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DIFFUSION CLIMATOLOGY FOR HYPOTHETICAL ACCIDENTS IN AREA 410 OF THE NEVADA TEST SITE

Kendall R. Peterson

May 20, 1976

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Contents

Abstract	1
Introduction	1
Regional Meteorology Around the Nevada Test Site	2
General Climate	2
Severe Weather	2
Air-Pollution Potential at NTS	4
Local Meteorology of the Nevada Test Site and Area 410	5
Station Summary	5
Winds	9
Atmospheric Stability	11
Humidity and Fog	29
Program of Onsite Meteorological Measurements	29
Long-Term (Routine) Diffusion Estimates	29
Short-Term (Accident) Diffusion Estimates	31
NE and Criticality Accidents	32
100-ton Fission Explosion	36
References	43

DIFFUSION CLIMATOLOGY FOR HYPOTHETICAL ACCIDENTS IN AREA 410 OF THE NEVADA TEST SITE

Abstract

The regional climate around the Nevada Test Site (NTS) is described. Then the specific climate of the NTS and Lawrence Livermore Laboratory's Area 410 is described, based mainly on observations of winds at 10 m above ground made during 1968 near the Super Kukla reactor. Emphasis is placed on the wind direction and speed and the atmospheric stability in Area 410. Included are estimates of the fastest winds expected in tornadoes and severe thunderstorms.

Three accident scenarios in Area 410 are covered: dispersal of 1 kg of Pu-239 from explosion of 68 kg (150 pounds) of high explosives, release of gross fission products from a 10^{19} fissions accident resulting from inadvertent formation of a

critical mass, and accidental detonation of a 100-ton fission primary.

An Instantaneous Point Source (IPS) code was developed at Lawrence Livermore Laboratory and is explained. The IPS code estimates concentrations in the surface air of radioactive particles that have negligible settling rates (have a radius less than 5 μ m). For each accident, this code calculated and plotted contour maps that show the estimated exposures of the area to radioactive particles from the explosion. The code calculated two types of exposure maps: one based on arithmetically averaged, integrated exposures and the other based on exposure limits that would be exceeded 5% of the time.

Introduction

This report describes the climatology of the Nevada Test Site and gives normalized, integrated estimates of surface air concentrations of the small particles (less than 5- μ m radius) that might be released to the atmosphere by the three more probable accident scenarios at Area 410, Nevada Test

Site. This area, staffed by LLL personnel, contains the Laboratory's assembly buildings for nuclear devices that are developed in Livermore and sent to Area 410 prior to testing.

This document is an adaptation of a memorandum prepared by the author for use in formulating the meteorological portion of a Safety

Analysis Report (SAR) on Area 410. The purpose of this document is twofold: (1) to be included as an appendix to the SAR, and (2) to serve

as an informative document to atmospheric-diffusion meteorologists and others who may not wish to receive the entire SAR.

Regional Meteorology Around the Nevada Test Site

GENERAL CLIMATE

NTS is located in the southern Nevada desert. This region is one of the most arid in the entire United States. Figure 1 shows the average annual rainfall for NTS and surrounding areas. Figure 2¹ shows the average monthly precipitation for selected areas near NTS. The 1962 to 1971 monthly averages and extremes of precipitation for Yucca Flat at NT, 18 km NE of Area 410, are shown in Fig. 3. The annual surface-water evaporation rate is many times greater than the rainfall in the region. No large bodies of surface water exist over the entire region, with the exception of Lake Mead, a man-made reservoir.

In the winter, the primary cause of the arid nature of the region is the so-called "rain shadow" caused by the Sierra Nevada Mountains, which make the eastward-moving Pacific storms lose their moisture on the upwind, western slopes. Low-pressure centers generally approach from the southwest to northwest, usually passing to the north of NTS. On the average, a storm system passes about

once every 7 to 10 days during the winter.

In the summer, Pacific storms do not affect southern Nevada, but moisture sometimes comes from the Gulf of Mexico or the Gulf of California. This moisture falls primarily in isolated convective storms, which can be intense over a few square kilometres. There may be large variations in precipitation within the storm's area.

The extent of summer showers over southern Nevada depends primarily on the penetration of the south winds. Thus, precipitation tends to diminish to the north. On rare occasions, tropical storms occurring off the west coast of Mexico in late summer and fall will move northward, bringing heavy and widespread precipitation to southern Nevada.

SEVERE WEATHER

Thunderstorms and dust devils are common occurrences at the Nevada Test Site. Tornadoes have never been observed at NTS, but a few have occurred within 250 km. McDonald,

Fig. 1. Mean annual precipitation of Nevada Test Site and vicinity. Based on a map by Ralph F. Quiring, Air Resources Laboratory, Las Vegas, Nevada (1965).

Fig. 2. Normal monthly precipitation in millimetres and inches at several points near NTS (1931-1960).

Minor, and Mehta² have used commonly accepted statistical techniques to estimate extreme winds from severe weather conditions. They suggest a maximum-design wind speed for NTS from tornadoes of 28 m/s (63 mph), with a recurrence interval of 10^6 years. Their extreme "straight line" design wind speed -- occurring in other meteorological phenomena, such as thunderstorms -- is 94 m/s (210 mph) for the same recurrence interval.

AIR-POLLUTION POTENTIAL AT NTS

A study of atmospheric stability conditions in the region indicates conditions are stable very rarely (less than 5% of the time, on an annual basis). Therefore, any locally generated pollution will be readily mixed with the ambient air, resulting in lower pollutant concentrations at the site's boundary than would occur in most other locations within the United States.

Fig. 3. Precipitation at Yucca Flat in NTS, 1962-71. Least monthly precipitation was less than 0.51 mm (0.02 in.) for all months.

Local Meteorology of the Nevada Test Site and Area 410

STATION SUMMARY

The climate of Area 410 is essentially the same as that of surrounding regions. Table 1 gives the weather summary for the years 1962 through 1971 for the Yucca Weather Station at NTS. Figure 3 shows the average, greatest, and least monthly precipitation at Yucca Flat during the same 10-year period. Yucca

is the only continuously manned weather station that has been in operation at NTS for 10 years. The data reported in Table 1 are fairly typical of NTS averages, although differences arise due to local topography.

The only significant difference between the weather at Area 410 and that of surrounding area is the greater rainfall due to elevation.

Table 1. Climatological summary (1962-1971) of Yucca Flat, Nevada -- Nevada Test Site (latitude 36°57'N, longitude 116°03'W, elevation 3,924 ft). Data from National Climatic Center, Asheville, North Carolina.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.
Temperature, °F													
Averages													
Daily maximum	52.1	56.7	60.9	67.8	78.9	87.6	96.1	95.0	86.4	76.1	61.8	50.7	72.5
Daily minimum	20.8	25.8	27.7	34.4	43.5	49.9	57.0	58.1	46.7	36.9	27.6	19.9	37.4
Monthly	36.5	41.3	44.3	51.1	61.2	68.8	76.6	76.6	66.5	56.5	44.7	35.3	54.9
Extremes													
Highest	73	77	87	89	97	107	107	107	105	94	82	70	Aug
(yr)	(1971)	(1963)	(1966)	(1962)	(1967)	(1970)	(1967)	(1970)	(1971)	(1964)	(1962)	(1964)	1970#
													107
Lowest	-2	5	9	13	25	29	40	39	25	12	13	-14	Dec
(yr)	(1970)	(1971)	(1969)	(1966)	(1967)	(1971)	(1964)	(1968)	(1971)	(1971)	(1966)	(1967)	1967
		#				#	#						-14
Degree days (base 65°)													
Heating	877	662	634	411	147	35	0	1	51	266	602	914	4600
Cooling	0	0	0	1	38	154	366	368	103	9	0	0	1039
Precipitation, in.													
Average	.53	.84	.29	.45	.24	.21	.52	.34	.66	.13	.71	.79	5.73
Greatest monthly	4.02	3.55	.60	2.57	1.62	1.13	1.34	1.04	2.38	.45	3.02	2.66	4.02
(yr)	(1969)	(1969)	(1969)	(1965)	(1971)	(1969)	(1966)	(1965)	(1969)	(1969)	(1965)	(1965)	Jan
													1969
Least monthly		T	.02	T	T	T	0	0	0	0	0	T	0
(yr)	(1971)	(1967)	(1966)	(1962)	(1970)	(1971)	(1963)	(1962)	(1968)	(1967)	(1962)	(1969)	Sep
	#	#			#				#	#		#	1968#
Greatest daily	1.25	1.16	.38	1.08	.86	.45	.77	.35	2.13	.42	1.10	1.31	2.13
(yr)	(1969)	(1969)	(1969)	(1965)	(1971)	(1969)	(1969)	(1971)	(1969)	(1969)	(1970)	(1965)	Sep
							#						1969

