint2(xa,ya,n,x,y,dy)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      parameter (nmax=10)
      dimension xa(n),ya(n),c(nmax),d(nmax)
      ns=1
      dif=dabs(x-xa(1))
      do i=1,n
        dift=dabs(x-xa(i))
        if (dift.lt.dif)then
          ns=i
          dif=dift
        end if
        c(i)=ya(i)
        d(i)=ya(i)
      end do
      y=ya(ns)
      ns=ns-1
      do m=1,n-1
        do i=1,n-m
          ho=xa(i)-x
          hp=xa(i+m)-x
          w=c(i+1)-d(i)
          den=ho-hp
          if (den.eq.0.d0) then
            write(6,*) "error in polint2"
            return
          end if
          den=w/den
          d(i)=hp*den
          c(i)=ho*den
        end do
```

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```
        if (2*ns.lt.n-m) then
          dy=c(ns+1)
        else
          dy=d(ns)
          ns=ns-1
        end if
        y=y+dy
      end do
      return
      end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      subroutine qromb1(func,a,b,s)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      parameter (eps=5.d-5,jmax=20,jmaxp=jmax+1,k=5,km=k-1)
      external func
      dimension ss(jmaxp),h(jmaxp)
      h(1)=1.d0
      it=0
      do j=1,jmax
        call trapzd1(func,a,b,ss(j),j,it)
        if (j.ge.k) then
          call polint1(h(j-km),ss(j-km),k,0.d0,s,dss)
          if (dabs(dss).le.eps*dabs(s)) then
            return
          end if
        end if
        ss(j+1)=ss(j)
        h(j+1)=0.25d0*h(j)
      end do
      write(6,*) "integration has too many steps 1"
      write(10,*) "integration has too many steps 1"
      return
      end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      subroutine trapzd1(func,a,b,s,n,it)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      external func
      if (n.eq.1) then
              s=0.5d0*(b-a)*(func(a)+func(b))
              it=1
      else
              itnm=it
              del=(b-a)/itnm
              xx=a+0.5d0*del
              sum=0.d0
              do j=1,it
                      sum=sum+func(xx)
                      xx=xx+del
              end do
              s=0.5d0*(s+(b-a)*sum/itnm)
              it=2*it
      end if
      return
      end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
```

MSJ

```
c
      subroutine polint1(xa,ya,n,x,y,dy)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      parameter (nmax=10)
      dimension xa(n),ya(n),c(nmax),d(nmax)
      ns=1
      dif=dabs(x-xa(1))
      do i=1,n
        dift=dabs(x-xa(i))
        if (dift.lt.dif)then
          ns=i
          dif=dift
        end if
        c(i)=ya(i)
        d(i)=ya(i)
      end do
      y=ya(ns)
      ns=ns-1
      do m=1,n-1
        do i=1,n-m
          ho=xa(i)-x
          hp=xa(i+m)-x
          w=c(i+1)-d(i)
          den=ho-hp
          if (den.eq.0.d0) then
            write(6,*) "error in polint1"
            return
          end if
          den=w/den
          d(i)=hp*den
          c(i)=ho*den
        end do
        if (2*ns.lt.n-m) then
          dy=c(ns+1)
        else
          dy=d(ns)
          ns=ns-1
        end if
        y=y+dy
      end do
      return
      end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      subroutine qromb(func,a,b,s,rho)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      parameter (eps=5.d-5d0,jmax=20,jmaxp=jmax+1,k=5,km=k-1)
      external func
      dimension ss(jmaxp),h(jmaxp)
      h(1)=1.d0
      it=0
      do j=1,jmax
        call trapzd(func,a,b,ss(j),j,rho,it)
        if (j.ge.k) then
          call polint(h(j-km),ss(j-km),k,0.d0,s,dss)
          if (dabs(dss).le.eps*dabs(s)) then
            return
```



```
          end if
        end if
        ss(j+1)=ss(j)
        h(j+1)=0.25d0*h(j)
      end do
      write(6,*) "integration has too many steps _"
      write(10,*) "integration has too many steps _"
      return
      end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      subroutine trapzd (func,a,b,s,n,rho,it)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      external func
      if (n.eq.1) then
              s=0.5d0*(b-a)*(func(a,rho)+func(b,rho))
              it=1
      else
              itnm=it
              del=(b-a)/itnm
              xx=a+0.5d0*del
              sum=0.d0
              do j=1,it
                      sum=sum+func(xx,rho)
                      xx=xx+del
              end do
              s=0.5d0*(s+(b-a)*sum/itnm)
              it=2*it
      end if
      return
      end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      subroutine polint(xa,ya,n,x,y,dy)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      parameter (nmax=10)
      dimension xa(n),ya(n),c(nmax),d(nmax)
      ns=1
      dif=dabs(x-xa(1))
      do i=1,n
        dift=dabs(x-xa(i))
        if (dift.lt.dif)then
          ns=i
          dif=dift
        end if
        c(i)=ya(i)
        d(i)=ya(i)
      end do
      y=ya(ns)
      ns=ns-1
      do m=1,n-1
        do i=1,n-m
          ho=xa(i)-x
          hp=xa(i+m)-x
          w=c(i+1)-d(i)
          den=ho-hp
          if (den.eq.0.d0) then
```

```
          write(6,*) "error in polint"
          return
        end if
        den=w/den
        d(i)=hp*den
        c(i)=ho*den
      end do
      if (2*ns.lt.n-m) then
        dy=c(ns+1)
      else
        dy=d(ns)
        ns=ns-1
      end if
      y=y+dy
    end do
    return
    end
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      function gasdev()
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      common /nine/ v,icount
      dimension v(10000)
      iset=0
      if (iset.eq.0) then
1             ran1=v(icount)
              icount=icount+1
              ran2=v(icount)
              icount=icount+1
              v1=2*ran1-1.d0
              v2=2*ran2-1.d0
              r=v1**2+v2**2
              if(r.ge.1.d0.or.r.eq.0.d0) then
                      go.to 1
              end if
              fac=dsqrt(-2.d0*dlog(r)/r)
              gset=v1*fac
              gasdev=v2*fac
              iset=1
       else
              gasdev=gset
              iset=0
       end if
       return
       end
C=====================================================================
      subroutine rand(iseed,v,max)
C=====================================================================
C Random number generator.
C
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      dimension v(max)
      data ia / 1021      /
      data m  / 1048576   /
      data am / 1048576.d0 /
C
      do 100 i = 1, max
        iseed = mod( iseed * ia, m )
        v(i) = dble( iseed ) / am
```

MSJ


```
 100  continue
C
      return
      end
```

MSJ

7-25-96 | Re-Write of subroutine "Fcumm" to enhance the running speed of the code (p. 77)

MSJ

1.) Make subroutine a "table look-up" w/ ~~extrap~~ interpolation (linear) — MSJ 7-25-96

2.) Table values of cdf for standard normal distribution from Schaum's Outline – Statistics (1984)

