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NUS 4148

RADIATION SHIELDING ANALYSIS FOR THE BRUNSWICK TECHNICAL SUPPORT CENTER/EMERGENCY OPERATING FACILITY

Prepared for

CAROLINA POWER & LIGHT COMPANY

by

R. W. Brode
S. J. Nathan

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Approved by: [signature] for
E. R. Schmidt
Manager,
Systems Analysis

NUS CORPORATION
910 Clopper Road
Gaithersburg, Maryland 20878

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1.0 INTRODUCTION AND SUMMARY

NUS determined the shielding requirements for the Technical Support Center (TSC) and Emergency Operating Facility (EOF) to be built at the Brunswick Steam Electric Plant. The location of this facility is shown on Figure 1-1. The TSC/EOF is designed to meet the criteria given in GDC-19 of 10 CFR 50 which specifies an exposure limit of 5 rem whole body or its equivalent to any part of the body for personnel within the facility for the duration of the accident. The accident duration used is 30 days. In order to achieve this dose, a design basis limit of 4.5 rem while occupying the facility was established by Carolina Power & Light Company (CP&L).

Sources of radioactivity that were considered in determining the shielding requirements included airborne radioactivity in the secondary containment (reactor building), radioactivity contained in pipes and other equipment both inside and outside the secondary containment, as well as radioactivity from the passing plume resulting from containment leakage. The whole body dose due to the passing plume, consisted of two source components, which are: 1) gaseous radioactivity surrounding the facility itself and 2) gaseous radioactivity that accumulates within the facility due to the operation of the ventilation system. NUS determined the whole body dose contribution from both components, and the thyroid dose contribution from the activity in the facility.

NUS also reviewed the plant design to determine the location of radioactivity sources in pipes and equipment during an accident. This was done in conjuction with CP&L personnel. The KAP-VI computer code was used to determine the shielding requirements for direct radiation from the secondary containment (reactor building) and other sources, and the AXIDENT code was used to determine the dose due to the passing plume.

The methods used to estimate atmospheric dispersion of radiological releases and the resulting dispersion factors are discussed in Section 2.0 of this report. The methods and assumptions used to perform radiological dose analyses, and the resulting integrated doses are presented in Section 3.0.

Based on these analyses, the proposed design for the TSC/EOF, which is a concrete building with the north wall (facing the reactor building) 18 inches thick and the other walls and roof 14 inches thick, will result in a whole body dose of 2.4 rem integrated over the 30 day duration of the accident.

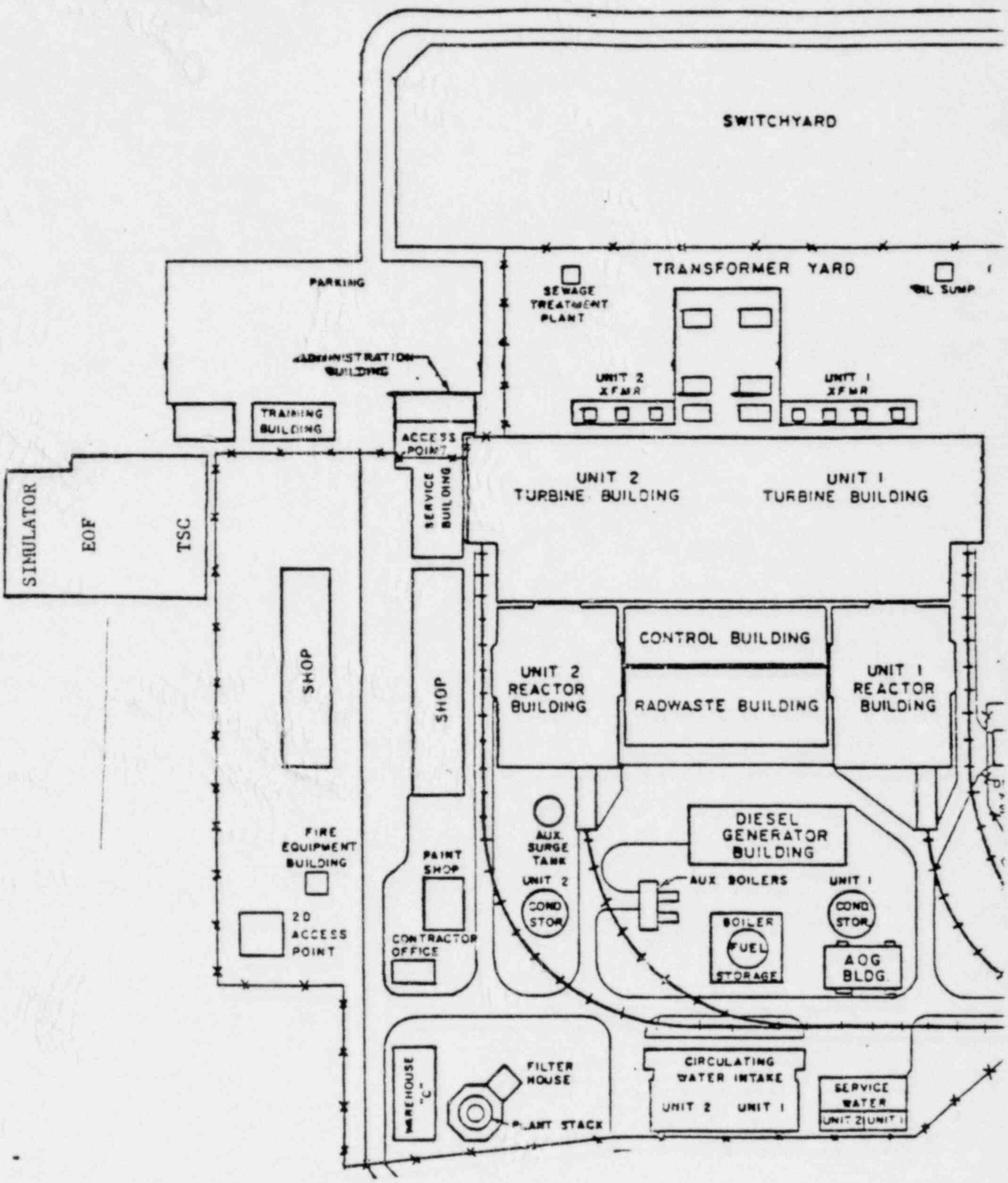


FIGURE 1-1

BRUNSWICK SITE PLAN

2.0 ATMOSPHERIC DISPERSION ANALYSES

Atmospheric dispersion estimates of radiological releases were calculated for the proposed Technical Support Center/Emergency Operating Facility at the Brunswick plant. Calculations of relative concentrations (X/Q) were based on appropriate conservative models and methodology. Values of X/Q were computed using guidance input information from the following:

- Regulatory Guide 1.145, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants." (Ref. 1)
- NUS-3697, "Control Room Habitability Evaluation Brunswick Steam Electric Plant." (Ref. 2)
- Partial Plot Plan Brunswick Plant (Draft), Drawing No. D-2386.

2.1 Meteorological Data

Meteorological data for the atmospheric dispersion analyses were collected at the site during the 4-year period January 1, 1976 through December 31, 1979. The data used for each source release type are listed below:

Analysis	Atmospheric Stability	Wind Speed/ Wind Direction	Combined Data Recovery %
Radiological releases, stack	T(105-11m)	105-m level (Wind speeds converted to 100-m)	98

The joint frequency distributions of wind speed and wind direction, by atmospheric stability class for the 105-meter level of wind data, are provided in Appendix A. A brief discription of the onsite meteorological system is provided in Appendix B.

2.2 Calculations

The methodologies of Reference 1 were used to compute X/Q values for radiological releases from the 100-meter stack located approximately 183 meters from the proposed TSC/EOF. Because the stack is freestanding, a 100 percent elevated release was assumed. Winds from the E, ESE, and SE were determined to affect the TSC/EOF. The highest 0.5 percent X/Q value from these sectors was determined for the 0- to 2-hour time period. Values for time periods greater than 2 hours were determined by logarithmic interpolation between the 2-hour and the sector annual average values. In addition, a X/Q value applicable to the first one-half hour of the accident was calculated representing the fumigation case for an elevated release at an inland site (greater than 3200 meters from a coastline). The X/Q values are given in Table 2-1.

TABLE 2-1
TSC/EOF X/Q VALUES FOR 100 m STACK RELEASES

Time Period	X/Q (s/m^3) (distance = 183m)
0-½ hrs	2.6×10^{-4} (fumigation)
½-2 hrs	3.1×10^{-6}
2-8 hrs	5.6×10^{-7}
8-24 hrs	2.4×10^{-7}
1-4 days	3.8×10^{-8}
4-30 days	2.7×10^{-9}

2.3 References

1. U. S. Nuclear Regulatory Commission. Regulatory Guide 1.145, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants."