Table 1. continued.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.
Snow													
Average	0.9	1.9	2.0	0.7	0	0	0	0	0	0	0.5	2.3	8.3
Greatest monthly (yr)	4.3 (1962)	17.4 (1969)	7.5 (1969)	3.0 (1964)	T (1964)	0	0	0	0	T (1971)	4.8 (1964)	9.9 (1971)	17.4 Feb 1969
Greatest daily (yr)	4.3 (1962)	6.2 (1969)	4.5 (1969)	3.0 (1964)	T (1964)	0	0	0	0	T (1971)	2.3 (1964)	7.4 (1971)	7.4 Dec 1971
Relative humidity, %													
Hour (Pacific Standard Time)													
04	67	67	58	52	46	39	40	44	43	46	61	68	53
10	49	45	31	27	22	19	20	23	21	24	39	50	31
16	35	32	23	21	17	14	15	16	17	19	31	41	23
22	60	56	44	38	31	26	28	30	32	36	52	64	41
Wind, mph^a													
Average speed	6.6	6.9	8.4	9.1	3.3	7.9	7.5	6.7	7.0	6.8	6.1	6.6	7.4
Peak speed (yr)	58 (1965)	52 (1967)	55 (1971)	60+ (1970)	60+ (1967)	60+ (1967)	55 (1971)	60+ (1968)	52 (1970)	60 (1971)	51 (1970)	53 (1970)	60+ Apr 1970 [#]
Resultant, Dir/Sp													
23-02 PST	233/ 0.7	273/ 1.1	240/ 1.8	250/ 2.2	260/ 1.5	272/ 1.9	278/ 0.9	222/ 1.5	281/ 1.3	286/ 1.3	234/ 1.2	288/ 1.9	---
11-14 PST	135/ 2.6	118/ 2.7	186/ 4.5	198/ 5.1	179/ 7.2	185/ 8.2	185/ 12.0	182/ 12.0	163/ 6.4	138/ 3.7	152/ 4.1	109/ 1.0	---
Station pressure, in.													
Averages	26.10	26.05	25.99	25.96	25.94	25.92	26.00	26.00	26.00	26.06	26.08	26.07	26.01
Highest	26.54	26.42	26.43	26.39	26.39	26.20	26.19	26.22	26.36	26.40	26.58	26.59	26.59
Lowest	25.42	25.56	25.48	25.50	25.47	25.56	25.68	25.71	25.56	25.52	25.64	25.49	25.42
Average sky cover,^b													
sunrise to sunset	4.9	5.0	4.8	4.5	4.3	3.0	3.0	3.0	2.1	2.9	4.8	4.6	3.9

Table 1, continued.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.
<u>Average number of days</u>													
Sunrise to sunset													
Clear	13	11	12	13	14	19	19	20	22	20	13	14	190
Partly cloudy	8	8	9	9	11	7	9	8	6	7	7	8	97
Cloudy	10	9	10	8	6	4	3	3	2	4	10	9	78
Precipitation													
.01 inch or more	2	3	3	3	2	2	3	3	2	1	3	3	30
.10 inch or more	1	2	1	1	1	1	2	1	1	1	2	1	14
.50 inch or more	*	*	0	*	*	0	*	0	1	0	*	1	3
1.00 inch or more	*	*	0	*	0	0	0	0	*	0	*	*	1
1.0 inch or more of snow	*	1	1	*	0	0	0	0	0	0	*	1	3
Thunderstorms	*	0	1	1	1	2	4	4	2	*	*	*	14
Temperature													
Maximum													
90°F or more	0	0	0	0	4	14	29	27	11	2	0	0	87
32°F or less	1	*	0	0	0	0	0	0	0	0	0	1	2
Minimum													
32°F or less	29	23	24	12	2	*	0	0	1	9	23	29	152
0°F or less	*	0	0	0	0	0	0	0	0	0	0	1	1

* One or more occurrences during the period of record but average less than 0.5 day.

Most recent of multiple occurrences.

+ Peak speed exceeded the upper limit of the analog recorder.

T Trace, an amount too small to measure.

(a) Average and peak speed are for the period starting with December 1964. The direction and magnitude of the resultant wind are from a summary covering the period December 1964 through May 1969.

(b) Sky cover is expressed in the range from 0 for no clouds to 10 when the sky is completely covered with clouds. Clear, partly cloudy and cloudy are defined as average daytime cloudiness of 0-3, 4-7 and 8-10 tenths, respectively.

Figure 4² shows the way in which rainfall increases with elevation for the region around NTS. Data collected from stations at NTS agree quite closely with the plot of average behavior shown in Fig. 4. Figure 5³ shows the predicted rainfall for storms of return periods varying from 1.1 to 1000 years. These curves are based on extreme value theory; the data represent average behavior for the NTS area.

WINDS

Table 2³ is a summary of wind data collected at Area 410 during 1964-1968. The recording equipment was unable to measure speeds in excess of 27 m/s (60 mph). However, it should be noted that only two observations of winds greater than 17 m/s (39 mph) were observed. Table 3² shows the maximum wind velocities to be expected in the area of NTS.

Fig. 4. Log-linear relationship between normal annual precipitation and elevation in southern Nevada (1931-1960).

Fig. 5. Probability of precipitation lasting from 5 min to 24 h at NTS.

Table 2. Breakdown of wind-speed observations for Area 410, 1964-68 at 9.1 m above ground. Data from Ref. 3.

Speed range		Percent of observations
m/s	mph	
0.5- 2.0	1- 4	16.8
2.1- 4.2	5- 9	44.5
4.3- 6.5	10-14	24.8
6.6- 8.7	15-19	9.3
8.8-13.2	20-29	4.1
13.3-17.7	30-39	0.4
17.8-22.1	40-49	<0.01 ^a
≥22.2	≥50	<0.01 ^b

^aThree observations.

^bOne observation.

Table 3. Extreme winds expected at NTS at 9.1 m (30 ft) above surface.

Return period, yr	Fastest ^a		Gust	
	mph	m/sec	mph	m/s
2	48	21	62	28
5	55	25	72	32
10	61	27	79	35
50	75	34	97	43
100	82	37	107	48

^a Approximately 1-min average wind.

Wind directions and speeds, as well as stability categories were averaged over half-hour intervals for the entire period from January through December, 1968. The measurements were taken near the Super Kukla reactor building at 10 m above the ground. To study seasonal effects, these data were divided into winter (October through February) and summer (March through September) seasons.*

The percentage frequencies of wind directions and average speeds are given in Table 4. In general, the strongest winds blow toward the north through east; the weakest winds blow toward the west through north. The winter and summer winds are remarkably similar in speed and average about 4 m/s for all directions.

*This breakdown of seasons was based on the afternoon resultant wind speeds shown in Table 1.

The frequencies vary more with direction than do the speeds. The annual frequencies show a double maximum -- in the directions toward north through east and toward south through west. The seasonal frequencies show a single maximum -- in the directions toward south through west for winter, and toward north through east for summer.