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```
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
      function Fcumm(rho)
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
      implicit double precision (a-h,o-z)
      implicit integer (i-n)
      common /one/ beta,q,ashdenmin,ashdenmax,dmean,dsigma,fshape
      common /three1/ dmin,dmax,rhomin,rhomax,rhomean
      dimension fc(400)
c
c     This subroutine will only accurately sample from the
c     cdf of the standard normal distribution out to the fourth
c     decimal place
c
      data fc/0.0000d0,0.0040d0,0.0080d0,0.0120d0,0.0160d0,
     &         0.0199d0,0.0239d0,0.0279d0,0.0319d0,0.0359d0,
     &         0.0398d0,0.0438d0,0.0478d0,0.0517d0,0.0557d0,
     &         0.0596d0,0.0636d0,0.0675d0,0.0714d0,0.0754d0,
     &         0.0793d0,0.0832d0,0.0871d0,0.0910d0,0.0948d0,
     &         0.0987d0,0.1026d0,0.1064d0,0.1103d0,0.1141d0,
     &         0.1179d0,0.1217d0,0.1255d0,0.1293d0,0.1331d0,
     &         0.1368d0,0.1406d0,0.1443d0,0.1480d0,0.1517d0,
     &         0.1554d0,0.1591d0,0.1628d0,0.1664d0,0.1700d0,
     &         0.1736d0,0.1772d0,0.1808d0,0.1844d0,0.1879d0,
     &         0.1915d0,0.1950d0,0.1985d0,0.2019d0,0.2054d0,
     &         0.2088d0,0.2123d0,0.2157d0,0.2190d0,0.2224d0,
     &         0.2258d0,0.2291d0,0.2324d0,0.2357d0,0.2389d0,
     &         0.2422d0,0.2454d0,0.2486d0,0.2518d0,0.2549d0,
     &         0.2580d0,0.2612d0,0.2642d0,0.2673d0,0.2704d0,
     &         0.2734d0,0.2764d0,0.2794d0,0.2823d0,0.2852d0,
     &         0.2881d0,0.2910d0,0.2939d0,0.2967d0,0.2996d0,
     &         0.3023d0,0.3051d0,0.3078d0,0.3106d0,0.3133d0,
     &         0.3159d0,0.3186d0,0.3212d0,0.3238d0,0.3264d0,
     &         0.3289d0,0.3315d0,0.3340d0,0.3365d0,0.3389d0,
     &         0.3413d0,0.3438d0,0.3461d0,0.3485d0,0.3508d0,
     &         0.3531d0,0.3554d0,0.3577d0,0.3599d0,0.3621d0,
     &         0.3643d0,0.3665d0,0.3686d0,0.3708d0,0.3729d0,
     &         0.3749d0,0.3770d0,0.3790d0,0.3810d0,0.3830d0,
     &         0.3849d0,0.3869d0,0.3888d0,0.3907d0,0.3925d0,
     &         0.3944d0,0.3962d0,0.3980d0,0.3997d0,0.4015d0,
     &         0.4032d0,0.4049d0,0.4066d0,0.4082d0,0.4099d0,
     &         0.4115d0,0.4131d0,0.4147d0,0.4162d0,0.4177d0,
     &         0.4192d0,0.4207d0,0.4222d0,0.4236d0,0.4251d0,
     &         0.4265d0,0.4279d0,0.4292d0,0.4306d0,0.4319d0,
     &         0.4332d0,0.4345d0,0.4357d0,0.4370d0,0.4382d0,
     &         0.4394d0,0.4406d0,0.4418d0,0.4429d0,0.4441d0,
     &         0.4452d0,0.4463d0,0.4474d0,0.4484d0,0.4495d0,
     &         0.4505d0,0.4515d0,0.4525d0,0.4535d0,0.4545d0,
     &         0.4554d0,0.4564d0,0.4573d0,0.4582d0,0.4591d0,
     &         0.4599d0,0.4608d0,0.4616d0,0.4625d0,0.4633d0,
     &         0.4641d0,0.4649d0,0.4656d0,0.4664d0,0.4671d0,
     &         0.4678d0,0.4686d0,0.4693d0,0.4699d0,0.4706d0,
     &         0.4713d0,0.4719d0,0.4726d0,0.4732d0,0.4738d0,
     &         0.4744d0,0.4750d0,0.4756d0,0.4761d0,0.4767d0,
     &         0.4772d0,0.4778d0,0.4783d0,0.4788d0,0.4793d0,
     &         0.4798d0,0.4803d0,0.4808d0,0.4812d0,0.4817d0,
     &         0.4821d0,0.4826d0,0.4830d0,0.4834d0,0.4838d0,
     &         0.4842d0,0.4846d0,0.4850d0,0.4854d0,0.4857d0,
     &         0.4861d0,0.4864d0,0.4868d0,0.4871d0,0.4875d0,
     &         0.4878d0,0.4881d0,0.4884d0,0.4887d0,0.4890d0,
     &         0.4893d0,0.4896d0,0.4898d0,0.4901d0,0.4904d0,
     &         0.4906d0,0.4909d0,0.4911d0,0.4913d0,0.4916d0,
```

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```
     &         0.4918d0,0.4920d0,0.4922d0,0.4925d0,0.4927d0,
     &         0.4929d0,0.4931d0,0.4932d0,0.4934d0,0.4936d0,
     &         0.4938d0,0.4940d0,0.4941d0,0.4943d0,0.4945d0,
     &         0.4946d0,0.4948d0,0.4949d0,0.4951d0,0.4952d0,
     &         0.4953d0,0.4955d0,0.4956d0,0.4957d0,0.4959d0,
     &         0.4960d0,0.4961d0,0.4962d0,0.4963d0,0.4964d0,
     &         0.4965d0,0.4966d0,0.4967d0,0.4968d0,0.4969d0,
     &         0.4970d0,0.4971d0,0.4972d0,0.4973d0,0.4974d0,
     &         0.4974d0,0.4975d0,0.4976d0,0.4977d0,0.4977d0,
     &         0.4978d0,0.4979d0,0.4979d0,0.4980d0,0.4981d0,
     &         0.4981d0,0.4982d0,0.4982d0,0.4983d0,0.4984d0,
     &         0.4984d0,0.4985d0,0.4985d0,0.4986d0,0.4986d0,
     &         0.4987d0,0.4987d0,0.4987d0,0.4988d0,0.4988d0,
     &         0.4989d0,0.4989d0,0.4989d0,0.4990d0,0.4990d0,
     &         0.4990d0,0.4991d0,0.4991d0,0.4991d0,0.4992d0,
     &         0.4992d0,0.4992d0,0.4992d0,0.4993d0,0.4993d0,
     &         0.4993d0,0.4993d0,0.4994d0,0.4994d0,0.4994d0,
     &         0.4994d0,0.4994d0,0.4995d0,0.4995d0,0.4995d0,
     &         0.4995d0,0.4995d0,0.4995d0,0.4996d0,0.4996d0,
     &         0.4996d0,0.4996d0,0.4996d0,0.4996d0,0.4997d0,
     &         0.4997d0,0.4997d0,0.4997d0,0.4997d0,0.4997d0,
     &         0.4997d0,0.4997d0,0.4997d0,0.4997d0,0.4998d0,
     &         0.4998d0,0.4998d0,0.4998d0,0.4998d0,0.4998d0,
     &         0.4998d0,0.4998d0,0.4998d0,0.4998d0,0.4998d0,
     &         0.4998d0,0.4998d0,0.4999d0,0.4999d0,0.4999d0,
     &         0.4999d0,0.4999d0,0.4999d0,0.4999d0,0.4999d0,
     &         0.4999d0,0.4999d0,0.4999d0,0.4999d0,0.4999d0,
     &         0.4999d0,0.4999d0,0.4999d0,0.4999d0,0.4999d0,
     &         0.4999d0,0.4999d0,0.4999d0,0.4999d0,0.4999d0,
     &         0.4999d0,0.4999d0,0.4999d0,0.4999d0,0.4999d0,
     &         0.5000d0,0.5000d0,0.5000d0,0.5000d0,0.5000d0,
     &         0.5000d0,0.5000d0,0.5000d0,0.5000d0,0.5000d0/
      deltax=0.01d0
      rhonorm=(rho-rhomean)/dsigma
      if (rhonorm.ge.4.d0) then
        Fcumm=1.d0
        return
      else if (rhonorm.le.-4.d0) then
        Fcumm=0.d0
        return
      end if
      av=dabs(rhonorm)
      ilow=idnint(dint(100*av))+1
      ihi=ilow+1
      if (rhonorm.lt.0.d0) then
        Fcumm=0.5d0-fc(ihi)+(av-((ihi-1)*deltax))*
     &        (fc(ilow)-fc(ihi))/(deltax)
      else if (rhonorm.gt.0.d0) then
        Fcumm=0.5d0+fc(ilow)+(rhonorm-((ilow-1)*deltax))*
     &        (fc(ihi)-fc(ilow))/(deltax)
      else if (rhonorm.eq.0.d0) then
        Fcumm=0.5d0
      end if
      return
      end
```