2. NUS-3697, "Control Room Habitability Evaluation Brunswick Steam Electric Plant," Slider, J. E.,et. al. (December 1980).

3.0 RADIOLOGICAL ANALYSIS

This section summarizes the methods and results of the radiation shielding analysis for the Technical Support Center/Emergency Operating Facility during postulated radiological accidents at the Brunswick plant.

The TSC/EOF is designed to meet the criteria given in GDC-19 of 10 CFR 50 which specifies a whole body exposure limit of 5 rem whole body or its equivalent to any part of the body for personnel within the facility for the duration of the accident. The accident duration used is 30 days.

Sources of radioactivity that were considered in determining the shielding requirements included direct shine from airborne radioactivity in the secondary containment (reactor building), radioactivity contained in pipes and other equipment both inside and outside the secondary containment as well as radioactivity from the passing plume resulting from secondary containment leakage. The whole body dose due to the passing plume consists of two source components, which are: 1) gaseous radioactivity surrounding the facility itself and 2) gaseous radioactivity that accumulates within the facility due to the operation of the ventilation system. The thyroid dose is due to iodine activity which accumulates in the facility.

3.1 Methods

The methods used to calculate the beta and gamma whole body doses and the thyroid dose to personnel in the TSC/EOF are standard calculational techniques for modeling the generation, release, transport, buildup, and removal of radionuclides. The equations used to model these phenomena are well known, and the specific equations incorporated into the computer program used in this study to calculate the TSC/EOF doses are presented in Appendix C of this report. The methods used to compute the whole body dose contributed by sources of direct radiation outside the TSC/EOF are based on the work of Jaeger, Chapter 6 (Ref. 1). The shine dose from liquid source terms is calculated using the NUS computer code CYLDOSE, which is described in Appendix C.

3.2 Assumptions

The assumptions used in this analysis of TSC/EOF radiation exposures are described below and in Table 3-1:

- o Radionuclides released from the reactor core are uniformly distributed throughout the primary containment. Radionuclides released to the secondary containment (reactor building) are assumed to be uniformly distributed throughout the secondary containment.

- o The primary containment leaks at a constant rate of 0.5 percent per day for the duration of the accident.

- o The primary containment is assumed to consist of a single volume with no washout of radionuclides by containment spray.

- o The secondary containment (reactor building) exhaust rate is assumed to be one secondary containment volume per day.

- o There is no direct leakage from the primary containment to the environment. All exhaust from the secondary containment (reactor building) is filtered by the standby gas treatment system.

- o The accident duration is assumed to be 30 days.
- o Radionuclides in the TSC/EOF are assumed to be uniformly distributed throughout that volume.
- o The breathing rate in the TSC/EOF is assumed to be 3.47×10^{-4} cubic meters per second for the duration of the accident.
- o X/Q values are not adjusted for the occupancy factors given in NRC Standard Review Plan 6.4, since the TSC/EOF is continuously occupied.
- o The TSC/EOF ventilation and cleanup system Iodine removal filters are sufficiently shielded to have a negligible dose contribution.

3.3 Results

The radiation dose to individuals within the TSC/EOF during a postulated design basis accident at the Brunswick station is computed using the assumptions above and those presented in Table 3-1 and Appendix C. The meteorological data are based on the information presented in Section 2.0.

As described in the Brunswick FSAR, the maximum calculated dose to individuals at the site boundary or within the control room occurs during a postulated loss of coolant accident (LOCA). This is because the magnitude and duration of the radionuclide release during a LOCA is much greater than that for any other accident. This is discussed further in References 2 and 3. Based on this information, the LOCA was selected as the basis for the shielding design of the TSC/EOF.

The dose to TSC/EOF personnel from radioactivity buildup within the facility is calculated using the HVAC system model and the data shown in Figure 3-1. This figure is based on information supplied by J. E. Sirrine[4]. The 30-day integrated dose due to airborne radioactivity within the TSC/EOF is summarized in Table 3-2. The dose due to various sources of radioactivity outside the TSC/EOF is also listed in Table 3-2 for the proposed shielding thicknesses.

The dose contribution due to secondary containment (reactor building) shine was calculated using the KAP-VI computer code (described in Appendix C). The features of the secondary containment (reactor building) and TSC/EOF building essential to the shielding analysis were inputs to the KAP-VI code. The sources used in the KAP-VI code were based on the method described in Appendix C. These results are based on a secondary containment (reactor building) concrete wall thickness of 2.0 feet up to the refueling floor and sheet metal (ignored for shielding calculations) from there to the roof. The dose due to the passing plume outside the building was calculated assuming an infinite disc source using the CYLDOSE computer code (described in Appendix C). The integrated dose as a function of shielding thickness is shown in Figure 3-2 for the secondary containment (reactor building) shine.

As shown in Table 3-2, the calculated doses are well within the current NRC criteria of 5 rem whole body for a TSC/EOF with 18 inches of concrete on the north wall and 14 inches of concrete on the roof and remaining walls.

3.4 References

1. Jaeger, R. G., et al., Engineering Compendium on Radiation Shielding, Volume 1, Springer-Verlag, Inc. New York (1968).

2. Carolina Power & Light Company, BSEP-1 & 2 FSAR, Amendment 13, p. M14.1-1, (1972).

3. Carolina Power & Light Company, BSEP-1 & 2 FSAR, Amendment 15, p. M14.4-1, (1972).

4. "Preliminary HVAC Basis for Design," J. E. Sirrine Co. (Sirrine Job No. R-1784), 5/15/82.

TABLE 3-1
ASSUMPTIONS IN RADIOLOGICAL ANALYSIS OF
BRUNSWICK TSC/EOF

Power level = 2,350 MWt

Operating time = 1,000 days

Fraction of core radionuclide inventory released to containment

Noble gases = 100 percent
Halogens = 25 percent

Drywell free volume = 164,000 Ft^3

Maximum/minimum wetwell free volume = 2,000,000 ft^3

Standby gas treatment system flow rate = 3,000 cfm

Standby gas treatment system filter efficiencies for iodine

Elemental = 95 percent
Organic = 95 percent
Particulate = 99 percent

Primary containment leak rate = 0.5 percent/day

Secondary containment air exchange rate = 100 percent/day

TSC/EOF volume = 313,600 ft^3

TSC/EOF intake flow rate = 1800 cfm

TSC/EOF ventilation system filter efficiencies for iodine

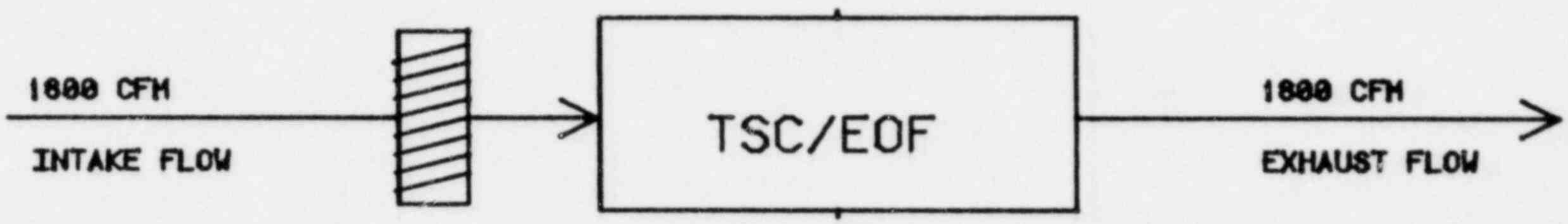
Elemental = 99 percent
Organic = 99 percent
Particulate = 99 percent

Stack height = 100 meters

TABLE 3-2

RESULTS OF RADIOLOGICAL ANALYSIS
OF THE BRUNSWICK TSC/EOF

ORGAN	DOSE (REM)
Whole Body	
Due to Activity in TSC/EOF	0.04
Due to Passing Plume	Negligible
Due to Activity in Containment	2.34
Due to Activity in Pipes and Equipment	0.008
Total	2.4
Thyroid	
Due to Activity in TSC/EOF	.01