ATMOSPHERIC STABILITY

Atmospheric stability was estimated from the wind-direction traces made during 1968. The method outlined by Slade⁴ was used to determine these (Pasquill-Gifford) stabilities. A description of these stability categories is given in Table 5. Table 6 shows the annual percentage frequencies and those for both seasons. The outstanding feature of this table is the relatively

Table 4. Frequencies and average speeds vs direction for winds in Area 410, 1968 data.

Direction toward which wind blows	Annual		Winter		Summer	
	Frequency, %	Av Speed, m/s	Frequency, %	Av Speed, m/s	Frequency, %	Av Speed, m/s
N	9.7	5.07	6.0	4.58	12.3	5.24
NNE	12.4	4.90	6.0	4.76	16.9	4.94
NE	8.9	4.25	5.4	4.90	11.4	4.03
ENE	10.3	3.76	6.9	5.16	12.7	3.22
E	5.7	3.11	3.3	3.96	7.3	2.84
ESE	3.6	3.28	2.9	3.72	4.1	3.07
SE	2.9	2.95	3.1	3.55	2.8	2.50
SSE	4.6	3.43	5.5	3.96	4.0	2.91
S	9.2	4.11	10.4	3.97	8.3	4.23
SSW	11.2	3.78	15.2	3.54	8.4	4.09
SW	10.5	3.61	18.0	3.83	5.2	3.08
WSW	5.0	4.15	10.3	4.46	1.3	2.40
W	0.8	5.10	2.0	5.14	0.1	1.90
WNW	0.4	2.64	0.4	2.50	0.4	2.73
NW	1.5	2.77	1.6	2.98	1.5	2.61
NNW	3.3	3.27	3.2	3.44	3.3	3.15
All directions	100.0	3.99	100.0	4.11	100.0	3.91

low frequency of stable conditions (E and F).^{*} There appears to be no significant seasonal variation. Finally, the unstable categories (A, B and C) account for about three-

fourths of all observations. This is a desirable feature since an unstable atmosphere will mix and dilute effluents more rapidly than at a site where neutral (D) and stable (E and F) categories predominate.

^{*}Other researchers, e.g., J. B. Knox (in a personal communication), have noted a tendency for a systematic bias, favoring more unstable categories, when the $\Delta\theta$ -method is used with strip charts of wind direction.

Tabular wind roses, classed by stability category, wind direction, and wind-speed range are given in Tables 7, 8, and 9 for annual, winter, and summer periods,

respectively. Note that the total of directional and wind-speed frequencies for a given stability

category is the percentage of time that particular stability occurred; these totals agree with the values

Table 5. Description of atmospheric stability categories (Pasquill-Gifford).

Category	Degree of stability	Angular spread of wind direction (30-min period)	Description
A	Extremely unstable	150°	Rapid mixing; usually occurs on hot afternoons.
B	Moderately unstable	120°	Moderate mixing; usually occurs on warm days.
C	Slightly unstable	90°	Usually occurs in daytime.
D	Neutral stability	60°	Occurs day or night, often during overcast skies.
E	Slightly stable	30°	Slow dilution; can occur day or night.
F	Moderately stable	15°	Very slow dilution; occurs at night with clear skies.

Table 6. Percentage frequency of stability categories at Area 410.

Stability category	Frequency, %		
	Annual	Winter (Oct-Feb)	Summer (Mar-Sept)
A	27.5	29.6	26.1
B	17.1	15.6	18.2
C	26.9	28.2	26.3
D	23.7	21.8	25.2
E	4.3	4.4	4.2
F	0.3	0.6	0.2

Table 7. Annual frequencies of winds.

Direction toward which the wind blows	Frequency, %						Totals by direction	Av speed
	For winds having speeds (in m/s) of:							
	0.5-2.0	2.1-3.5	3.6-5.5	5.6-9.0	9.1-12.0	>12		
	Stability Category A							
N	0.47	0.98	0.61	0.17	0.0	0.0	2.23	3.30
NNE	0.34	0.88	1.24	0.53	0.02	0.0	3.01	4.19
NE	0.48	0.67	0.84	0.26	0.0	0.0	2.25	3.64
ENE	0.44	0.41	0.57	0.47	0.14	0.01	2.04	4.58
E	0.35	0.53	0.38	0.15	0.0	0.0	1.41	3.37
ESE	0.51	0.33	0.39	0.14	0.0	0.0	1.37	3.18
SE	0.74	0.35	0.31	0.16	0.0	0.0	1.56	2.87
SSE	0.55	0.32	0.44	0.13	0.03	0.0	1.47	3.30
S	0.71	0.31	0.40	0.36	0.02	0.0	1.80	3.56
SSW	0.50	0.75	0.73	0.60	0.01	0.0	2.59	4.07
SW	0.38	1.0	0.88	0.70	0.09	0.01	3.06	4.41
WSW	0.25	0.99	0.94	0.53	0.16	0.05	2.81	4.75
W	0.02	0.19	0.33	0.19	0.06	0.0	0.78	5.19
WNW	0.02	0.02	0.0	0.0	0.0	0.0	0.04	2.03
NW	0.07	0.09	0.07	0.0	0.0	0.0	0.23	2.86
NNW	0.25	0.49	0.12	0.03	0.0	0.0	0.89	2.75
Total	6.08	8.19	8.25	4.42	0.53	0.07	27.54	3.88

Table 7, continued.

<u>Stability Category B</u>								
N	0.20	0.53	0.74	0.67	0.03	0.0	2.17	4.75
NNE	0.29	0.47	1.37	1.06	0.02	0.01	3.22	4.97
NE	0.12	0.28	0.49	0.39	0.01	0.0	1.29	4.74
ENE	0.17	0.23	0.10	0.07	0.0	0.01	0.58	3.40
E	0.12	0.07	0.10	0.09	0.0	0.0	0.38	3.84
ESE	0.23	0.09	0.05	0.09	0.0	0.0	0.46	3.10
SE	0.24	0.03	0.06	0.02	0.01	0.0	0.36	2.52
SSE	0.11	0.12	0.16	0.10	0.02	0.0	0.51	4.20
S	0.62	0.35	0.32	0.31	0.02	0.0	1.62	3.51
SSW	0.87	0.80	0.62	0.72	0.02	0.0	3.03	3.83
SW	0.31	0.60	0.47	0.32	0.0	0.0	0.10	3.17
WSW	0.01	0.06	0.03	0.0	0.0	0.0	0.0	0.0
NW	0.11	0.25	0.10	0.01	0.0	0.0	0.47	2.91
NNW	0.34	0.51	0.28	0.12	0.0	0.0	1.25	3.20
Total	3.74	4.39	4.89	3.97	0.13	0.02	17.14	4.08

<u>Stability Category C</u>								
N	0.19	0.49	0.93	0.94	0.22	0.06	3.73	6.19
NNE	0.21	0.76	1.14	1.74	0.17	0.06	4.08	5.63
NE	0.18	0.64	0.95	0.59	0.07	0.03	2.46	4.81
ENE	0.34	1.11	0.65	0.26	0.06	0.04	2.46	3.91
E	0.19	0.30	0.26	0.07	0.0	0.0	0.82	3.38

Table 7, continued.