MSJ

Sample output file to check operation of subroutine

rhomean= 1.00000000000000
dsigma= 1.00000000000000

	rho=	Fcumm=
	-5.50000	.00000
	-5.00000	.00000
	-4.50000	.00000
	-4.00000	.00000
	-3.50000	.00000
	-3.00000	.00000
	-2.50000	.00020
	-2.00000	.00130
1)	-1.50000	.00620
	-1.00000	.02280
	-.50000	.06680
	.00000	.15870
	.50000	.30850
	1.00000	.50000
2)	1.50000	.69150
	2.00000	.84130
	2.50000	.93320
	3.00000	.97720
	3.50000	.99380
	4.00000	.99870
	4.50000	.99980
	5.00000	1.00000
	5.50000	1.00000
	6.00000	1.00000

MSJ

HAND CALCULATION - CHECK W/ TABLE IN SCHAUMS

1) $\int_{-\infty}^{-2.5} \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left(-\frac{\rho-\rho_{mean}}{2\sigma^2}\right)d\rho = 0.0062$ FROM SCHAUMS ✓

2) $\int_{-\infty}^{+0.5} \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left(\frac{-\rho-\rho_{mean}}{2\sigma^2}\right)d\rho = 0.6915$ FROM SCHAUMS ✓

7-26-96
MSJ

VERIFICATION EXCERSIZE

COMPARISON OF CODE RESULTS W/ PUBLISHED CALCULATIONS (SUZUKI (1983))

INPUT DATA SET

TOTAL ASH MASS = 10^{15} g EVENT DURATION (T) = 3.3177E5 s

COLUMN HT = 10 km $\dot{Q}$ = 3.014E9 g/s

ERUPTION VELOCITY = 10^4 cm/s

MEAN PARTICLE DIAMETER = 1 mm

SIGMA ON PARTICLE DIAMETER = 0.4

WIND SPEED = 10^3 cm/s

ASH DENSITY = 0.8 g/cm^3

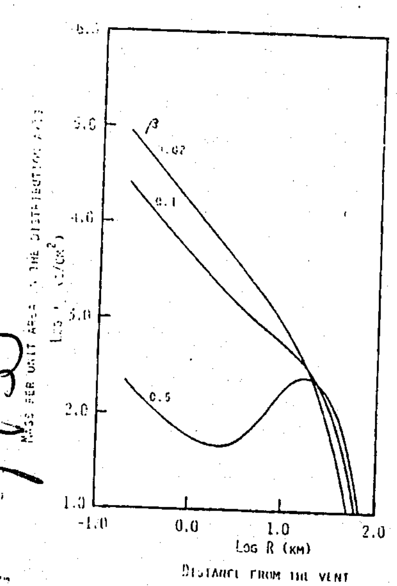
PARTICLE SHAPE PARAMETER = 0.5

AIR DENSITY = 0.001293 g/cc

AIR VISCOSITY = 0.00018 g/cm-s

EDDY DIFFUSIVITY = 400 cm^2/s$^{5/2}$

MSJ

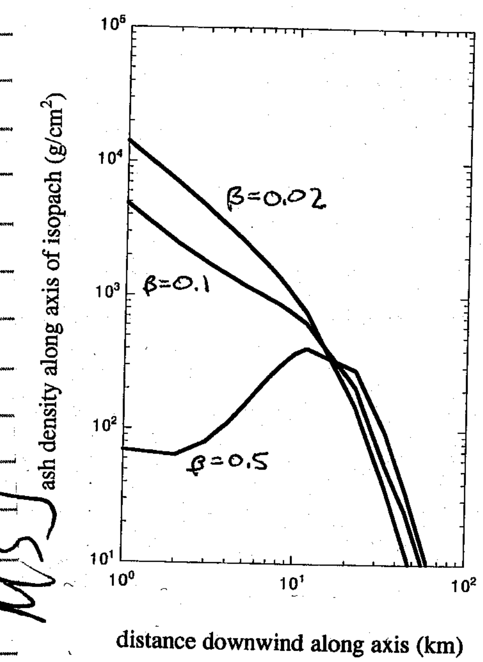


SUZUKI (1983)

MSJ

FROM ASHPLUME

Comparison plot with Suzuki (1983)



10/9/96
MSJ

INVESTIGATIONS FOR DEC. APPENDIX 7 AND ACNW MEETINGS ON VOLCANIC HAZARDS

PURPOSE: INVESTIGATE CODE RESULTS USING ASHPLUME CODE W/ DIFFERENT FUEL DISTRIBUTIONS AND INCORPORATION RATIOS

- THE FOLLOWING MEMO DESCRIBES THE 9 SETS OF RUNS TO BE MADE WITH THE ASHPLUME.EXE CODE VERSION 1.0
- 300 REALIZATIONS EACH (OF THE 9 SETS); N=300
- $\mu_{DIR} \equiv -90°$ FOR ALL RUNS; $p(\mu_{dir} = -90°) = 0.14045$
- PARAMETERS ARE DEFINED ON p. 35 OF THIS NOTEBOOK

$\bar{x}$ = EXPERIMENTALLY DETERMINED MEAN OF THE SET OF REALIZATIONS

$$\bar{x} = \frac{1}{N} \sum_{n=1}^{N} D_n \cong \mu$$

D_n = ANNUAL EDE ESTIMATE FOR REALIZATION n

$$\sigma^2 \cong s^2 = \frac{1}{N-1} \sum_{n=1}^{N} (D_n - \bar{x})^2$$

$$= \frac{1}{N-1} \sum_{n=1}^{N} D_n^2 - 2D_n\bar{x} + \bar{x}^2$$

$$= \frac{1}{N-1} \left[\sum_{n=1}^{N} D_n^2 - 2\bar{x} \sum_{n=1}^{N} D_n + \sum_{n=1}^{N} \bar{x}^2 \right]$$

$$= \frac{1}{N-1} \left[\sum_{n=1}^{N} D_n^2 - 2\bar{x} \sum_{n=1}^{N} D_n + N \cdot \bar{x}^2 \right]$$

* NOTE: THESE NO.'S NEED TO BE MULTIPLIED BY $p(\mu_{DIR} = -90)$

From: Mark S. Jarzemba

To: Interested CNWRA and NRC parties

Re: Parameter values to be used for the November meeting

The following Table describes the parameter values to be used for the 9 sets of runs to be presented at the November meeting on this subject.