SCHEMATIC HVAC FLOW DIAGRAM

FIGURE 3-1

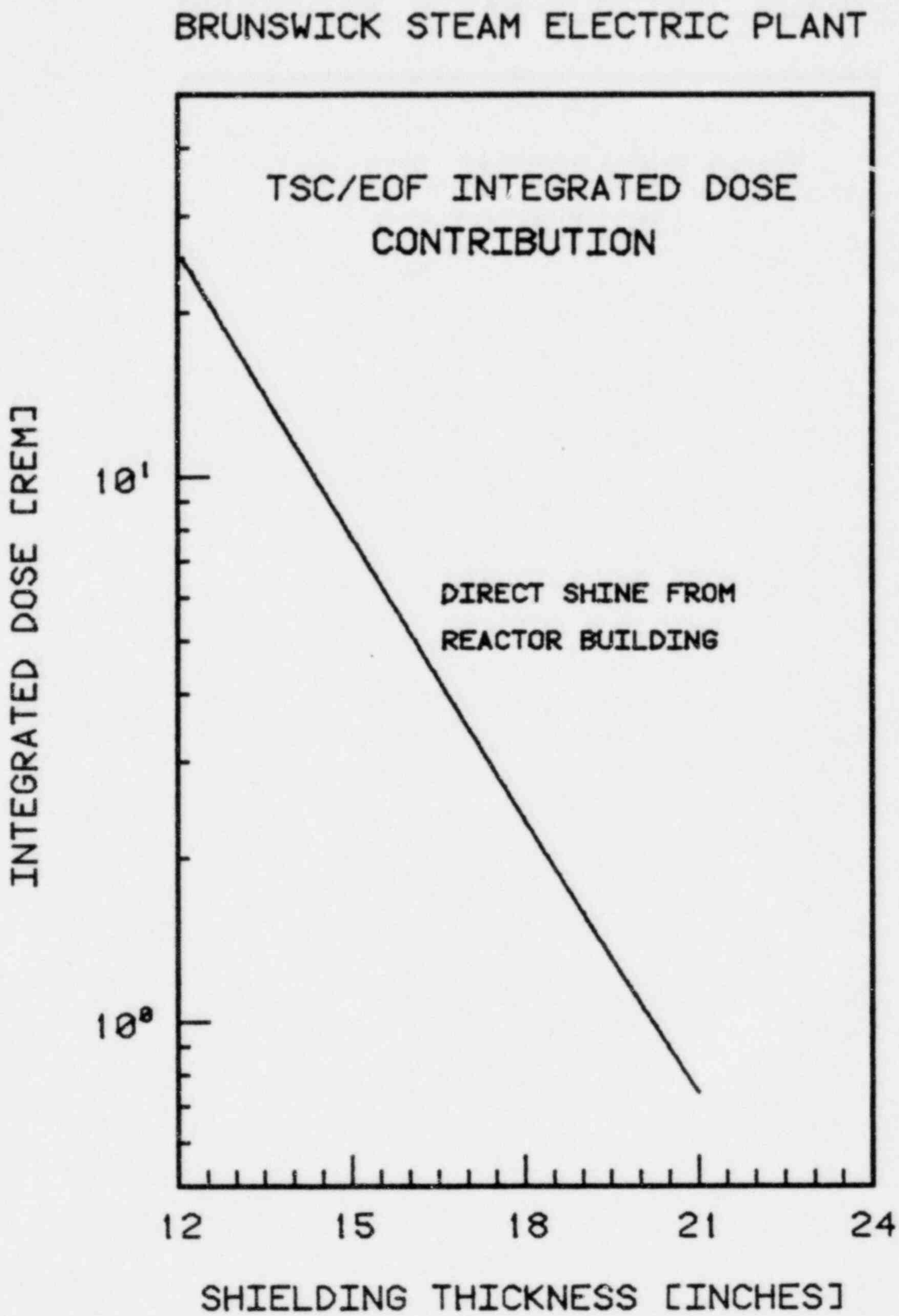

BRUNSWICK STEAM ELECTRIC PLANT
TSC/EOF INTEGRATED DOSE
CONTRIBUTION
INTEGRATED DOSE [REM]
10¹
10⁰
DIRECT SHINE FROM
REACTOR BUILDING
12
15
18
21
24
SHIELDING THICKNESS [INCHES]

FIGURE 3-2

APPENDIX A
JOINT FREQUENCY DISTRIBUTIONS OF WIND SPEED AND WIND DIRECTION BY ATMOSPHERIC STABILITY CLASS

January 1, 1976 - December 31, 1979

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JOINT PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED
FOR THE PERIOD 12:00 AM 1/ 1/76 TO 11:00 PM 12/31/79

STABILITY CLASS A
STABILITY CALCULATED FROM DIFF. TEMPERATURE #1+2

BRUNSWICK ON-SITE METEOROLOGICAL FACILITY

UPPER WIND DIRECTION	CALM	0.75- 3.5	3.5- 7.5	SPEED CLASS(MPH) 7.5-12.5	12.5-18.5	18.5-25.0	GREATER THAN 25.0	TOTAL	AVG. WIND SPEED
N	0.0	0.00	0.00	0.01	0.01	0.02	0.01	0.05	16.76
NNE	0.0	0.0	0.0	0.02	0.0	0.0	0.0	0.02	10.73
NE	0.0	0.0	0.00	0.02	0.02	0.01	0.0	0.05	14.39
ENE	0.0	0.0	0.00	0.01	0.05	0.01	0.0	0.07	15.72
E	0.0	0.0	0.01	0.02	0.07	0.01	0.0	0.10	14.52
ESE	0.0	0.0	0.01	0.05	0.01	0.0	0.0	0.07	10.24
SE	0.0	0.0	0.00	0.10	0.01	0.00	0.0	0.12	10.46
SSE	0.0	0.0	0.01	0.03	0.00	0.0	0.0	0.04	9.09
S	0.0	0.0	0.00	0.01	0.00	0.0	0.0	0.01	10.36
SSW	0.0	0.0	0.01	0.01	0.01	0.00	0.00	0.03	14.23
SW	0.0	0.0	0.0	0.01	0.01	0.01	0.0	0.03	15.33
WSW	0.0	0.0	0.00	0.01	0.01	0.01	0.0	0.03	13.54
W	0.0	0.0	0.00	0.00	0.00	0.00	0.0	0.01	12.18
WNW	0.0	0.0	0.0	0.01	0.01	0.02	0.0	0.03	17.67
NW	0.0	0.0	0.00	0.00	0.01	0.02	0.0	0.04	17.91
NNW	0.0	0.0	0.00	0.03	0.01	0.01	0.0	0.05	11.95
TOTAL	0.0	0.00	0.06	0.33	0.24	0.12	0.01	0.75	13.44

NUMBER OF CALMS - 0
NUMBER OF BAD HOURS - 432

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JOINT PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED
FOR THE PERIOD 12:00 AM 1/ 1/75 TO 11:00 PM 12/31/79

STABILITY CLASS B
STABILITY CALCULATED FROM DIFF. TEMPERATURE #1+2

BRUNSWICK ON-SITE METEOROLOGICAL FACILITY

UPPER WIND DIRECTION	CALM	0.75- 3.5	3.5- 7.5	7.5-12.5	12.5-18.5	18.5-25.0	GREATER THAN 25.0	TOTAL	AVG. WIND SPEED
		SPEED CLASS (MPH)							
N	0.0	0.0	0.01	0.02	0.06	0.02	0.00	0.10	14.95
NNE	0.0	0.0	0.00	0.01	0.03	0.01	0.0	0.06	13.66
NE	0.0	0.0	0.00	0.03	0.11	0.06	0.01	0.21	16.44
ENE	0.0	0.0	0.01	0.05	0.19	0.02	0.00	0.27	14.73
E	0.0	0.0	0.00	0.05	0.10	0.01	0.0	0.16	13.49
ESE	0.0	0.00	0.02	0.10	0.02	0.00	0.0	0.16	10.22
SE	0.0	0.00	0.04	0.13	0.03	0.00	0.0	0.22	9.76
SSE	0.0	0.0	0.01	0.06	0.02	0.00	0.0	0.09	11.78
S	0.0	0.0	0.0	0.03	0.05	0.02	0.0	0.10	15.31
SSW	0.0	0.0	0.01	0.04	0.08	0.02	0.0	0.15	14.56
SW	0.0	0.0	0.0	0.01	0.14	0.13	0.03	0.31	18.91
WSW	0.0	0.0	0.0	0.00	0.01	0.01	0.0	0.03	17.02
W	0.0	0.0	0.0	0.01	0.01	0.0	0.01	0.03	17.64
WNW	0.0	0.0	0.0	0.01	0.04	0.06	0.03	0.14	20.24
NW	0.0	0.0	0.00	0.01	0.09	0.05	0.01	0.16	17.52
NNW	0.0	0.0	0.01	0.03	0.07	0.03	0.00	0.15	14.91
TOTAL	0.0	0.01	0.11	0.60	1.06	0.45	0.09	2.32	15.07

NUMBER OF CALMS - 0
NUMBER OF BAD HOURS - 10

JOINT PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED
FOR THE PERIOD 12:00 AM 1/ 1/76 TO 11:00 PM 12/31/79