ESE	0.19	0.21	0.14	0.06	0.01	0.0	0.61	3.29
SE	0.23	0.05	0.13	0.05	0.02	0.0	0.48	3.32
SSE	0.44	0.17	0.24	0.11	0.02	0.0	0.98	3.20
S	0.52	0.52	0.82	0.60	0.09	0.0	2.55	4.38
SSW	0.93	0.87	0.75	0.55	0.15	0.0	3.25	3.88
SW	0.98	1.20	0.77	0.35	0.05	0.0	3.35	3.33
WSW	0.14	0.24	0.10	0.09	0.0	0.0	0.57	3.44
W	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WNW	0.03	0.06	0.0	0.0	0.0	0.0	0.09	2.28
NW	0.22	0.23	0.10	0.01	0.0	0.0	0.56	2.58
NNW	0.19	0.28	0.25	0.18	0.02	0.0	0.92	4.00
Total	4.88	7.13	7.23	6.60	0.88	0.19	26.91	4.43

Stability Category D

N	0.04	0.11	0.32	0.66	0.24	0.02	1.39	6.81
NNE	0.14	0.47	0.64	0.58	0.10	0.11	2.04	5.56
NE	0.26	1.01	0.90	0.54	0.07	0.03	2.81	4.41
ENE	0.64	2.48	1.31	0.35	0.01	0.04	4.83	3.51
E	0.53	1.04	0.25	0.13	0.05	0.0	2.00	3.09
ESE	0.14	0.32	0.24	0.13	0.03	0.0	0.86	3.99
SE	0.11	0.12	0.11	0.06	0.0	0.0	0.40	3.53
SSE	0.36	0.36	0.35	0.18	0.01	0.0	1.26	3.55
S	0.24	0.55	0.83	0.85	0.09	0.0	2.56	4.99

Table 7, continued.

SSW	0.58	0.51	0.22	0.43	0.06	0.0	1.80	3.85
SW	0.65	0.77	0.25	0.19	0.05	0.01	1.92	3.21
WSW	0.21	0.57	0.20	0.21	0.0	0.01	1.20	3.71
W	0.0	0.01	0.0	0.0	0.0	0.0	0.01	2.80
WNW	0.06	0.06	0.05	0.03	0.0	0.0	0.20	3.45
NW	0.07	0.11	0.03	0.04	0.0	0.0	0.25	3.30
NNW	0.04	0.03	0.05	0.09	0.0	0.0	0.21	4.85
Total	4.07	8.52	5.75	4.47	0.71	0.22	23.74	4.15

Stability Category E

N	0.01	0.0	0.02	0.02	0.0	0.0	0.05	4.99
NNE	0.0	0.03	0.0	0.0	0.0	0.0	0.03	2.80
NE	0.01	0.02	0.05	0.0	0.01	0.0	0.09	4.46
ENE	0.09	0.30	0.01	0.01	0.0	0.0	0.31	2.55
E	0.20	0.71	0.11	0.03	0.0	0.0	1.05	2.82
ESE	0.01	0.19	0.04	0.03	0.0	0.0	0.27	3.50
SE	0.03	0.02	0.05	0.01	0.0	0.0	0.11	3.58
SSE	0.02	0.14	0.14	0.06	0.0	0.0	0.36	4.14
S	0.12	0.18	0.25	0.11	0.0	0.0	0.66	3.93
SSW	0.10	0.19	0.05	0.17	0.0	0.0	0.51	4.17
SW	0.11	0.12	0.07	0.09	0.0	0.01	0.40	4.00
WSW	0.03	0.13	0.09	0.09	0.0	0.0	0.34	4.32
W	0.01	0.0	0.0	0.0	0.0	0.0	0.01	1.25

Table 7, continued.

WNW	0.03	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04	1.64
NW	0.01	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03	3.45
NNW	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02	2.80
Total	0.08	1.96	0.90	0.62	0.01	0.01	4.28	3.58				
<u>Stability Category F</u>												
N	0.01	0.0	0.01	0.0	0.0	0.0	0.0	0.02	2.90			
NNE	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.01	7.30			
NF	0.01	0.01	0.0	0.0	0.0	0.0	0.0	0.02	2.03			
ENE	0.0	0.01	0.01	0.0	0.0	0.03	0.0	0.05	7.80			
E	0.0	0.01	0.0	0.0	0.0	0.0	0.0	0.01	2.80			
ESE	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.02	2.80			
SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
SSE	0.01	0.0	0.0	0.01	0.01	0.01	0.0	0.03	6.37			
S	0.0	0.0	0.0	0.02	0.0	0.0	0.0	0.02	7.30			
SSW	0.02	0.01	0.0	0.01	0.0	0.0	0.0	0.04	3.15			
SW	0.02	0.04	0.01	0.0	0.0	0.0	0.0	0.07	2.61			
WSW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
W	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.01	1.25			
WNW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
NW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
NNW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Total	0.08	0.10	0.03	0.05	0.04	0.0	0.30	4.35				

Table 8. Winter (Oct-Feb) frequencies of winds.

Direction toward which the wind blows	Frequency, %						Totals by direction	Av speed
	For winds having speeds (in m/s) of:							
	0.5-2.0	2.1-3.5	3.6-5.5	5.6-9.0	9.1-12.0	> 12		
<u>Stability Category A</u>								
N	0.56	0.38	0.10	0.20	0.0	0.0	1.24	2.97
NNE	0.43	0.38	0.20	0.18	0.03	0.0	1.22	3.40
NE	0.43	0.23	0.28	0.10	0.0	0.0	1.04	3.06
ENE	0.48	0.41	0.66	0.87	0.33	0.03	2.78	5.41
E	0.33	0.33	0.26	0.23	0.0	0.0	1.15	3.65
ESE	0.41	0.23	0.28	0.18	0.0	0.0	1.10	3.40
SE	0.66	0.26	0.33	0.26	0.0	0.0	1.51	3.28
SSE	0.69	0.26	0.46	0.20	0.08	0.0	1.69	3.54
S	0.89	0.28	0.31	0.56	0.05	0.0	2.09	3.79
SSW	0.61	0.61	0.59	0.51	0.03	0.0	2.35	3.91
SW	0.48	1.35	1.58	1.33	0.20	0.03	4.97	4.80
WSW	0.41	1.91	2.22	1.28	0.38	0.13	6.33	4.94
W	0.05	0.45	0.79	0.46	0.15	0.0	1.91	5.18
WNW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NNW	0.15	0.05	0.03	0.03	0.0	0.0	0.26	2.63
Total	6.58	7.14	8.09	6.39	1.25	0.19	29.64	4.31

Table 8, continued.

<u>Stability Category B</u>								
N	0.26	0.69	0.15	0.28	0.05	0.0	1.43	3.85
NNE	0.31	0.31	0.38	0.13	0.05	0.03	1.21	4.06
NE	0.13	0.18	0.23	0.15	0.03	0.0	0.72	4.34
ENE	0.18	0.13	0.10	0.05	0.0	0.03	0.49	3.79
E	0.05	0.08	0.18	0.13	0.0	0.0	0.44	4.67
ESE	0.23	0.15	0.03	0.10	0.0	0.0	0.51	3.09
SE	0.13	0.03	0.15	0.03	0.03	0.0	0.37	3.96
SSE	0.08	0.18	0.28	0.18	0.05	0.0	0.77	4.83
S	0.97	0.43	0.36	0.36	0.05	0.0	2.17	3.32
SSW	1.35	0.94	0.61	0.99	0.05	0.0	3.94	3.77
SW	0.43	0.46	0.38	0.69	0.0	0.0	1.96	4.38
WSW	0.0	0.03	0.03	0.0	0.0	0.0	0.06	3.68
W	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WNW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NW	0.08	0.18	0.13	0.03	0.0	0.0	0.42	3.37
NNW	0.41	0.31	0.15	0.20	0.0	0.0	1.07	3.29
Total	4.61	4.10	3.16	3.32	0.31	0.06	15.56	3.86

<u>Stability Category C</u>								
N	0.38	0.51	0.38	0.59	0.28	0.0	2.14	5.09
NNE	0.31	0.46	0.56	0.64	0.26	0.03	2.26	5.35
NE	0.26	0.38	0.43	0.87	0.15	0.03	2.12	5.53

Table 8, continued.