Table. A description of the parameters to be varied the 9 sets of runs proposed for the November meeting.

increasing ρ_c ↓	LO — increasing m(ρf) →	MED	HI
LO	ρ^f_{lo} = 1 micron ρ^f_{med} = 10 microns ρ^f_{hi} = 100 microns ρ_c = 1 (10:1)	ρ^f_{lo} = 0.1 mm ρ^f_{med} = 1 mm ρ^f_{hi} = 10 mm ρ_c = 1 (10:1)	ρ^f_{lo} = 0.1 cm ρ^f_{med} = 1 cm ρ^f_{hi} = 10 cm ρ_c = 1 (10:1)
MED	ρ^f_{lo} = 1 micron ρ^f_{med} = 10 microns ρ^f_{hi} = 100 microns ρ_c = 0.7 (5:1)	ρ^f_{lo} = 0.1 mm ρ^f_{med} = 1 mm ρ^f_{hi} = 10 mm ρ_c = 0.7 (5:1)	ρ^f_{lo} = 0.1 cm ρ^f_{med} = 1 cm ρ^f_{hi} = 10 cm ρ_c = 0.7 (5:1)
HI	ρ^f_{lo} = 1 micron ρ^f_{med} = 10 microns ρ^f_{hi} = 100 microns ρ_c = 0.3 (2:1)	ρ^f_{lo} = 0.1 mm ρ^f_{med} = 1 mm ρ^f_{hi} = 10 mm ρ_c = 0.3 (2:1)	ρ^f_{lo} = 0.1 cm ρ^f_{med} = 1 cm ρ^f_{hi} = 10 cm ρ_c = 0.3 (2:1)

Notes:

1. ρ^f_{lo}, ρ^f_{med} and ρ^f_{hi} describe the fuel particulate size distribution to be used (parameters for the logtriangular distribution).

2. ρ_c describes the ratio of the ash size to incorporable fuel size on a log scale; e.g. a ρ_c = 1 means that there is a 10 to 1 ratio on this process meaning that , for example, a 10 mm ash particle can incorporate fuel particles of 1 mm or smaller. Further, according to the model of Jarzemba and LaPlante (1996), the 10 mm ash particle is also in simultaneous competition for the 1 mm and smaller fuel particles with all of the other ash particles larger than 10 mm.