STABILITY CLASS C
STABILITY CALCULATED FROM DIFF. TEMPERATURE #1+2

BRUNSWICK ON-SITE METEOROLOGICAL FACILITY

UPPER WIND DIRECTION	SPEED CLASS(MPH) CALM	0.75- 3.5	3.5- 7.5	7.5-12.5	12.5-18.5	18.5-25.0	GREATER THAN 25.0	TOTAL	AVG. WIND SPEED
N	0.0	0.0	0.02	0.12	0.13	0.04	0.01	0.32	13.84
NNE	0.0	0.00	0.01	0.05	0.08	0.04	0.0	0.19	13.81
NE	0.0	0.0	0.01	0.11	0.26	0.14	0.02	0.54	16.14
ENE	0.0	0.0	0.01	0.20	0.25	0.03	0.00	0.50	13.48
E	0.0	0.0	0.05	0.20	0.12	0.01	0.00	0.39	11.63
ESE	0.0	0.0	0.05	0.19	0.03	0.01	0.0	0.29	10.20
SE	0.0	0.0	0.01	0.24	0.05	0.01	0.01	0.31	11.03
SSE	0.0	0.0	0.03	0.13	0.08	0.01	0.01	0.27	11.81
S	0.0	0.0	0.01	0.09	0.17	0.03	0.00	0.31	14.20
SSW	0.0	0.0	0.0	0.11	0.32	0.04	0.02	0.49	15.18
SW	0.0	0.0	0.01	0.10	0.60	0.44	0.12	1.27	18.39
WSW	0.0	0.0	0.01	0.04	0.11	0.06	0.01	0.23	16.07
W	0.0	0.0	0.01	0.04	0.04	0.02	0.01	0.12	14.18
WNW	0.0	0.0	0.02	0.04	0.10	0.06	0.04	0.27	17.46
NW	0.0	0.0	0.01	0.15	0.15	0.08	0.03	0.43	15.51
NNW	0.0	0.0	0.01	0.17	0.17	0.07	0.01	0.42	14.05
TOTAL	0.0	0.00	0.30	1.97	2.65	1.10	0.29	6.32	14.19

NUMBER OF CALMS - 0
NUMBER OF BAD HOURS - 15

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JOINT PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED
FOR THE PERIOD 12:00 AM 1/ 1/75 TO 11:00 PM 12/31/79

STABILITY CLASS D
STABILITY CALCULATED FROM DIFF. TEMPERATURE #1+2

BRUNSWICK ON-SITE METEOROLOGICAL FACILITY

UPPER WIND DIRECTION	CALM	SPEED CLASS(MPH) 0.75- 3.5	3.5- 7.5	7.5-12.5	12.5-18.5	18.5-25.0	GREATER THAN 25.0	TOTAL	AVG. WIND SPEED
N	0.0	0.01	0.13	0.58	1.00	0.47	0.05	2.25	14.93
NNE	0.0	0.01	0.16	0.60	1.49	0.74	0.05	3.06	15.53
NE	0.0	0.01	0.21	0.58	1.16	0.71	0.16	2.83	15.80
ENE	0.0	0.01	0.22	0.71	0.83	0.34	0.05	2.15	13.82
E	0.0	0.01	0.20	0.64	0.51	0.10	0.01	1.58	12.25
ESE	0.00	0.03	0.17	0.49	0.27	0.07	0.04	1.07	11.97
SE	0.0	0.01	0.25	0.50	0.15	0.04	0.03	0.98	10.67
SSE	0.0	0.02	0.16	0.51	0.30	0.12	0.09	1.20	13.05
S	0.0	0.01	0.20	0.73	0.54	0.24	0.15	1.86	14.03
SSW	0.0	0.01	0.25	1.03	1.56	0.89	0.35	4.10	16.00
SW	0.0	0.01	0.15	0.91	2.49	1.86	0.96	6.38	18.48
WSW	0.00	0.03	0.23	0.78	1.18	0.84	0.20	3.26	15.87
W	0.0	0.02	0.26	0.59	0.45	0.22	0.07	1.60	13.04
WNW	0.0	0.02	0.15	0.40	0.50	0.30	0.13	1.49	15.06
NW	0.0	0.01	0.15	0.37	0.50	0.35	0.12	1.50	15.42
NNW	0.0	0.01	0.17	0.50	0.83	0.52	0.10	2.13	15.39
TOTAL	0.31	0.25	3.06	9.90	13.94	7.80	2.57	37.43	14.46

NUMBER OF CALMS - 2
NUMBER OF BAD HOURS - 106

JOINT PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED
FOR THE PERIOD 12:00 AM 1/ 1/76 TO 11:00 PM 12/31/79

STABILITY CLASS E
STABILITY CALCULATED FROM DIFF. TEMPERATURE #1+2

BRUNSWICK ON-SITE METEOROLOGICAL FACILITY

UPPER WIND DIRECTION	SPEED CLASS(MPH) CALM	0.75- 3.5	3.5- 7.5	7.5-12.5	12.5-18.5	18.5-25.0	GREATER THAN 25.0	TOTAL	AVG. WIND SPEED
N	0.0	0.02	0.08	0.24	0.62	0.46	0.01	1.42	15.81
NNE	0.0	0.01	0.13	0.24	1.12	0.85	0.02	2.37	16.60
NE	0.0	0.02	0.10	0.29	0.78	0.47	0.03	1.65	15.66
ENE	0.0	0.01	0.10	0.41	0.94	0.38	0.04	1.89	15.21
E	0.0	0.02	0.10	0.50	0.72	0.13	0.03	1.49	13.57
ESE	0.0	0.01	0.13	0.35	0.47	0.13	0.06	1.14	13.88
SE	0.0	0.02	0.14	0.34	0.30	0.17	0.16	1.13	15.24
SSE	0.00	0.02	0.13	0.49	0.39	0.28	0.42	1.74	17.55
S	0.0	0.01	0.15	0.50	0.47	0.29	0.57	2.00	18.55
SSW	0.00	0.02	0.18	0.44	0.90	0.70	0.72	2.95	19.00
SW	0.0	0.01	0.14	0.45	1.74	1.61	0.82	4.78	19.23
WSW	0.00	0.02	0.20	0.93	1.49	0.88	0.37	3.90	16.18
W	0.0	0.01	0.18	0.68	0.68	0.29	0.01	1.84	13.20
WNW	0.0	0.01	0.09	0.25	0.45	0.58	0.04	1.42	16.63
NW	0.0	0.01	0.08	0.22	0.39	0.32	0.04	1.07	15.73
NNW	0.0	0.01	0.09	0.27	0.56	0.44	0.02	1.39	15.79
TOTAL	0.01	0.22	2.02	6.62	11.97	7.97	3.36	32.17	16.11

NUMBER OF CALMS - 3
NUMBER OF BAD HOURS - 19

JOINT PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED
FOR THE PERIOD 12:00 AM 1/ 1/76 TO 11:00 PM 12/31/79

STABILITY CLASS F
STABILITY CALCULATED FROM DIFF. TEMPERATURE #1+2

BRUNSWICK ON-SITE METEOROLOGICAL FACILITY

UPPER WIND DIRECTION	SPEED CLASS(MPH) CALM	0.75- 3.5	3.5- 7.5	7.5-12.5	12.5-18.5	18.5-25.0	GREATER THAN 25.0	TOTAL	AVG. WIND SPEED
N	0.0	0.02	0.08	0.16	0.35	0.34	0.01	0.96	15.76
NNE	0.0	0.01	0.08	0.18	0.39	0.33	0.01	1.00	15.49
NE	0.0	0.03	0.10	0.24	0.45	0.10	0.0	0.93	13.21
ENE	0.0	0.01	0.09	0.27	0.29	0.03	0.0	0.70	12.05
E	1.00	0.04	0.12	0.23	0.14	0.04	0.0	0.57	10.68
ESE	0.0	0.03	0.10	0.19	0.13	0.02	0.02	0.49	11.09
SE	0.0	0.03	0.11	0.16	0.14	0.03	0.04	0.50	11.99
SSE	0.0	0.02	0.11	0.32	0.13	0.09	0.14	0.81	14.64
S	0.0	0.01	0.12	0.31	0.15	0.15	0.04	0.78	13.22
SSW	0.0	0.01	0.14	0.23	0.18	0.12	0.03	0.71	13.18
SW	0.0	0.01	0.09	0.33	0.31	0.23	0.03	1.00	14.34
WSW	0.0	0.03	0.19	0.42	0.32	0.16	0.05	1.17	12.75
W	0.0	0.03	0.17	0.39	0.28	0.15	0.01	1.04	12.35
WNW	0.0	0.01	0.07	0.19	0.33	0.29	0.03	0.92	15.92
NW	0.0	0.02	0.05	0.13	0.27	0.21	0.03	0.72	15.75
NNW	0.0	0.01	0.07	0.11	0.23	0.22	0.01	0.66	15.58
TOTAL	0.00	0.34	1.70	3.96	4.09	2.51	0.47	12.96	13.62

NUMBER OF CALMS - 1
NUMBER OF BAD HOURS - 64

JOINT PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED
FOR THE PERIOD 12:00 AM 1/ 1/76 TO 11:00 PM 12/31/79