ENE	0.18	0.48	0.36	0.38	0.15	0.10	1.65	5.49
E	0.13	0.18	0.26	0.05	0.0	0.0	0.62	3.57
ESE	0.05	0.15	0.05	0.13	0.03	0.0	0.41	4.82
SE	0.18	0.10	0.20	0.03	0.05	0.0	0.56	3.86
SSE	0.36	0.28	0.38	0.15	0.05	0.0	1.22	3.76
S	0.97	0.74	0.59	0.71	0.10	0.0	3.11	3.93
SSW	1.99	1.20	0.94	0.54	0.28	0.0	4.95	3.44
SW	1.71	2.04	1.35	0.79	0.13	0.0	6.02	3.51
WSW	0.18	0.31	0.20	0.20	0.0	0.0	0.89	3.89
W	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
WNW	0.03	0.05	0.0	0.0	0.0	0.0	0.08	2.22
NW	0.31	0.20	0.13	0.03	0.0	0.0	0.67	2.62
NNW	0.43	0.36	0.36	0.31	0.03	0.0	1.49	3.87
Total	7.47	7.44	6.19	5.42	1.51	0.16	28.19	4.12

Stability Category D

N	0.10	0.05	0.18	0.43	0.33	0.0	1.09	7.07
NNE	0.15	0.18	0.26	0.54	0.18	0.03	1.34	6.09
NE	0.13	0.20	0.28	0.66	0.10	0.05	1.42	6.07
ENE	0.28	0.33	0.41	0.56	0.03	0.08	1.69	5.17
E	0.18	0.20	0.15	0.20	0.13	0.0	0.86	5.00
ESE	0.05	0.20	0.28	0.08	0.05	0.0	0.66	4.56
SE	0.13	0.18	0.08	0.13	0.0	0.0	0.52	3.81

Table 8, continued.

SSE	0.28	0.38	0.23	0.38	0.03	0.0	1.30	4.27
S	0.36	0.48	0.61	0.89	0.13	0.0	2.47	5.04
SSW	1.12	0.77	0.31	0.69	0.10	0.0	2.99	3.70
SW	1.35	1.50	0.61	0.46	0.13	0.03	4.08	3.39
WSW	0.33	0.94	0.48	0.51	0.0	0.03	2.29	4.11
W	0.0	0.03	0.0	0.0	0.0	0.0	0.03	2.80
WNW	0.03	0.08	0.10	0.0	0.0	0.0	0.21	3.41
NW	0.10	0.23	0.05	0.08	0.0	0.0	0.46	3.44
NNW	0.10	0.08	0.08	0.13	0.0	0.0	0.39	4.26

Total	4.69	5.83	4.11	5.74	1.21	0.22	21.80	4.53
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Stability Category E

N	0.03	0.0	0.0	0.03	0.0	0.0	0.06	4.28
NNE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NE	0.03	0.0	0.0	0.0	0.03	0.0	0.06	5.90
ENE	0.05	0.03	0.03	0.03	0.0	0.0	0.14	3.59
E	0.10	0.05	0.03	0.08	0.0	0.0	0.26	3.79
ESE	0.03	0.08	0.0	0.05	0.0	0.0	0.16	3.92
SE	0.03	0.0	0.08	0.03	0.0	0.0	0.14	4.43
SSE	0.03	0.10	0.18	0.15	0.0	0.0	0.46	4.85
S	0.13	0.05	0.15	0.20	0.0	0.0	0.53	4.61
SSW	0.20	0.18	0.10	0.41	0.0	0.0	0.89	4.72
SW	0.18	0.23	0.15	0.20	0.0	0.03	0.79	4.38

Table 8, continued.

MSW	0.03	0.28	0.20	0.20	0.0	0.0	0.0	0.71	4.50
N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NNW	0.08	0.03	0.0	0.0	0.0	0.0	0.0	0.11	1.67
NW	0.03	0.0	0.05	0.0	0.0	0.0	0.0	0.08	3.31
NNW	0.0	0.05	0.0	0.0	0.0	0.0	0.0	0.05	2.80
Total	0.95	1.08	0.97	1.38	0.03	0.03	4.44	4.38	
<u>Stability Category F</u>									
N	0.03	0.0	0.0	0.0	0.0	0.0	0.03	1.25	
NNE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
NE	0.0	0.03	0.0	0.0	0.0	0.0	0.03	2.80	
ENE	0.0	0.03	0.03	0.0	0.08	0.0	0.14	7.60	
E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
ESE	0.0	0.03	0.0	0.0	0.0	0.0	0.03	2.80	
SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
SSE	0.0	0.0	0.0	0.03	0.03	0.0	0.06	8.93	
S	0.0	0.0	0.0	0.05	0.0	0.0	0.05	7.30	
SSW	0.05	0.03	0.0	0.03	0.0	0.0	0.11	3.32	
SW	0.05	0.08	0.0	0.0	0.0	0.0	0.13	2.20	
WSW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
W	0.03	0.0	0.0	0.0	0.0	0.0	0.03	1.25	
WNW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
NW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
NNW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total	0.16	0.20	0.03	0.11	0.11	0.0	0.61	4.69	

Table 9. Summer (March-September) frequencies of winds.

Direction toward which the wind blows	Frequency, %						Totals by direction	Av speed
	For winds having speeds (in m/s) of:							
	0.5-2.0	2.1-3.5	3.6-5.5	5.6-9.0	9.1-12.0	> 12		
<u>Stability Category A</u>								
N	0.40	1.41	0.98	0.15	0.0	0.0	2.94	3.40
NNE	0.27	1.23	1.97	0.78	0.02	0.0	4.27	4.37
NE	0.51	0.98	1.23	0.38	0.0	0.0	3.10	3.79
ENE	0.42	0.42	0.51	0.18	0.0	0.0	1.53	3.49
E	0.36	0.67	0.47	0.09	0.0	0.0	1.59	3.22
ESE	0.58	0.40	0.47	0.11	0.0	0.0	1.56	3.07
SE	0.80	0.42	0.29	0.09	0.0	0.0	1.60	2.60
SSE	0.45	0.36	0.43	0.07	0.0	0.0	1.31	3.08
S	0.58	0.33	0.47	0.22	0.0	0.0	1.60	3.37
SSW	0.42	0.85	0.83	0.67	0.0	0.0	2.77	4.18
SW	0.31	0.74	0.38	0.25	0.0	0.0	1.68	3.58
WSW	0.15	0.15	0.04	0.0	0.0	0.0	0.34	2.32
W	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WNW	0.04	0.04	0.0	0.0	0.0	0.0	0.08	2.03
NW	0.13	0.15	0.13	0.0	0.0	0.0	0.41	2.86
NNW	0.33	0.80	0.18	0.04	0.0	0.0	1.35	2.79
Total	5.75	8.95	8.38	3.05	0.02	0.0	26.13	3.55

Table 9, continued.

ENE	0.45	1.56	0.85	0.18	0.0	0.0	3.04	3.33
E	0.24	0.38	0.27	0.09	0.0	0.0	0.98	3.32
ESE	0.29	0.25	0.20	0.02	0.0	0.0	0.76	2.79
SE	0.27	0.02	0.07	0.07	0.0	0.0	0.43	2.84
SSE	0.51	0.09	0.15	0.07	0.0	0.0	0.82	2.54
S	0.20	0.36	0.98	0.53	0.07	0.0	2.14	4.82
SSW	0.18	0.63	0.62	0.56	0.05	0.0	2.04	4.62
SW	0.47	0.60	0.36	0.04	0.0	0.0	1.47	2.86
WSW	0.11	0.20	0.02	0.0	0.0	0.0	0.33	2.39
W	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WNW	0.04	0.07	0.0	0.0	0.0	0.0	0.11	2.24
NW	0.16	0.25	0.07	0.0	0.0	0.0	0.48	2.54
NNW	0.02	0.22	0.18	0.09	0.02	0.0	0.53	4.39
Total	3.27	6.89	7.97	7.47	0.45	0.24	26.29	4.66

Stability Category D

N	0.0	0.15	0.42	0.81	0.18	0.04	1.60	6.71
NNE	0.13	0.67	0.91	0.62	0.04	0.16	2.53	5.35
NE	0.36	1.57	1.34	0.45	0.05	0.02	3.79	3.97
ENE	0.89	4.00	1.95	0.20	0.0	0.02	7.06	3.25
E	0.78	1.63	0.33	0.07	0.0	0.0	2.81	2.69
ESE	0.20	0.40	0.22	0.16	0.02	0.0	1.00	3.75
SE	0.09	0.07	0.13	0.02	0.0	0.0	0.31	3.37
SSE	0.42	0.34	0.43	0.04	0.0	0.0	1.23	3.03

Table 9, continued.