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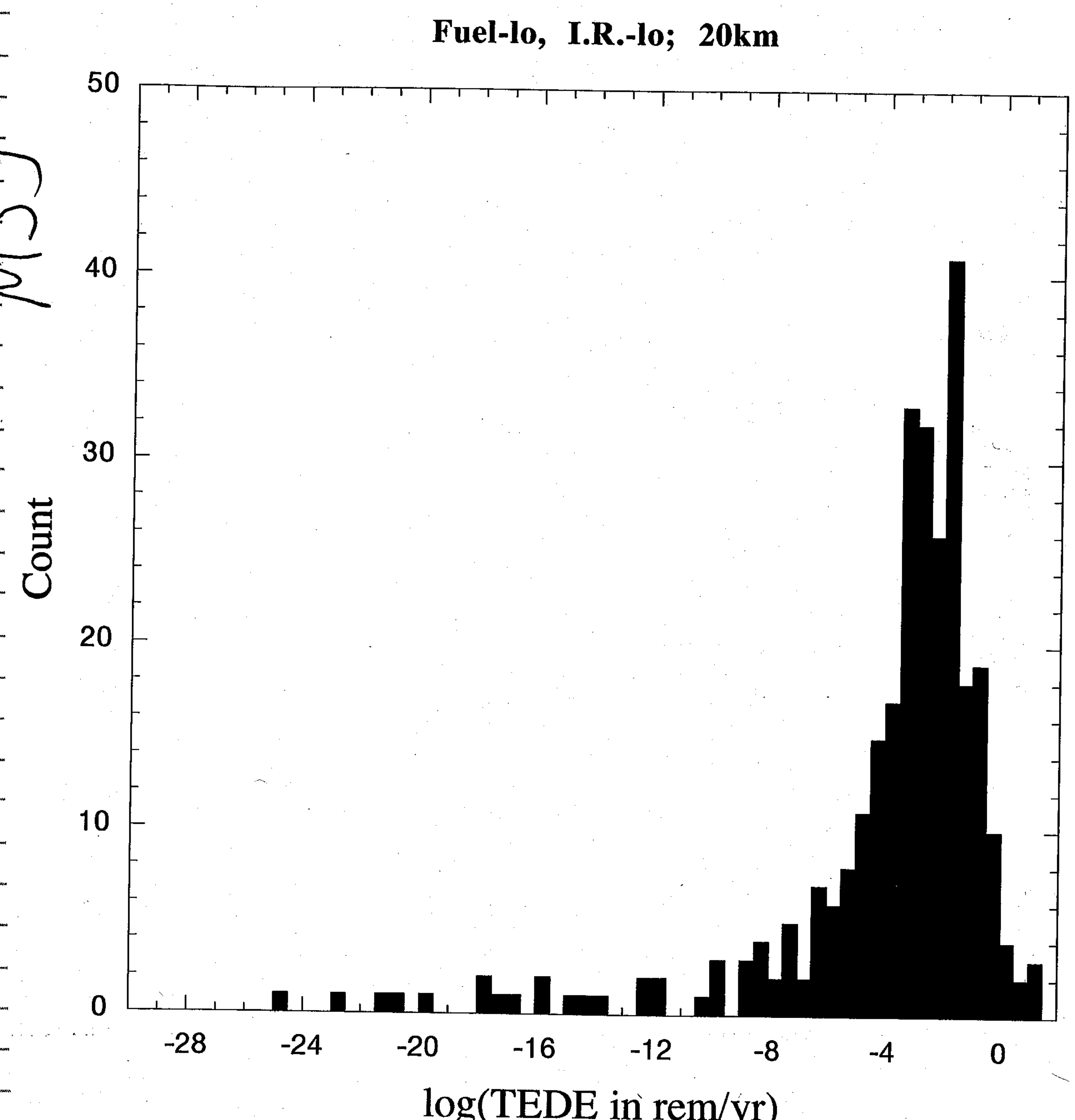
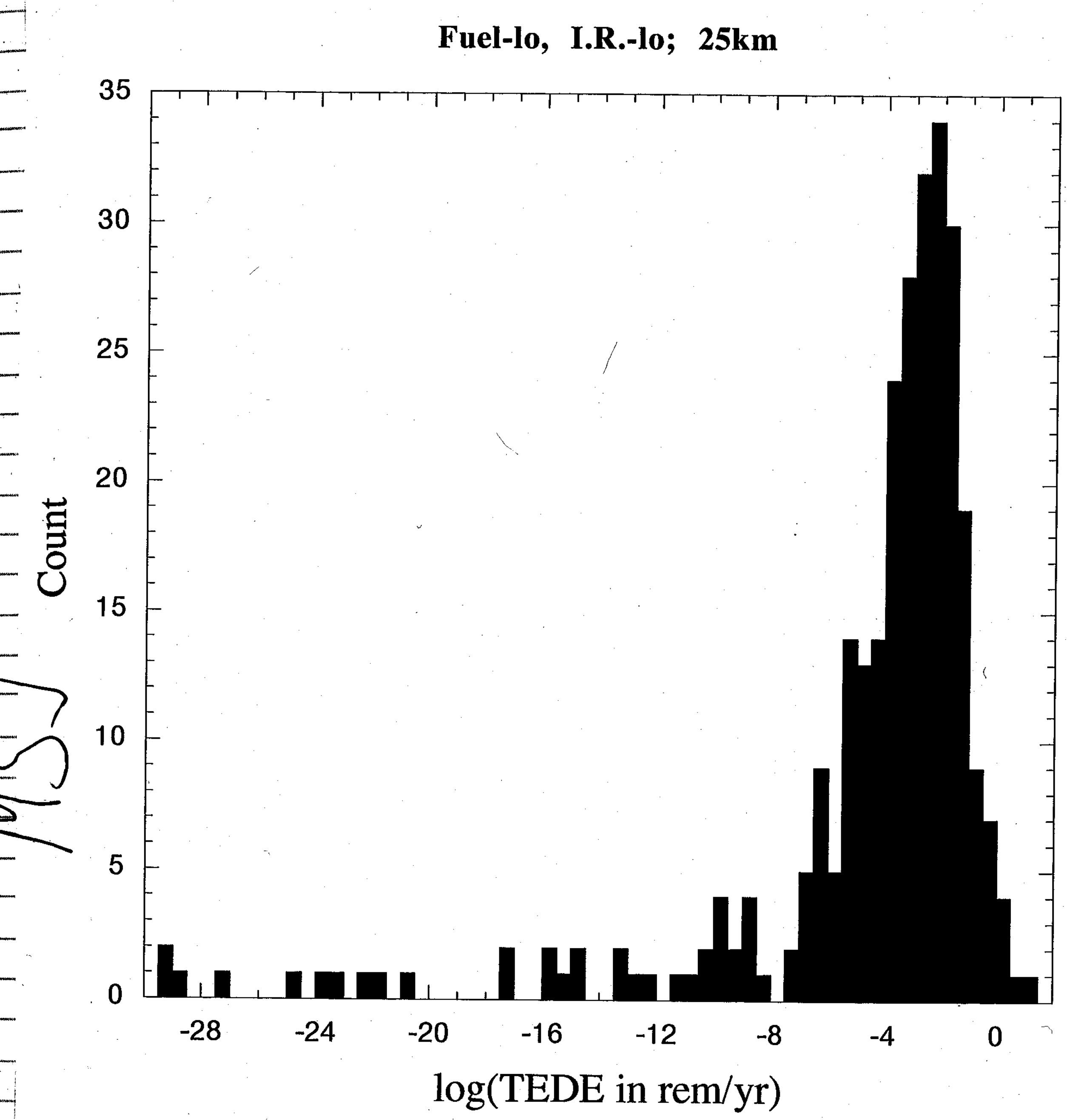
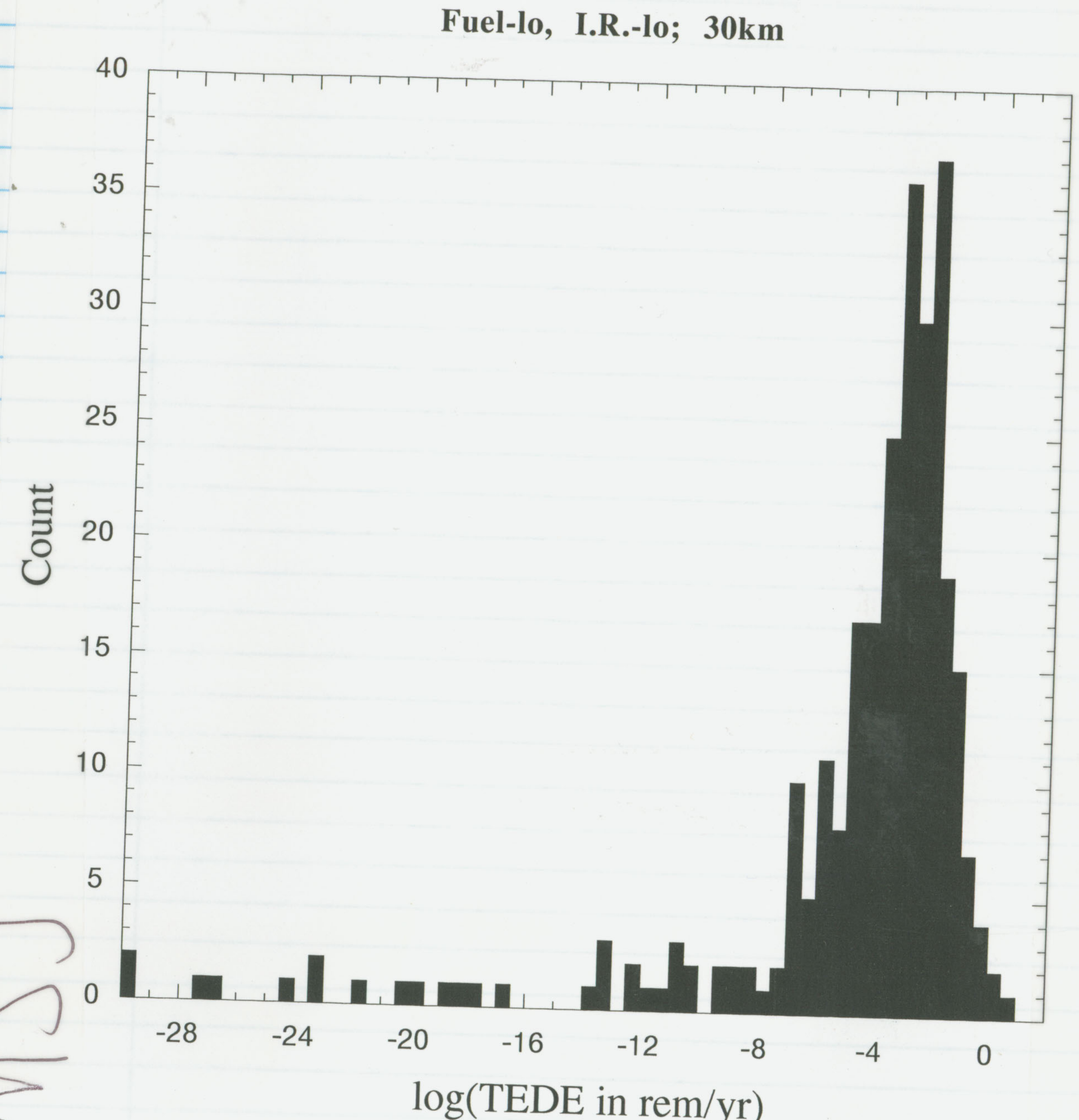
CASE 1 - FUEL: LOW DISTRIBUTION
INCORPORATION RATIO: 0.3 (LO)