STABILITY CLASS G
STABILITY CALCULATED FROM DIFF. TEMPERATURE #1+2

BRUNSWICK IN-SITE METEOROLOGICAL FACILITY

UPPER WIND DIRECTION	SPEED CLASS(MPH)								
	CALM	0.75- 3.5	3.5- 7.5	7.5-12.5	12.5-18.5	18.5-25.0	GREATER THAN 25.0	TOTAL	AVG. WIND SPEED
N	0.0	0.03	0.04	0.11	0.13	0.09	0.01	0.45	12.99
NNE	0.0	0.01	0.10	0.17	0.27	0.12	0.01	0.58	13.60
NE	0.0	0.01	0.09	0.23	0.27	0.03	0.0	0.63	12.13
ENE	0.0	0.03	0.13	0.18	0.11	0.0	0.0	0.45	9.43
E	0.0	0.03	0.13	0.15	0.06	0.0	0.0	0.36	8.57
ESE	0.0	0.04	0.15	0.12	0.09	0.00	0.0	0.40	8.82
SE	0.0	0.04	0.13	0.16	0.06	0.01	0.01	0.40	9.17
SSE	0.0	0.03	0.14	0.16	0.06	0.02	0.01	0.42	9.16
S	0.00	0.04	0.16	0.15	0.07	0.01	0.00	0.43	8.94
SSW	0.0	0.03	0.16	0.15	0.12	0.02	0.00	0.49	9.98
SW	0.0	0.03	0.13	0.14	0.09	0.01	0.01	0.41	10.09
WSW	0.0	0.03	0.19	0.22	0.13	0.04	0.01	0.62	10.25
W	0.0	0.02	0.22	0.22	0.13	0.06	0.01	0.66	10.55
WNW	0.0	0.03	0.09	0.17	0.16	0.13	0.03	0.61	13.66
NW	0.0	0.02	0.09	0.15	0.17	0.12	0.01	0.56	13.42
NNW	0.0	0.03	0.07	0.14	0.14	0.08	0.01	0.47	12.60
TOTAL	0.00	0.44	2.05	2.53	2.07	0.75	0.10	8.04	10.83

NUMBER OF CALMS - 1
NUMBER OF BAD HOURS - 13

JOINT PERCENTAGE FREQUENCIES OF WIND DIRECTION AND SPEED
FOR THE PERIOD 12:33 AM 1/ 1/76 TO 11:00 PM 12/31/79

SUMMARY
STABILITY CALCULATED FROM DIFF. TEMPERATURE #1+2

BRUNSWICK IN-SITE METEOROLOGICAL FACILITY

UPPER WIND DIRECTION	CALM	SPEED CLASS(MPH) 0.75- 3.5	3.5- 7.5	7.5-12.5	12.5-18.5	18.5-25.0	GREATER THAN 25.0	TOTAL	AVG. WIND SPEED
N	0.0	0.08	0.40	1.24	2.29	1.43	0.10	5.55	15.10
NNE	0.0	0.34	0.49	1.27	3.39	2.08	0.09	7.37	15.62
NE	0.0	0.07	0.52	1.49	3.02	1.53	0.21	6.04	15.11
ENE	0.0	0.06	0.55	1.32	2.67	0.82	0.10	6.02	13.76
E	0.00	0.09	0.60	1.79	1.81	0.31	0.04	4.64	12.23
ESE	0.00	0.11	0.62	1.49	1.02	0.23	0.13	3.61	11.86
SE	0.0	0.10	0.69	1.63	0.74	0.26	0.24	3.66	12.07
SSE	0.00	0.09	0.60	1.70	0.98	0.53	0.66	4.56	14.56
S	0.00	0.07	0.64	1.82	1.45	0.78	0.76	5.49	15.18
SSW	0.00	0.08	0.74	2.01	3.16	1.79	1.14	8.92	16.36
SW	0.0	0.06	0.53	1.96	5.39	4.29	1.98	14.19	18.19
WSW	0.01	0.11	0.83	2.40	3.25	2.00	0.64	9.24	15.23
W	0.0	0.08	0.85	1.93	1.59	0.74	0.11	5.30	12.70
WNW	0.0	0.08	0.41	1.07	1.58	1.44	0.30	4.89	15.79
NW	0.0	0.07	0.39	1.03	1.59	1.15	0.25	4.48	15.41
NNW	0.0	0.05	0.42	1.25	2.01	1.37	0.15	5.26	15.11
TOTAL	0.02	1.27	9.29	25.91	35.92	20.70	6.90	100.00	15.16

NUMBER OF CALMS - 7
NUMBER OF BAD HOURS - 719

APPENDIX B

B1.0 ONSITE METEOROLOGICAL PROGRAM

A 360-foot, guyed, open-latticed tower supports the lower and upper levels of meteorological instrumentation. Wind direction, wind speed, wind variance (sigma theta), and dew point temperatures are recorded at both levels. Ambient temperature is measured at the lower level. The differential temperature between the upper and lower levels is measured by twin, redundant delta temperature systems operating simultaneously. Solar radiation and precipitation are collected near ground level. The wind sensors are mounted on 12-foot booms oriented perpendicular to the general northeast-southwest prevailing wind flow to minimize tower shadow effects. The temperature probes and lithium chloride dew point sensor are housed in Climet aspirated shields mounted on 8-foot booms. A complete specification of major system component operating conditions is presented in Table B-1; component manufacturer and manufacturer model numbers may be found in Table B-2. Operational sensor elevations are displayed in Table B-3 and component accuracies are shown in Table B-4.

The meteorological tower is located 0.3 miles north-northeast of the reactor complex, with the base of the tower at 21 feet above mean sea level. An environmentally controlled shelter, which houses recording instruments, signal conditioning devices, and remote data access equipment, is located adjacent to the tower.

The Westinghouse Environmental Monitoring System is the primary data collection system. This system converts sensor outputs to a proportional number of discrete pulses that are electronically integrated and recorded on magnetic tape in 15-minute averaging periods. Also, direct readout of any parameter is possible with this system. A test jack for each parameter is provided so that a pulse test counter may be plugged into it. The counter sums the pulses produced in a specific time interval, and the subsequent pulse total can then be converted to engineering units by use of a formula of the form $y = mx + b$.

Esterline Angus Twin Strip Chart Recorders are used for providing an analog record of both the upper and lower level wind directions and speeds to back up the Westinghouse system. In addition, 15-minute averaged upper and lower level wind speeds and directions, both differential temperatures, and ambient temperature parameters are telemetered to the CP&L general offices on an hourly basis via voice grade telephone lines to the site, giving CP&L the capability of detecting malfunctions of these parameters within 24 hours.

B2.0 DATA REDUCTION

The Westinghouse system magnetic tape cassettes are changed and brought back to the general office approximately once per month for translating. Computer programs convert all parameter pulse totals into engineering units. The data is then reviewed and checked for consistency with the onsite strip charts and the Wilmington, North Carolina, Weather Service data. The edited 15-minute averaged data is then compiled into hourly averages and stored on magnetic-history tapes.

Routine computer outputs from the Westinghouse pulse data collection system include the following:

a. Monthly Data Summaries listing maximum temperature, average temperature, barometric pressure, precipitation, solar radiation, and upper level and lower level dew point temperatures as a daily average and monthly average.

b Hourly averages of precipitation, barometric pressure, ambient temperature, differential temperature, upper and lower level dew points, upper and lower level wind directions and wind speeds, upper and lower level wind direction variance (sigma theta), Pasquill stability classes (as outlined in Regulatory Guide 1.23) computed from the average of the two delta temperature systems, and accumulated solar radiation (langleys/minute)

c. The 15-minute averages of both upper and lower level wind directions, speeds, and sigma theta; barometric pressure; and accumulated solar radiation

d. Joint wind frequency distributions by direction (as outlined in Regulatory Guide 1.23) for both upper and lower levels, showing average wind speeds and number of unrecovered data hours

The analog strip charts are changed twice per month. They are used as backup data to provide checks on the other systems and to provide consistency of data.

B3.0 MAINTENANCE AND CALIBRATION

An onsite maintenance and calibration program was initiated in 1976. Regulatory Guide 1.23 data recovery requirements are met by performing scheduled calibrations carried out on a semiannual basis such that

a. All wind systems are changed and replaced with National Bureau of Standards (NBS) traceable calibrated wind sensors, per Regulatory Guide 1.23

b. All ambient and differential temperature systems are changed and replaced with NBS traceable calibrated systems, per Regulatory Guide 1.23

c. The lithium chloride dew point sensor bobbin is changed

d. The Cambridge dew point systems are changed

e. Calibrations of the barometric pressure, solar radiation, and precipitation systems are verified (sensors are changed on an annual basis)

f. All other onsite equipment is calibrated or its calibration is verified

In addition to the scheduled calibrations, interim calibrations are performed at 6-week intervals. A further enhancement of data recovery is achieved by operating twin, redundant, delta temperature systems simultaneously. Comparison of the two systems on a real-time basis through the hourly data (received at the CP&L general offices) gives CP&L the capability to detect discrepancies in either system, usually within 24 hours (except on weekends).