S	0.16	0.60	0.98	0.41	0.05	0.0	2.60	5.42
SSW	0.20	0.33	0.16	0.27	0.05	0.0	0.98	5.53
SW	0.15	0.25	0.0	0.0	0.0	0.0	0.00	5.52
WSW	0.13	0.11	0.0	0.0	0.0	0.0	0.58	5.15
S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SSW	0.09	0.05	0.02	0.05	0.0	0.0	0.72	1.47
SW	0.05	0.02	0.02	0.02	0.0	0.0	0.24	1.27
WSW	0.0	0.0	0.05	0.05	0.0	0.0	0.09	6.08
Total	3.65	10.39	6.05	3.55	0.38	0.25	26.56	1.93
Stability Category E								
N	0.0	0.0	0.05	0.02	0.0	0.0	0.06	5.27
NNE	0.0	0.05	0.0	0.0	0.0	0.3	0.05	2.80
NE	0.0	0.05	0.09	0.0	0.0	0.0	0.13	5.01
ENE	0.11	0.33	0.0	0.0	0.0	0.0	0.58	2.51
E	0.27	1.18	0.16	0.0	0.0	0.0	1.64	2.71
ESE	0.0	0.27	0.07	0.02	0.0	0.0	0.16	1.39
SE	0.05	0.05	0.05	0.0	0.0	0.0	0.17	2.82
SSE	0.02	0.16	0.11	0.0	0.0	0.0	0.29	1.36
S	0.11	0.27	0.33	0.05	0.0	0.0	0.75	1.68
SSW	0.02	0.20	0.02	0.0	0.0	0.0	0.25	2.82
SW	0.05	0.05	0.02	0.0	0.0	0.0	0.11	2.51
WSW	0.05	0.02	0.0	0.0	0.0	0.0	0.06	1.27
N	0.02	0.0	0.0	0.0	0.0	0.0	0.02	1.25

Table 9, continued.

NNW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NNW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.68	2.60	0.88	0.08	0.0	0.0	0.0	4.24	3.00
<u>Stability Category F</u>									
N	0.0	0.0	0.02	0.0	0.0	0.0	0.0	0.02	4.55
NNE	0.0	0.0	0.0	0.02	0.0	0.0	0.0	0.02	7.30
NE	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.02	1.25
ENE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
E	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.02	2.80
ESE	0.0	0.02	0.0	0.0	0.0	0.0	0.0	0.02	0.80
SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SSE	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.02	1.25
S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SSW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SW	0.0	0.02	0.02	0.0	0.0	0.0	0.0	0.04	3.68
WSW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WNW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NNW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.04	0.06	0.04	0.02	0.0	0.0	0.0	0.16	3.41

in Table 6. Tables 7, 8, and 9 show the relative uniformity of average wind speed between stability categories.

Also, for certain wind directions, higher wind-speed ranges occur relatively frequently in stability categories that are traditionally thought to occur at low windspeeds. In part, this is due to the mechanics of extracting stabilities from wind-speed traces. The present state of the art precludes using more sophisticated techniques. A summary of these stability wind-rose tables for winter and summer is shown in Table 10.

HUMIDITY AND FOG

The only humidity records taken routinely at NTS are made at Yucca Flat. The climatological summary, Table 1, shows typically high humidities in early morning, with significantly lower readings in the afternoon. The reported averages reflect the desert climate -- an annual-average 4:00 a.m. value of 53% and a 4:00 p.m. value of 23%. Fog is a rare occurrence at NTS. Fog is present fewer than six days per year in southern Nevada.⁵ Most of these cases occur in winter, but the trend is not pronounced.

Program of Onsite Meteorological Measurements

A CLIMET 013-1 wind-sensing system is operated on a 10-m tower at "Area 410 Basin NW." This location is northwest of the LLL assembly buildings. The starting speed of

the CLIMET system is less than 0.5 m/s. Recordings are made on strip charts and the unit is serviced every two weeks by National Oceanic and Atmospheric Administration personnel.

Long-Term (Routine) Diffusion Estimates

Due to the nature of Area 410 activities, there are no routine releases of ionizing radiation or

other potentially harmful pollutants. Hence, no estimates of long-term diffusion were made in our study.

Table 10. Summary of wind frequency tables by stability categories, based on records for 1968. Directions are those toward which the wind blows.

Wind statistic	Stability category					
	A	B	C	D	E	F
<u>Winter^a season</u>						
Most frequent direction	WSW	SSW	SW	SW	SSW	ENE, SW
Frequency, %	6.3	3.9	6.0	4.1	0.9	0.1, 0.1
Speed, m/s	5.0	3.8	3.5	3.4	4.7	7.6, 2.2
Least frequent direction	WNW, W	W, WNW	W	W	NNE, W	7 sectors ^b
Frequency, %	0	0	0	<0.1	0, 0	0
Speed, m/s	0	0	0	2.8	0, 0	0
Highest average speed, m/s	5.4	4.7	5.5	7.1	5.9	7.6
Direction	ENE	E	NE	N	NE	ENE
Frequency, %	2.8	0.4	2.1	1.1	<0.1	0.1
Lowest average speed, m/s	0	0	0	3.4	0, 0	0
Direction	WNW, W	W, WNW	W	SW	NNE, W	7 sectors ^b
Frequency, %	0	0	0	4.1	0, 0	0
<u>Summer^c season</u>						
Most frequent direction	NNE	NNE	NNE	ENE	E	SW
Frequency, %	4.3	4.6	5.4	7.1	1.6	<0.1
Speed, m/s	4.4	5.2	5.7	3.3	2.7	3.7
Least frequent direction	W	W, WNW	W	W	WNW>NNW	9 sectors ^b
Frequency, %	0	0	0	0	0	0
Speed, m/s	0	0	0	0	0	0
Highest average speed, m/s	4.4	5.2	5.7	6.7	5.5	4.6
Direction	NNE	NNE	NNE	N	N	N
Frequency, %	4.3	4.6	5.4	1.6	<0.1	<0.1
Lowest average speed, m/s	0	0	0	0	0	0
Direction	W	W, WNW	W	W	WNW>NNW	9 sectors ^b
Frequency, %	0	0	0	0	0	0

^aOctober through February.

^bDirection divided into 16 sectors each 22.5° wide.

^cMarch through September.

Short-Term (Accident) Diffusion Estimates

Arithmetic-average and probability maps of exposure (time-integrated ground level concentrations of radioactive particles) were obtained from the instantaneous point source (IPS) code developed by Peterson.⁶ The input data were the tower winds observed near Super Kukla. The generalized diffusion equation for surface exposure concentration under an explosion's cloud centerline is

$$\psi_s = \frac{Q}{\pi \sigma_{y1} \sigma_{z1}} \exp \left(-\frac{h^2}{2\sigma_{z1}^2} \right)$$

where ψ_s = surface exposure, in units of $Q \cdot s/m^3$.

Q = source term, assumed unity in this report.

σ_{y1} = instantaneous crosswind horizontal standard deviation, in m.