MEAN = 0.297 REM/YR STANDARD DEV. = σ = 2.01 REM/YR



MEAN = 0.108 REM/YR STANDARD DEV. = 0.732 REM/YR



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MEAN = 0.0491 REM/YR   STANDARD DEVIATION = 0.393

- TO RECORD HISTOGRAMS FOR ALL THESE CASES WOULD BE TOO CUMBERSOME
- EXCEL SPREADSHEETS HAVE BEEN USED TO DO DOSE CONVERSION ($S^{-1}/cm^2 \Rightarrow$ MREM/YR) AND TO CALCULATE MEANS AND STANDARD DEVIATIONS

TABLE: MEANS AND ST. DEV. FOR THE THREE DOSE POINTS AND 9 CASES

FUEL DIST.	I.R.	DOSE PT. (KM)	MEAN (REM/YR) $\bar{x}$ (p.94)	ST. DEV. (REM/YR) s (p.94)
LO	0.3	-20	0.297	2.01
		-25	0.108	0.732
		-30	0.049	0.393
LO	0.7	-20	0.290	2.01
		-25	0.100	0.705
		-30	0.045	0.378
LO	1.0	-20	0.270	1.93
		-25	0.089	0.646
MSJ 10/8/96 ~~MED~~	~~0.3~~	-30	0.037	0.329
MED	0.3	-20	4.06 E-02	3.91 E-01
		-25	5.97 E-03	5.67 E-02
		-30	6.45 E-04	7.10 E-03
MED	0.7	-20	8.20E-03	9.46E-02
		-25	8.22 E-04	9.82 E-03
		-30	5.39 E-05	8.14E-04
MED	1.0	-20	8.49 E-04	1.01 E-02
		-25	2.37 E-05	3.27 E-04
		-30	3.33 E-07	4.17 E-06
HI	0.3	-20	4.72 E-06	5.80 E-05
		-25	1.64 E-08	2.76 E-07
		-30	5.68 E-11	9.84 E-10
HI	0.7	-20	6.04 E-11	1.05 E-09
		-25	7.23 E-18	1.25 E-16
		-30	9.72 E-29	1.68 E-27
HI	1.0	-20	9.00 E-21	1.56 E-19
		-25	1.06 E-36	1.83 E-35
		-30	0	0

10/10/96 Note: New scheme for sampling power (P) in W and
MSJ event duration has been used (T in sec)

T: sampled loguniformly over $[6.39\times10^{+4}, 7.26\times10^{6}]$ s

P: sampled loguniformly over $[2.6\times10^{9}, 3.6\times10^{11}]$ W

– This was done on the advice of Britt Hill.

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Volcanic Systems of the Basin and Range Brittain Hill [signature] 7/10/96

		A	B	C	D	E	F	G	H	I	J	K
	8		Observed	Duration				DRE				
	9		H (km)	(s)	H (m)	Q (W)	(kg/m3)	v (m3/s)	s (J/kgK)	T (°K)	Tf	F
X	10	Hekla 1947	24	1.80E +03	21.1	4.3E +13	2500	17000	1.1E +03	1200	270	1
X	11	Hekla 1970	14	7.20E +03	14.0	8.5E +12	2500	3333	1.1E +03	1200	270	1
X	12	Tarawera 1886	9.5	1.08E +04	30.4	1.9E +14	2640	84259	1.1E +03	1375	270	0.7
	16											
	17	Heimaey	2	2.25E +06	2.2	4.9E +09	2600	2.3	1.1E +03	1325	270	0.7
	18	Paricutin	4-6	7.26E +06	4.0	5.7E +10	2530	26.6	1.1E +03	1375	270	0.7
	19	Tolbachik Cone 1	6-10	1.21E +06	4.8	1.1E +11	2640	49.6	1.1E +03	1400	270	0.7
	20	Tolbachik Cone 2	2-3	3.28E +06	3.5	3.2E +10	2610	14.0	1.1E +03	1400	270	0.7
	21											
	22	CN47	4-6.5	8.64E +05	3.5	3.3E +10	2600	15.9	1.1E +03	1325	270	0.7
	23	CN68	1-1.5	3.63E +06	1.9	2.6E +09	2600	1.2	1.1E +03	1325	270	0.7
	24	CN71	6	6.05E +05	3.8	4.9E +10	2600	23.0	1.1E +03	1325	270	0.7
	25	CN92	6.5	6.39E +04	6.4	3.6E +11	2600	172.1	1.1E +03	1325	270	0.7
	26	CN95	2	3.46E +05	2.4	7.9E +09	2600	3.8	1.1E +03	1325	270	0.7

Table ERUPTDYN: Eruption dynamics for analog basalt volcanoes.

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X – Denotes elimination from consideration in these analyses.

10/11/96 – For the record: the former distribution "scheme" for P and T
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$$u = \frac{-\ln(1-r_2)}{\lambda(r_1)} \tag{7}$$

ERUPTION PARAMETERS

A number of relationships exist in the literature that describe how eruption parameters are correlated with each other. These correlations are described in this section. Wilson et al., (1978), Luhr and Simkin (1993), Fedotov and Markhinin (1983) and Self et al. (1974) all describe volcanic eruptions in terms of their power (*P*) and the time duration of the eruption (*T*). The data for small-volume basaltic eruptions similar to those that may have occurred in the YM region in the past are summarized in Table 2. It is assumed that the data contained in Table 2 define the ranges of values of *P* and *T* for YM. For the purposes of this paper, it is assumed that a postulated volcanic event erupts at a constant power over the duration of the event. Figure 1 shows a plot of log (*P*) versus log (*T*) for data on observed eruptions. The volcanic eruptions included in Figure 1 were chosen because of their similarity to postulated volcanic eruptions at YM. The similarity is supported by the presence of ash deposits 3 km and 6 km north of Lathrop Wells cinder cone, and ash deposits in Solitario Canyon 10 km east of the Quaternary Crater Flat volcanoes (Hill, et al., 1995).

It is noted that the duration of volcanic events is one of the most easily observed parameters for the event, as is, to a lesser extent, the height of the eruption column (a direct function of volcanic power, Wilson, et al., 1978). This fact means that driving the stochastic realization from these two parameters will likely lead to the most realistic simulations of volcanic events.