TABLE B-1

OPERATING CONDITIONS

Component	Conditions
Wind sensor	-40°F to $+120^{\circ}$F, up to 100 percent relative humidity, up to 125 mph wind speed
Temperature sensors	-50° F to $+130^{\circ}$ F
Aspirated temperature shields	-60° F to $+150^{\circ}$ F
Honeywell dew point sensor	-40° F to $+160^{\circ}$ F, 11 percent relative humidity and above
Cambridge dew point system	
Transmitter Unit	-80° F to $+160^{\circ}$ F
Control unit	-80° F to $+120^{\circ}$ F
Total precipitation sensor	No limitations
Solar radiation sensor	No limitations
Barometric pressure sensor	-30° F to $+170^{\circ}$ F, 0 percent to 90 percent relative humidity
Magnetic tape recording packages	-20° F to $+140^{\circ}$ F
Strip chart recorder	$+20^{\circ}$ F to $+120^{\circ}$ F
Signal converter (transmuter)	-40° F to $+120^{\circ}$ F, 5 percent to 95 percent relative humidity
Telecoder[R] (encoder)	0° F to $+120^{\circ}$ F, 0 percent to 100 percent relative humidity at $+77^{\circ}$ F to $+104^{\circ}$ F without condensation

TABLE B-2

MAJOR COMPONENTS

Component	Manufacturer	Model Number
Sensors		
Wind sensor	Meteorology Research, Inc.	1074-22
Single-element temperature sensor	Rosemount	104ABG-1
Dual-element temperature sensor	Rosemount	104ABG-2
Dew point sensor	Honeywell	SSP029D021
Total precipitation sensor	Weathermeasure Corp.	P-511E
Solar radiation sensor	Eppley Laboratory, Inc.	8-48
Barometric pressure sensor	Rosemount	1105A9A1
Cambridge dew point sensor (transmitter unit)	EG&G International, Inc.	110
Sensor support equipment		
Cambridge dew point control	EG&G International, Inc.	110-C1
Strip chart recorders for wind speed and direction	Esterline Angus	E1102R
Aspirated temperature shield for single-element temperature sensor	Climet	016-1
Aspirated temperature shield for dual-element temperature sensor and Honeywell dew point sensor	Climet	016-2

TABLE B-3

OPERATIONAL SENSOR ELEVATIONS

Sensor	Operational Elevations Above Tower Base (m)
Wind	11.5 and 104.6
Honeywell dew point	10.3
Cambridge dew point	11.5 and 104.6
Solar radiation	1.5
Differential temperature	10.2 to 103.2
Precipitation	1.5
Barometric pressure	1.5

TABLE B-4

COMPONENT ACCURACY

Component	Accuracy
Wind sensor	
Wind speed	±0.4 mph or 1 percent, whichever is greater = 1.0 mph
Wind direction, 0 to 540	± 5.4 degrees
Honeywell dew point sensor	±2 F at or above 11 percent relative humidity
Cambridge dew point system	±0.5 F (error extreme) above a dew point of -20° F (excluding readout instrumentation). Error extreme increases in approximately linear fashion to ±2 degrees at -80 °F.
Solar radiation sensor (pyranometer)	±0.04 calories/square centimeter/minute (langleys)
Differential temperature system	±0.186 F over ambient temperature range from -50° F to +130° F
Ambient temperature system	±0.498 F
Magnetic tape recorder	±1 pulse per interval
Strip chart recorder	±1 percent of full scale, direction = ±5.4 degrees, speed = ± 1.0 mph
Total precipitation sensor	±0.5 percent calibrated at 0.5 inch per hour)
Barometric pressure sensor	±0.006 inch of mercury (temperature effect: ±0.1 inch of mercury per 100 degrees of Fahrenheit operating temperature span)

APPENDIX C

METHODS USED IN RADIOLOGICAL ANALYSIS

The dose calculation computer program (AXIDENT) which consists of a release pathway model and a dose evaluation model was used to evaluate dose contributions from the passing plume. The release model computes activity inventories and releases in the containment and TSC/EOF based on TID-14844 (Ref. 1) releases and prespecified flow rates, filter efficiencies, halogen non-removal factors, and meteorological data. The program computes individual doses within the TSC/EOF.

C1.0 RELEASE MODEL

The activity release pathway model is shown in Figure C-1. Four activity nodes are represented: two primary containment volumes (sprayed and unsprayed), the secondary containment volume, and the TSC/EOF. The equations for nodal activities, containment release and integrated TSC/EOF activity are derived from first order activity balances in the following paragraphs. The definitions of all variables used are presented in Section C3.0.

C1.1 Primary Activity

The primary containment activity is the sum of the activity in the sprayed and unsprayed regions.

$$A_p = A_1 + A_2 \tag{1}$$

$$\frac{dA_1}{dt} = -\lambda_{sp} A_1 - \lambda_1 A_1 - \lambda_r A_1 - \lambda_p A_1 - \frac{Q}{V_1} A_1 + \frac{Q}{V_2} A_2 \tag{2}$$

$$\frac{dA_2}{dt} = -\lambda_1 A_2 - \lambda_r A_2 - \lambda_p A_2 - \frac{Q}{V_2} A_2 + \frac{Q}{V_1} A_1 \tag{3}$$

The simultaneous solutions of Equations 2 and 3 when combined with Equation 1 gives the primary containment activity as

$$A_p = C_2 e^{-m_2 t} - C_1 e^{-m_1 t} \tag{4}$$

$$C_2 = \frac{A_{10}(\lambda_1' - m_1) + A_{20}(\lambda_2' - m_1)}{m_2 - m_1} \tag{5}$$

$$C_1 = \frac{A_{10}(\lambda_1' - m_2) + A_{20}(\lambda_2' - m_2)}{m_2 - m_1} \tag{6}$$

$$m_1, m_2 = \tfrac{1}{2}(\lambda_1' + \lambda_2' + \frac{Q}{V_1} + \frac{Q}{V_2}) \pm \tfrac{1}{2}\left[(\lambda_1' + \lambda_2' + \frac{Q}{V_1} + \frac{Q}{V_2})^2 - 4(\frac{Q}{V_2}\lambda_1' + \frac{Q}{V_1}\lambda_2' + \lambda_1'\lambda_2')\right]^{\frac{1}{2}} \tag{7}$$

$$\lambda_1' = \lambda_1 + \lambda_r + \lambda_p + \lambda_{sp} \tag{8}$$

$$\lambda_2' = \lambda_1 + \lambda_r + \lambda_p \tag{9}$$

$$A_1 = C_4 \; e^{-m_2 t} - C_3 e^{-m_1 t} \tag{10}$$

$$C_4 = \frac{A_{10}(\lambda_1' - m_1 + \frac{Q}{V_1}) - \frac{Q}{V_2} A_{20}}{m_2 - m_1} \quad (11)$$

$$C_3 = \frac{A_{10}(\lambda_1' - m_2 + \frac{Q}{V_1}) - \frac{Q}{V_2} A_{20}}{m_2 - m_1} \quad (12)$$

$$A_2 = (C_2 - C_4)e^{-m_2 t} - (C_1 - C_3)e^{-m_1 t} \quad (13)$$

Note that the above solution for A_p degenerates to a one-volume problem if $\lambda_{sp} = 0$.

C1.2 Secondary Activity

The rate of change of secondary containment activity is the fraction of the primary activity that goes to the secondary containment less the removal by decay, cleanup, and leakage (or exhaust) to the environment.

$$\frac{dA_s}{dt} = f_s \lambda_1 A_p - \lambda_3 A_s - \lambda_r A_s - \lambda_s A_s \quad (14)$$

$$= f_s \lambda_1 A_p - \lambda_4 A_s \quad (15)$$

$$\lambda_4 = \lambda_3 + \lambda_r + \lambda_s \quad (16)$$

$$A_s = \frac{f_s \lambda_1 C_2}{\lambda_4 - m_2} e^{-m_2 t} - \frac{f_s \lambda_1 C_1}{\lambda_4 - m_1} e^{-m_1 t} + C_5 e^{-\lambda_4 t} \quad (17)$$

$$C_5 = A_{so} - \frac{f_s \lambda_1 C_2}{\lambda_4 - m_2} + \frac{f_s \lambda_1 C_1}{\lambda_4 - m_1} \quad (18)$$

C1.3 Containment Activity Release Rate

The containment activity release rate has two components: the secondary containment release after filtration, and the fraction of the primary containment leakage that bypasses the secondary containment.