σ_{z1} = instantaneous vertical standard deviation, in m.

u = horizontal windspeed at cloud center, in m/s.

h = height of cloud center above ground, in m.

The IPS code uses Walton's⁷ scale-dependent diffusion approach to determine σ_{y1} ; σ_{z1} is obtained from the equation $\sigma_{z1} = (2K_z t)^{1/2}$, where K_z , the vertical diffusion coefficient, is a stability-dependent input parameter, and t is travel time downwind. Scaling equations developed from observations of explosions were used to determine the height and geometry of the stabilized cloud. The calculations in this section include surface exposures and deposition from a "puff" of gases and particles that have no appreciable fall velocity (radius less than $\sim 5 \mu m$). Fallout of larger particles, which could produce substantially higher depositions, is not included.

Three types of accidents have been postulated, and this report presents contour maps of radioactive exposure presented for all types. These accidents are:

- The dispersal of plutonium by detonation of 68 kg (150 lb) of high explosives (HE),
- a criticality accident involving 10^{19} fissions of uranium-235 (equivalent to about a 140-lb high-explosives detonation), and
- an inadvertent 100-ton fission explosion.

HE AND CRITICALITY ACCIDENTS

For accidents (a) and (b), the explosive yields are nearly equal. Hence, it is assumed that their resulting cloud geometries are the same, and one set of exposure-contour

maps covering both these accidents is presented in Figs. 6, 7, and 8. Each of these figures gives radioactive exposures calculated on the basis of annual, winter, and summer wind data, respectively. Half of the maps on each time period show the arithmetic

Fig. 6. Relative exposures (in s/m^3) around Area 410 for HE or criticality accident, based on annual wind data: (a) and (b) average exposures at near and far perspectives, respectively; (c) and (d) exposure limits exceeded 5% of the time at near and far perspectives, respectively.

Fig. 7. Relative exposures (in s/m^3) around Area 410 for HE or criticality accident, based on winter (October-February) wind data: (a) and (b) average exposures at near and far perspectives, respectively; (c) and (d) exposure limits exceeded 5% of the time at near and far perspectives, respectively.

Fig. 8. Relative exposures (in s/m^3) around Area 410 for HE or criticality accident, based on summer (March-September) wind data: (a) and (b) average exposures at near and far perspectives, respectively; (c) and (d) exposure limits exceeded 5% of the time at near and far perspectives, respectively.

average exposures, and the other half were computed allowing a 5% probability that the specified exposures will be exceeded. The latter maps are prepared by assuming a lognormal distribution of exposure and omitting the top 5% of the distribution. Hence, one random accident out of twenty will result in exposures greater than shown on the map. Both close-up and distant maps are presented for each of the average and 5% cases within each time period, with the distant map showing exposures as far as 80 km from Area 410. Also, the NTS site boundary is sketched on the contour maps.

The IPS code depletes the puff with distance according to the deposition velocity, which was assumed to be 0.01 m/s. The product of the exposure and the deposition velocity yields deposition, in units of m^{-2} . Hence, multiplying the exposure-contour values by 0.01 m/s gives surface-deposition contour values. All atmospheric stability categories, weighted by their relative frequencies, were included by the code when it calculated the maps. The specific exposure values for each contour are entered on the diagrams.

The annual average maps have a nearly circular distribution, with a slight diminution of exposures toward the west and west-southwest. The annual 5% maps show a northeast-

southwest elongation with diminished values toward the west-northwest. The average and 5% exposure contours of winter are close to those of the annual maps in both shape and magnitude. The northeast-southwest elongation is more pronounced in the winter 5% maps. This is due to wind and stability conditions that favor higher exposures when the wind direction is from the NE and SW.

In the summer, the average exposure pattern shows a general east-west elongation. However, the 5% contours for the same period are nearly circular except for zero exposure values toward the west. The zero values are due to the fact that only one wind toward the west (from the east) was observed in the summer of 1968. The probability routine in the IPS code is unable to treat one case.

The direction toward which exposure at the site boundary is greatest is referred to as the "critical azimuth." Table 11 presents the directions and relative exposures where the critical azimuth crosses the site boundary, as well as those at the closest site boundary (to the south). Note that the critical-azimuth values are less than 20% greater than exposures to the south. Exposure values at various distances to 100 km are presented in Table 12.

Table 11. Relative exposures^a at the site boundary's intersection with the critical azimuth and at the closest point of the boundary that would result from an HE or criticality explosion.

	Arithmetic av			95%-probable limit		
	Annual	Winter	Summer	Annual	Winter	Summer
Direction of the critical azimuth	SSW	SSW	SE	SSW	SSW	S
Exposure, s/m ³	1.5×10^{-7}	1.8×10^{-7}	1.0×10^{-7}	1.1×10^{-6}	1.7×10^{-6}	5.7×10^{-7}
Direction of the closest site boundary	S	S	S	S	S	S
Exposure, s/m ³	1.3×10^{-7}	1.6×10^{-7}	9.4×10^{-8}	9.5×10^{-7}	1.5×10^{-6}	5.7×10^{-7}

^aDeposition values (in units of m⁻²) are 1/100 of exposure values.

100-TON FISSION EXPLOSION

A 100-ton fission explosion would generate a stabilized cloud center at about 1800 m above the surface. This altitude is well beyond the valid range for the power-law wind profile, used to adjust wind speeds at 10 m above the surface to those at the approx 200-m cloud-center height for an HE or criticality accident. Hence, we prepared new input data, using the 1968 upper-air wind conditions observed twice-daily at Yucca Flat. These winds are representative of those at Area 410. The corresponding stability categories were determined from these observations and the near-surface to cloud, center-temperature profile.

The frequencies and average speeds of these upper-air winds as a function of the direction toward which the wind blows are presented in Table 13. The average speeds are generally greater than those of 10-m winds (listed in Table 4), but by less than a factor of two. Winter wind speeds are greater than summer wind speeds. Such behavior is consistent with usual winds in middle latitudes. The wind frequencies at 1800 m also differ from those at 10 m. For the 1800-m winds, the most frequent directions are toward the SSW and SW in both winter and summer. (The 10-m winds show a pronounced reversal toward the NNE in summer.)

The frequencies of stability categories affecting a 100-ton fission accident are shown in Table

Table 12. Relative exposures ($\mu\text{Ci}/\text{m}^3$) along the critical azimuth at site boundary and other points at distances to 100 km; for HE or criticality accident.

Type of exposure	Critical azimuth	Distance along critical azimuth - km							
		at distances (in km) of:							
		1	2	5	10	SB ^a	20	50	100
Based on annual data									
arithmetic average	SSW	7.8×10^{-7}	7.5×10^{-7}	4.3×10^{-7}	2.1×10^{-7}	1.5×10^{-7}	8.0×10^{-8}	2.0×10^{-8}	5.8×10^{-9}
95%-probable limit	SSW	7.2×10^{-6}	8.4×10^{-6}	4.7×10^{-6}	1.7×10^{-6}	1.1×10^{-6}	4.5×10^{-7}	7.5×10^{-8}	1.8×10^{-8}
Based on winter data									
arithmetic average	SSW	1.0×10^{-6}	9.3×10^{-7}	5.3×10^{-7}	2.5×10^{-7}	1.8×10^{-7}	1.0×10^{-7}	2.3×10^{-8}	6.6×10^{-9}
95%-probable limit	SSW	1.2×10^{-5}	1.4×10^{-5}	8.3×10^{-6}	2.9×10^{-6}	1.7×10^{-6}	7.5×10^{-7}	1.0×10^{-7}	2.5×10^{-8}
Based on summer data									
arithmetic average	SE	2.2×10^{-6}	1.6×10^{-6}	7.7×10^{-7}	2.9×10^{-7}	1.0×10^{-7}	9.0×10^{-8}	2.1×10^{-8}	5.8×10^{-9}
95%-probable limit	S	3.3×10^{-6}	3.6×10^{-6}	2.2×10^{-6}	8.6×10^{-7}	5.7×10^{-7}	2.5×10^{-7}	4.5×10^{-8}	1.2×10^{-8}

^aSB = Critical azimuth site boundary; 13.5 km to SSW, 12.5 km to S, 19 km to SE.