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The procedure to stochastically sample *P* and *T* used in the paper is to first sample log (*T*) from a uniform probability distribution over the range:

$$\log(T) \in [3.25\ ,\ 6.83] \tag{8}$$

With log (*T*) determined, a mean value, used to sample log (*P*) from a normal distribution, is

Table 2. A list of the volcanic events used to extrapolate the relationship between log(*P*) and log(*T*) along with the sources of the data

Event	Information Source	log(*T*) (*T* in s)	log(*P*) (*P* in W)
Cerro Negro, 1992	Connor, et al., 1992	4.8	12.0
Hekla, 1970	Wilson et al., 1978	3.9	12.8
Tolbachik, 1975	Fedotov and Markhinin, 1983	6.1	11.7
Paricutin, 1944 I	Luhr and Simkin, 1993	5.6	9.0
Paricutin, 1944 II	Luhr and Simkin, 1993	6.8	11.5
Paricutin, 1946	Luhr and Simkin, 1993	6.8	9.0
Hekla, 1947	Wilson et al., 1978	3.3	13.8
Heimaey, 1973	Self et al., 1974	6.4	9.9

determined from the least squares fit shown in Figure 1. The variance of log(*P*) (i.e. σ_P^2) is determined from the sum of the squared distances of the data points from the linear fit of the data, and is found to be 0.5. The probability distribution function, f, used to determine log(*P*) is given by:

$$f[\log(P)] = \frac{1}{\sqrt{2\pi}\,\sigma_P}\exp\left[\frac{\{\log(P)-[16.73-0.962\log(T)]\}^2}{2\sigma_P^2}\right] \tag{9}$$

Wilson et al. (1978) describes the following relationship between the volcanic power (*P*) and volcanic column height (*H*):

$$H = 0.0082P^{0.25} \tag{10}$$

where *H* is in km and *P* is in watts. The Hekla, 1947 eruption is considered to be a maximum power event for this type of eruption style. The maximum eruption column height of this eruption was about

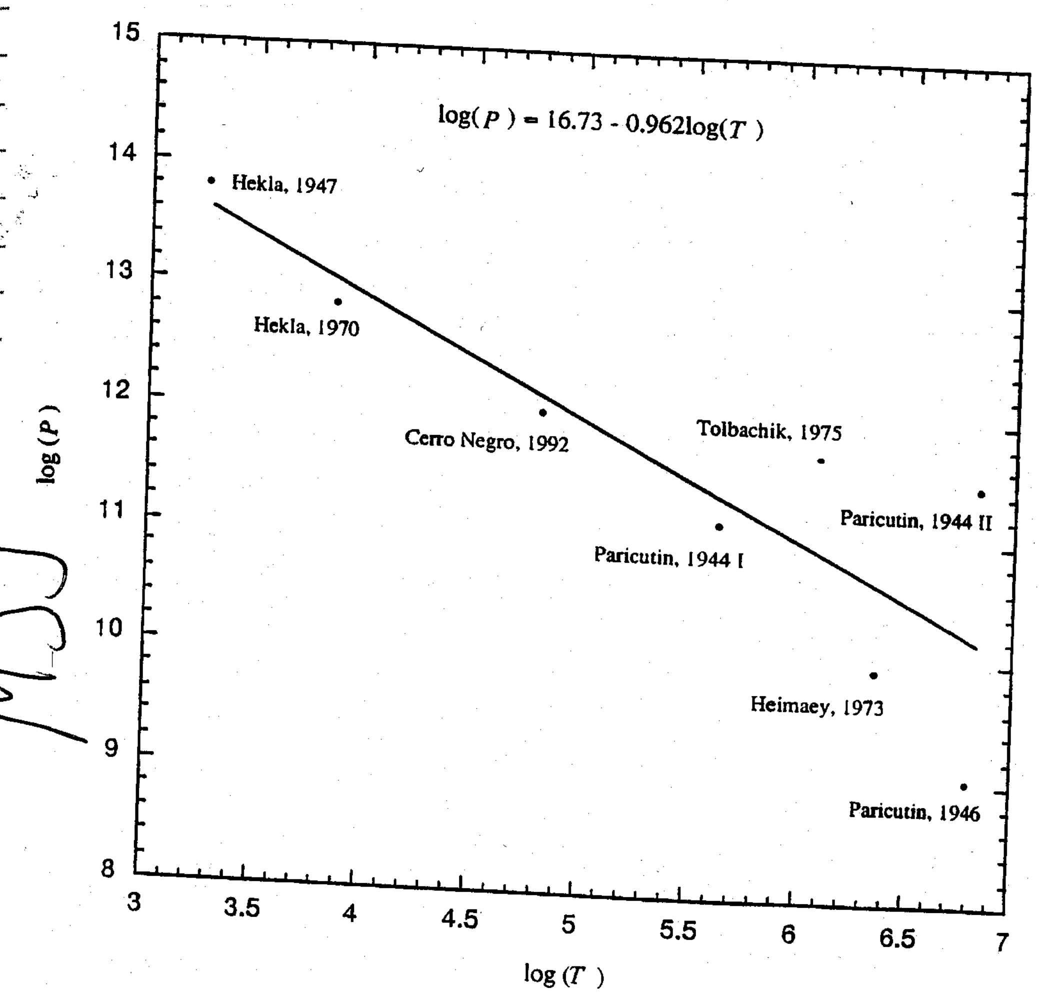

Figure 1. A plot of log(P) versus log(T) for several volcanoes of composition similar to that expected at Yucca Mountain

24 km. This maximum height corresponds to a P of 7×10^{13} W; therefore, $\log(P)$ is limited to a maximum of 13.8 in this paper.

The literature also contains other volcanic parameter interrelationships. Assuming that the volcanic power has been determined by the means described above, the mass ejection rate of material from the volcano ($\dot{Q}$) in g per sec is given in Walker et al. (1984) as

$$\dot{Q} = 1{,}000\left(\frac{H}{0.24}\right)^4 \tag{11}$$

and therefore;

$$Q = \dot{Q}T \tag{12}$$

where it has been assumed that the mass ejection rate is constant over the duration of the event. The eruption velocity at the vent exit (W_0) is given by:

$$W_0 = \frac{\dot{Q}}{\psi_p \pi r_v^2} \tag{13}$$

where r_v is the vent radius in cm. An expression for the volcanic vent radius is extracted from Wilson and Head (1981) to be:

$$\log_{10}(r_v) = -0.069 + 2\log_{10}(\psi_p) + 0.274\log_{10}(\dot{Q}) \tag{14}$$

Equations (8) through (14) describe how to determine the important volcanic parameters for calculating ash distributions (and hence radionuclide distributions) after an basaltic eruption is assumed to occur. These parameters are determined from Monte Carlo sampling that stochastically samples the volcanic energy and time duration from the stated ranges and distributions.

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THE RESULTS ON p. 99 NEED TO BE MULTIPLIED THROUGH BY $p(u_{DIR}=-90)$ SINCE u_{DIR} WAS −90 FOR ALL RUNS [NOTE: $p(u_{DIR}=-90) = 0.14045$]

TABLE: A PLOT OF $\bar{x}$ AND S WHERE

$$\bar{x} = \left[\sum_{n=1}^{300}(D_n)\right]\frac{1}{300}\cdot p(u_{DIR}=-90)$$

$$s = \left[\sum_{n=1}^{300}(D_n-\bar{x})^2\right]\frac{1}{299}\cdot p(u_{DIR}=-90)$$