$$R_r = F \lambda_3 A_s + (1 - f_s) \lambda_1 A_p \quad (19)$$

$$R_r = F \lambda_3 f_s \lambda_1 \left[\frac{C_2}{\lambda_4 - m_2} e^{-m_2 t} - \frac{C_1}{\lambda_4 - m_1} e^{-m_1 t} \right] \quad (20)$$

$$+ F\lambda_3 C_5 \; e^{-\lambda_4 t} +$$

$$(1 - f_s) \lambda_1 \left[C_2 e^{-m_2 t} - C_1 e^{-m_1 t} \right]$$

$$R_r = C_6 e^{-m_2 t} - C_7 e^{-m_1 t} + C_8 e^{-\lambda_4 t} \quad (21)$$

$$C_6 = \left[\frac{F\lambda_3 f_s}{\lambda_4 - m_2} + 1 - f_s \right] \lambda_1 C_2 \quad (22)$$

$$C_7 = \left[\frac{F\lambda_3 f_s}{\lambda_4 - m_1} + 1 - f_s \right] \lambda_1 C_1 \quad (23)$$

$$C_8 = F \lambda_3 C_5 \quad (24)$$

C1.4 Integrated Release from Containment

The integrated release from the containment is obtained by integrating the release rate, Equation 21, over the time period of interest.

$$R = \int R_r dt \quad (25)$$

$$R = \frac{C_6}{m_2}(1-e^{-m_2 t}) - \frac{C_7}{m_1}(1-e^{-m_1 t}) + \frac{C_8}{\lambda_4}(1-e^{-\lambda_4 t}) \quad (26)$$

C1.5 TSC/EOF Activity

The rate of change of activity in the TSC/EOF is the difference between the rate at which activity is drawn in from the outside air and the rate at which it is removed by decay, cleanup, and leakage (or exhaust).

$$\frac{dA_c}{dt} = F_2 q_{cc} (\chi/Q)_c R_r - \lambda_r A_c - \frac{q_{cc}}{V_{cc}} A_c - \lambda_c A_c \quad (27)$$

$$\frac{dA_c}{dt} = C_9 R_r - \lambda_7 A_c \quad (28)$$

$$\lambda_7 = \lambda_r + \frac{q_{cc}}{V_{cc}} + \lambda_c \quad (29)$$

$$C_9 = F_2 q_{cc} (\chi/Q)_c \quad (30)$$

$$\frac{dA_c}{dt} = C_9 C_6 e^{-m_2 t} - C_9 C_7 e^{-m_1 t} + C_9 C_8 e^{-\lambda_4 t} - \lambda_7 A_c \quad (31)$$

$$A_c = \frac{C_9 C_6}{\lambda_7 - m_2} e^{-m_2 t} - \frac{C_9 C_7}{\lambda_7 - m_1} e^{-m_1 t} + \frac{C_9 C_8}{\lambda_7 - \lambda_4} e^{-\lambda_4 t} + C_{10} e^{-\lambda_7 t} \quad (32)$$

$$C_{10} = A_{co} - \frac{C_9 C_6}{\lambda_7 - m_2} + \frac{C_9 C_7}{\lambda_7 - m_1} - \frac{C_9 C_8}{\lambda_7 - \lambda_4} \quad (33)$$

C1.6 Integrated Activity in TSC/EOF

The integrated activity in the TSC/EOF is obtained by integrating Equation 32 over the time period of interest.

$$R_c = \int A_c dt \quad (34)$$

$$R_c = \frac{C_9 C_6}{(\lambda_7 - m_2) m_2} (1 - e^{-m_2 t}) - \frac{C_9 C_7}{m_1 (\lambda_7 - m_1)} (1 - e^{-m_1 t}) + \frac{C_9 C_8}{\lambda_4 (\lambda_7 - \lambda_4)} (1 - e^{-\lambda_4 t}) + \frac{C_{10}}{\lambda_7} (1 - e^{-\lambda_7 t}) \quad (35)$$

Implicit in the above derivations is the assumption of constant coefficients. In the actual transient simulation, solutions are broken into a sequence of discrete time intervals over which the input parameters that make up the coefficients are prespecified constants. The input parameters consist of flow rates, X/Qs, decay and iodine removal constants, provided as stepwise constant functions of time.

Initial secondary containment and TSC/EOF activity inventories are assumed to be zero. Initial primary activity may be based on the analysis of TID-14844 (Ref. 1) using the fractional iodine release assumptions of Regulatory Guide 1.3 (Ref. 2) or 1.4 (Ref. 3). The source term equation is

$$A_{p_o} = 8.65 \times 10^3 \, P_o \, \gamma_i \, f_r f_i (1 - e^{-\lambda_r T_o}) \quad \text{(curies)} \quad (36)$$

C2.0 DOSE MODEL

At the end of each time interval, TSC/EOF individual thyroid and whole body doses are determined using the containment release rate, integrated TSC/EOF activity, and input values of X/Q at the TSC/EOF intake.

Thyroid inhalation dose in the TSC/EOF is given by the following equation:

$$D_T = \sum_i D_{T_i} \text{ (rem)} \qquad (37)$$

$$= \frac{BR}{V_{cc}} \sum_i R_{c_i} \cdot DCF_i$$

where

BR = breathing rate

= $3.47 \times 10^{-4} m^3/sec$ (Ref. 4)

Beta dose in the TSC/EOF is given by:

$$D_\beta = \sum_i D_{\beta_i} \text{ (rem)} \qquad (38)$$

$$= \frac{0.23}{V_{cc}} \sum R_{c_i} \cdot \bar{E}_{\beta_i} \qquad (39)$$

where

$\bar{E}_\beta$ = average beta energy (MeV/dis) (See Table C-2.)

Gamma dose in the TSC/EOF is given by

$$D_\gamma = \sum_i D_{\gamma_i} \quad \text{(rem)} \tag{40}$$

$$= \frac{0.25}{V_{cc}} \sum_i R_{c_i} \sum_j E_{\gamma_{i,j}} f_{i,j} \left\{1 - e^{-\mu_j r}\left[1 + \left(\mu_j - \mu_{a_j}\right) r\right]\right\} \tag{41}$$

Gamma energies and fractions are presented in Table C-1. Absorption coefficients divided by the density of air are listed in Table C-2.

C3.0 NOMENCLATURE

A_p = Primary containment activity

A_1 = Activity in sprayed volume

A_2 = Activity in unsprayed volume

λ_1 = Primary containment leak rate

λ_r = Radiological decay constant (Sec^{-1}) (See Table C-1)

λ_p = Cleanup rate in primary containment

f_1 = Fraction of activity released to sprayed volume

f_2 = Fraction of activity released to unsprayed volume

V_1 = Sprayed volume

V_2 = Unsprayed volume

λ_3 = Secondary leak rate

λ_{sp} = Spray removal rate

f_s = Fraction of primary leakage which enters secondary containment

F = Filter non-removal factor for secondary building exhaust system

F_2 = Filter non-removal factor for TSC/EOF (center) intake system

$(X/Q)_c$ = Atmospheric dispersion to TSC/EOF

q_{cc} = TSC/EOF intake flow

V_{cc} = Combined TSC/EOF volume

$\bar{E}_{\gamma i}$ = Average gamma energy (MeV/dis) See Table C-2)

$\bar{E}_{\beta i}$ = Average beta energy (MeV/dis) See Table C-2)

R = Integrated release from both containments (Ci)

V_{cr} = TSC or EOF free volume (m^3)

$E_{\gamma i,j}$ = Energy of jth gamma of ith isotopes (MeV/γ) (See Table C-3)

$f_{i,j}$ = Fraction of jth gamma of ith isotope (γ/dis)

μ_{a_j} = Energy absorption coefficient for air (m^{-1}) (See Table C-4)

μ_j = Total absorption coefficient for air (m^{-1}) (See Table C-4)

r = Radius of hemisphere with same volume as TSC or EOF (m)

λ_s = Cleanup rate in secondary containment

λ_c = Cleanup rate in TSC/EOF

V_{cc} = Combined TSC/EOF free volume (m^3)

R_{c_i} = Integrated TSC/EOF activity (Ci-sec)

DCF_i = Dose conversion factor (rem/curie) (See Table C-2)

P_o = Base loaded core power (Mwt)

γ_i = Fission yield (percent) (See Table C-1)

T_o = 1000 days (assumed)

f_r = Fraction of core inventory available for release
= 0.25 (for iodines) (Ref. 2)
= 1.0 (for noble gases)

f_i = 0.91 (for elemental iodine) (Ref. 2)
= 0.05 (for particulate iodine)
= 0.04 (for organic iodine)
= 1.0 (for noble gases)

Q = Mixing flow rate between sprayed and unsprayed volumes

C4.0 CALCULATION OF DOSE DUE TO DIRECT RADIATION FROM THE BRUNSWICK REACTOR BUILDING

The KAP-VI Code (Ref. 10) is used to compute the integrated dose to different points within the TSC/EOF building from direct radiation from the reactor building after a postulated loss-of-coolant accident. KAP-VI is a derivative of the QAD (Ref.5) series of point-kernel computer programs designed for estimating the effects of gamma rays and neutrons that originate in a volume-distributed source.