Table 13. Frequency and average speeds vs wind direction of winds at 1800 m above ground affecting a 100-ton fission explosion at Area 410 (based on 1968 data).

Direction toward which wind blows	Annual		Winter		Summer	
	Frequency, %	Av speed, m/s	Frequency, %	Av speed, m/s	Frequency, %	Av speed, m/s
N	6.0	8.2	6.5	9.4	5.7	7.4
NNE	4.6	8.7	5.4	9.1	4.0	8.4
NE	4.1	7.8	6.2	8.8	2.9	6.4
ENE	1.8	6.0	1.5	9.0	1.9	4.5
E	1.3	5.6	1.9	6.8	1.0	4.0
ESE	0.7	5.4	0.8	3.0	0.7	7.0
SE	1.5	4.4	0.8	3.5	1.9	4.6
SSE	4.3	5.7	2.7	8.3	5.2	4.8
S	6.6	6.7	2.7	3.7	9.0	7.2
SSW	16.9	9.3	10.8	12.2	20.7	8.4
SW	15.9	9.6	15.8	13.2	16.0	7.4
WSW	7.8	6.6	8.5	8.0	7.4	5.6
W	7.1	6.4	5.8	8.3	7.9	5.6
WNW	5.6	6.5	6.9	7.8	4.8	5.2
NW	10.3	8.4	14.6	9.8	7.6	6.8
NNW	5.6	9.2	9.2	10.8	3.3	6.4
All directions	100.	7.2	100.	8.2	100.	6.2

14. On an annual basis, "D" (neutral) stability occurs over 60% of the time at 1800 m above ground. In the winter, essentially all the stabilities are "D" or "E", with "E" occurring almost 60% of the time, while in the summer "D" stability predominates over 70% of the time. More stable conditions are to be

expected in winter, particularly in a desert environment.

A comparison of Table 14 with Table 6 (based on 10-m winds) indicates considerably higher frequencies of stable conditions affecting the 100-ton nuclear accident. This is consistent with daytime observations of lapse rate

Table 14. Frequency of stability categories for 100-ton fission explosion at Area 410 (based on winds at 1800 m above ground).

Stability category	Frequency, %		
	Annual	Winter (Oct-Feb)	Summer (Mar-Sept)
A	0.4	0	0.7
B	4.0	0	6.4
C	6.9	0	11.2
D	61.3	41.9	73.3
E	27.2	57.7	8.3
F	0.2	0.4	0

vs height. Super-adiabatic lapse rates (very unstable) often occur near the surface, especially in a desert environment. At higher levels, the lapse rate usually becomes neutral or slightly stable. Also, it has been observed, upon occasion, that the $\Delta\theta$ -method of assessing stabilities (from wind-direction strip charts) has tended to yield stabilities that are too unstable, by about one Pasquill category.

The upper-air winds were used to calculate relative exposures for annual, winter, and summer periods for both the arithmetic average exposure and the 5% probability that specified exposures would be exceeded.

Due to the geometry of the 100-ton fission explosion's stabilized cloud (at about a height of 1800 m above the ground), the gradient of

exposure values along a radial is small for both the arithmetic average and the 5% calculations. This small gradient is due to the fact that as the cloud moves downwind, the surface concentrations of a pollutant decrease while the cloud's time in passing increases at a nearly compensating rate. As a result, the exposure at any point during cloud passage is nearly constant.

Instead of calculating exposure values at intervals so small that they greatly exceed the estimated error of the calculations, it is preferable to present the average of exposures out to 100 km, with an indication of the variation about the average. This latter approach has been used in Figs. 9-11. The top number within each sector represents the average of exposure values out to 100 km, in units of 10^{-10} s/m³.

Fig. 9. Relative Exposures (in 10^{-10} s/m^3) for 100-ton fission accident, based on annual wind data. Percentages indicate variation of exposures within each zone up to 100 km from Area 410. Fig. 6a gives the arithmetic average exposures, Fig. 6b gives a limit of exposure exceeded 5% of the time.

Fig. 10. Relative exposures (in 10^{-10} s/m^3) for 100-ton fission accident, based on winter (October-February) wind data. Percentages indicate variation of exposures within each zone up to 100 km for Area 410. Fig. 6a gives the arithmetic average exposures; Fig. 6b gives a limit of exposure exceeded 5% of the time.

Fig. 11. Relative exposures (in 10^{-10} s/m^3) for 100-ton fission accident, based on summer (March-September) wind data. Percentages indicate variation of exposures within each zone up to 100 km from Area 410. Fig. 6a gives the arithmetic average exposures, Fig. 6b gives a limit of exposure exceeded 5% of the time.

The bottom number is the absolute range of calculated values within each sector, expressed as a percentage. For example, in Fig. 9a, the numbers at the top center indicate an arithmetic average exposure of $1.1 \times 10^{-10} \text{ s/m}^3$, with a range of exposures between 0.8×10^{-10} and 1.4×10^{-10} . On all the charts, the highest value in each sector is less than a factor of two greater than the average (+100% and -50% are factors of two from the average). Those sectors with the larger percentages are generally associated with the smaller exposure values during the winter season. Note that the highest annual exposures are toward the NW and ESE for the arithmetic average and 5% values,

respectively. During the winter, arithmetic averages are greatest toward the NW and N; 5% values show a maximum toward the S. In summer, maximum values occur toward the SW (arithmetic average) and the ESE and SW (5% values). Surface deposition values, in relative units of m^{-2} , may be obtained by dividing the exposures by v_d (0.01 m/s).

Table 15 gives the relative exposures (s/m^3) at the site boundary along the critical azimuth and at the closest boundary from Area 410, in the event of a 100-ton fission explosion. Table 16 presents relative exposures at various distances along the critical azimuth. Note the uniformity of the arithmetic averages at from 1 to 100 km.

Table 15. Relative exposures^a at site boundary along the critical azimuth and at the closest boundary for a 100-ton fission explosion.

	Arithmetic average			95%-probable limit		
	Annual	Winter	Summer	Annual	Winter	Summer
Direction of critical azimuth	NW	NW	NW	ESE	S	ESE
Exposure, s/m ³	2.3×10^{-10}	2.0×10^{-10}	9.0×10^{-11}	4.2×10^{-10}	5.0×10^{-10}	4.7×10^{-10}
Closest site boundary	S	S	S	S	S	S
Exposure, s/m ³	9.9×10^{-11}	1.1×10^{-10}	2.6×10^{-10}	3.1×10^{-10}	5.0×10^{-10}	2.2×10^{-10}

^aDeposition values (in m⁻²) are 1/100 of exposure values.

Table 16. Relative exposures (in units of 10^{-10} s/m³) at various distances along the critical azimuth for a 100-ton fission explosion.

		Distance along critical azimuth - km						
Direction of critical azimuth		1	2	5	10	20	50	100
Annual exposure								
arithmetic average	NW	2.0	2.0	1.9	1.8	1.9	2.5	3.4
95%-probable limit	ESE	4.3	4.2	4.1	4.0	4.2	5.7	8.2
Winter exposure								
arithmetic average	NW	2.2	2.1	1.9	1.7	1.6	1.7	2.1
95%-probable limit	S	5.3	5.2	5.1	5.0	5.2	6.4	8.7
Summer exposure								
arithmetic average	NW	2.0	1.9	1.8	1.8	2.0	2.8	3.7
95%-probable limit	ESE	4.3	4.2	4.2	4.2	4.7	6.6	1.0

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