FUEL DIST	I.R.	DOSE PT.	$\bar{x}$ (REM/YR)	S (REM/YR)
Lo	0.3	-20	4.17E-02	2.82E-01
		-25	1.52E-02	1.03E-01
		-30	6.88E-03	5.52E-02
Lo	0.7	-20	4.07E-02	2.82E-01
		-25	1.40E-02	9.90E-02
		-30	6.32E-03	5.31E-02
Lo	1.0	-20	3.79E-02	2.71E-02
		-25	1.25E-02	9.07E-02
		-30	5.20E-03	4.62E-02
MED	0.3	-20	5.70E-03	5.49E-02
		-25	8.38E-04	7.96E-03
		-30	9.06E-05	9.97E-04
MED	0.7	-20	1.15E-03	1.33E-02
		-25	1.15E-04	1.38E-03
		-30	7.57E-06	1.14E-04
MED	1.0	-20	1.19E-04	1.42E-03
		-25	3.36E-06	4.59E-05
		-30	4.68E-08	5.86E-07
Hi	0.3	-20	6.63E-07	8.15E-06
		-25	2.30E-09	3.88E-08
		-30	7.98E-12	1.38E-10
Hi	0.7	-20	8.48E-12	1.47E-10
		-25	1.02E-18	1.76E-17
		-30	1.37E-29	2.36E-28
Hi	1.0	-20	1.26E-21	2.19E-20
		-25	1.49E-37	2.57E-36
		-30	0	0

10/16/96 MSJ — THE OUTPUT DATA FROM ASHPLUME.EXE FOR THE 9 CASES HAS BEEN ELECTRONICALLY DOCUMENTED ON DISKETTE AND IS TAPED TO THE BACK OF THIS NOTEBOOK. THE DATA IS IN EXCEL SPREADSHEETS.

THE VERSION OF ASHPLUME USED TO CALCULATE THE DATA IS INCLUDED AS WELL

10/17/96 — THE TIME OF THE EVENT SHOULD BE THE TIME OF THE FIRST EVENT IN THE TPI GIVEN THAT AT LEAST ONE EVENT OCCURS IN THE TPI

$$P(\text{AT LEAST ONE EVENT IN THE TPI}) = P(V \in TPI)$$

$$p(\text{TIME OF THE FIRST EVENT} \mid V \in TPI) = p(t_v \mid V \in TPI)$$

NOTE: P INDICATES PROBABILITY; p INDICATES PROBABILITY DENSITY

$$P(V \in TPI) = \exp(-\lambda t_\ell) - \exp(-\lambda t_u)$$

t_u = UPPER LIMIT OF THE TPI (YR)
t_ℓ = LOWER LIMIT OF THE TPI (YR)
λ = RECURRENCE RT. (1/YR) [ASSUME 3×10^{-8} 1/YR]

$$p(t_v \mid V \in TPI) = \frac{\lambda \exp(-\lambda t)}{\exp(-\lambda t_\ell) - \exp(-\lambda t_u)}$$

$$P(t_v < t \mid V \in TPI) = \frac{\exp(-\lambda t_\ell) - \exp(-\lambda t)}{\exp(-\lambda t_\ell) - \exp(-\lambda t_u)}$$

SAMPLING: LET $\zeta \in [0,1]$ W/ A UNIFORM DISTRIBUTION

GOLDEN RULE: $$\zeta = \frac{\exp(-\lambda t_\ell) - \exp(-\lambda t)}{\exp(-\lambda t_\ell) - \exp(-\lambda t_u)}$$

$c_1 = \exp(-\lambda t_\ell)$ $\quad c_2 = \exp(-\lambda t_\ell) - \exp(-\lambda t_u)$

$$\zeta = \frac{c_1}{c_2} - \frac{\exp(-\lambda t)}{c_2}$$

$$-\zeta + \frac{c_1}{c_2} = \frac{\exp(-\lambda t)}{c_2}$$

$$\ln\left[c_2\left(\frac{c_1}{c_2} - \zeta\right)\right] = -\lambda t \implies t = \frac{-\ln\left[c_2\left(\frac{c_1}{c_2} - \zeta\right)\right]}{\lambda} = \frac{-\ln(c_1 - c_2\zeta)}{\lambda}$$

- THE FIGURES IN THE TABLE ON THE PREVIOUS PAGE NEED TO BE RE-CALCULATED USING THE ABOVE METHODOLOGY FOR EVENT TIME SAMPLING.

TABLE; RECALCULATION OF TABLE ON p. 105 W/NEW TIME SAMPLING SCHEME

MSJ- 10/22/96

FUEL DIST.	I.R.	DOSE PT	$\bar{X}$ (REM/YR)	S (REM/YR)	MAX DOSE (REM/YR)
LO	+0.3	-20	4.66E-02	3.33E-01	30.6
	(LO)	-25	1.63E-02	1.07E-01	8.73
		-30	6.49E-03	4.40E-02	4.53
LO	+0.7	-20	4.49E-02	3.34E-01	30.9
	(Med)	-25	1.52E-02	1.04E-01	8.80
		-30	5.70E-03	3.98E-02	4.13
LO	+1.0	-20	4.22E-02	3.28E-01	30.7
	(hi)	-25	1.40E-02	1.04E-01	8.71
		-30	4.46E-03	3.25E-02	3.30
MED	+0.3	-20	8.72E-03	9.30E-02	9.21
	(LO)	-25	1.52E-03	1.82E-02	2.06
		-30	1.76E-04	2.57E-03	0.316
MED	+0.7	-20	2.13E-03	2.45E-02	2.25
	(Med)	-25	2.61E-04	3.34E-03	0.381
		-30	2.08E-05	3.21E-04	3.95E-02
MED	+1.0	-20	2.51E-04	3.03E-03	0.311
	(hi)	-25	8.48E-06	1.27E-04	1.56E-02
		-30	1.15E-07	1.53E-06	1.83E-04
HI	+0.3	-20	1.62E-06	2.18E-05	2.64E-03
	(LO)	-25	3.15E-09	5.04E-08	6.20E-06
		-30	1.04E-11	1.79E-10	2.21E-08
HI	+0.7	-20	1.10E-11	1.91E-10	2.35E-08
	(Med)	-25	1.32E-18	2.28E-17	2.81E-15
		-30	1.77E-29	3.07E-28	3.78E-26
HI	+1.0	-20	1.64E-21	2.84E-20	3.50E-18
	(hi)	-25	1.93E-37	3.34E-36	4.12E-34
		-30	0	0	0

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MSJ 10-25-96

NOTE - ~~$I.R. \equiv -\log_{10}\left(\frac{d^f_{max}}{d^a_{min}} [\text{IN CM}]\right) \equiv p_c$~~

WHERE:

d^f_{max} = THE FUEL PARTICULATE MAXIMUM DIAMETER THAT CAN BE INCORPORATED INTO ASH PARTICLES OF d^a_{min} OR LARGER

$$I.R. = p_c \equiv \log\left(\frac{d^a_{min}}{d^f_{max}}\right)$$ ALL d IN cm

2/19/99 With the completion of initial ASHPLUME
MSJ development, this project phase is closed

"I have reviewed this scientific notebook and find it in compliance with QAP-001. There is sufficient information regarding procedures used for conducting tests, acquiring and analyzing data so that another qualified individual could repeat the activity.

Gordon Wittmeyer 2/23/99

(Element Manager signature and date above line, Name of Element beneath line)"

Gordon Wittmeyer

ADDITIONAL INFORMATION FOR SCIENTIFIC NOTEBOOK #: 164

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File Types: (.exe, .bat, .zip, etc.)	Various
Remarks: (computer runs, etc.)	Media contains: ASHPLUME1 results of 9 cases; ASHPLUME2-results of 9 cases.