KAP-VI is a point-kernel code designed to calculate the radiation level at detector points located within or outside a complex radiation source geometry describable by a combination of quadratic surfaces. The code evaluates the material thicknesses intercepted along the line-of-sight from the source point to the detector point. These material thicknesses (or path lengths) then are employed in attenuation functions to calculate the flux, dose rate, or heating rate at the detector. The attenuation function for gamma rays employs exponential attenuation with a buildup factor. Three optional neutron attenuation functions are included: (1) a modified Albert-Welton function for calculating fast neutron dose rate using removal cross sections; (2) a bivariant polynomial expression for computing neutron spectra using infinite media moments data; and (3) a monovariant polynomial for computing neutron spectra using infinite media moments data.

The code also handles either cylindrical, spherical, slab, disc, line, or point sources. Different source distributions may be employed for neutrons and gamma rays. A variety of options are available for describing the source distribution.

The source distributions are assumed separable along the geometric axes. An option is provided to describe azimuthal source density variation by specifying input data for discrete point sources.

Specific desirable features which have been incorporated in the KAP-VI code are:

(1) Input data preparation has been simplified to allow minimum input for running "stacked" cases.

(2) The code uses the "point-in-region" concept to calculate the boundary surface-zone relationship (ambiguity index) which is required as input in other point-kernel codes.

(3) A routine is included in the code to calculate gamma ray mass absorption coefficients for up to twenty elements as a function of input gamma ray energy from either internal calculations or from magnetic tape data and internal calculations.

(4) A routine is included in the program to calculate the cubic polynomial coefficients for buildup factors as a function of input gamma ray energy from a library of bivariant polynomial data.

(5) A routine is included which will interpolate a closely-spaced source distribution (obtained from a discrete ordinate transport source calculation) to a source mesh description more economic and amenable to point-kernel calculations.

(6) A routine is included which calculates and normalizes point source strengths for a variety of source geometries and functional variations of source distributions.

(7) Input data are checked for consistency to eliminate many erroneous calculations that can occur if input data for a problem are incomplete.

(8) The program has the capability to calculate fluxes and/or other radiation responses such as heating rates at multiple detector points for each source region.

(9) The program has no set limit on the number of source regions which can be run in a single problem. This feature is handled as a set of stacked source region problems. The program computes the summation at each detector point of the neutron and/or photon radiation from each source region

(10) The program allows the user to input separate source distributions for neutrons and gamma rays within the same source region.

(11) The program eliminates unnecessary response function computations by accumulating flux data as a function of detector point and energy group during the calculation for each source region. Calculations for up to ten response functions are performed only at the completion of each source region calculation and/or at the completion of source region problems.

(12) An option is included for calculating the flux at a detector located within a gamma ray source region. This option circumvents the numerical difficulties introduced by the "inverse square law" when a source point is too close to the detector.

The radiation source strength in the secondary containment (reactor building) is obtained from the activity in the secondary containment using the equations derived in Section C1.2. For conservatism, the effects of leakage from the secondary containment to the atmosphere are ignored. The conversion from isotopic inventory to source strength is based on the radioactive decay schemes of Lederer et. al. (Ref. 7) Integrated source strengths are obtained by trapezoided integration of the calculated time dependent source strength.

C5.0 CALCULATION OF DOSE DUE TO DIRECT RADIATION FROM PIPING SOURCES

The NUS developed CYLDOSE computer code (Ref. 11) is used to calculate the dose due to radioactive fluids contained in the pipes in the plant. CYLDOSE calculates the linear attenuation, scatter buildup, and resulting tissue dose rate from a cylindrical gamma radiation source. Multiple source materials and shield materials may be specified. Dose points may be selected anywhere along the side of the source, or at its end on the axis or outside the outer radius. A line source approximation is used for dose points at the side of the source and at the end outside the outer radius whereas a truncated cone source approximation is used for dose points on the axis at the end of the source. For convenience of calculation, the gamma energy emitted by the source(s) is divided into groups and each group is designated by a number and an average energy for that group. Calculations may be done considering one or a combination of these groups. Source strengths associated with these energy groups may be read into the code as data or calculated by the code. The code will, at the user's option, increment the initial thickness value of the last shield material by a specified amount until a pre-specific dose rate limit is reached.

C6.0 REFERFNCES

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8. "Final Environmental Statement Concerning Proposed Rule Making Action: Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion 'As Low as Practicable' for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluent," WASH-1258, Volume 2, Directorate of Regulatory Standards, U.S.A.E.C. (July 1973).

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TABLE C-1

NUCLIDE DECAY CONSTANTS AND FISSION YIELDS (Ref.6)

Nuclide	Decay Constant (sec^{-1})	Fission Yield (percent)
I^{131}	9.97 (-7)[a]	2.91
I^{132}	8.37 (-5)	4.33
I^{133}	9.17 (-6)	6.69
I^{134}	2.22 (-4)	7.8
I^{135}	2.87 (-5)	6.2
Kr^{83m}	1.03 (-4)	0.52
Kr^{85m}	4.38 (-5)	1.3
Kr^{85}	2.04 (-9)	0.27
Kr^{87}	1.52 (-4)	2.5
Kr^{88}	6.88 (-5)	3.56
Xe^{131m}	6.79 (-7)	0.022
Xe^{133m}	3.55 (-6)	0.17
Xe^{133}	1.52 (-6)	6.69
Xe^{135m}	7.40 (-4)	1.8
Xe^{135}	2.11 (-5)	6.3
Xe^{138}	6.60 (-4)	5.9

[a] Read as 9.97×10^{-7}

TABLE C-2

AVERAGE BETA AND GAMMA ENERGIES AN IODINE INHALATION DOSE CONVERSION FACTORS

Nuclide	$\bar{E}_\gamma$ (MeV/dis) (Ref.7)	$\bar{E}_\beta$ (MeV/dis) (Ref. 7)	DCF (rem/curie) (Ref. 8)
I^{131}	0.371	0.197	1.48 (+6)
I^{132}	2.40	0.448	5.35 (+4)
I^{133}	0.477	0.423	4.00 (+5)
I^{134}	1.939	0.455	2.50 (+4)
I^{135}	1.779	0.308	1.24 (+5)
Kr^{83m}	0.005	0.034	
Kr^{85m}	0.156	0.233	
Kr^{85}	0.0021	0.223	
Kr^{87}	1.375	1.050	
Kr^{88}	1.743	0.341	
Xe^{131m}	0.022	0.135	
Xe^{133m}	0.033	0.155	
Xe^{133}	0.030	0.146	
Xe^{135m}	0.422	0.097	
Xe^{135}	0.246	0.322	
Xe^{138}	2.870	0.800	

TABLE C-3

ISOTOPIC GAMMA ENERGIES AND DECAY FRACTIONS (Ref.6)

I-131	I-132	I-133	I-134	I-135	XE-131M	XE-133M	XE-133
.0300 5.60E-02	.1472 2.00E-03	.5300 9.40E-01	.1360 5.00E-02	.2204 1.80E-02	.0050 6.00E-02	.0297 1.41E-01	.0308 3.82E-01
.0802 2.50E-02	.2630 2.00E-02	.7500 2.60E-02	.1800 7.00E-02	.2884 3.40E-02	.0300 5.90E-01	.0338 3.26E-02	.0353 8.60E-02
.1772 2.50E-03	.2950 5.00E-03	.8600 7.00E-02	.3900 7.00E-02	.4175 3.20E-02	.1640 2.30E-02	.2320 8.00E-02	.0796 6.00E-03
.2843 5.90E-02	.5040 1.00E-02	1.0330 1.00E-02	.4100 6.40E-03	.4340 8.20E-03			.0810 3.70E-01
.3258 2.50E-02	.5090 2.00E-02	1.2400 2.00E-02	.4300 3.00E-02	.5269 1.49E-01			.1607 6.60E-04
.3645 7.97E-01	.5230 1.60E-01	1.3500 2.00E-02	.5100 9.00E-03	.5465 6.20E-02			.2234 2.40E-06
.5030 3.60E-01	.6206 4.00E-02		.5400 8.00E-02	.7077 5.90E-03			.3031 5.10E-05
.6370 6.80E-02	.6330 1.90E-01		.6100 2.49E-01	.8369 5.00E-02			.3841 2.30E-04
.7229 1.58E-02	.6507 4.00E-02		.6400 7.30E-02	.9724 1.80E-02			
	.6521 4.00E-02		.7500 1.00E-02	1.0387 9.00E-02			
	.6674 9.20E-01		.7700 6.00E-02	1.1017 1.70E-02			
	.6697 6.00E-02		.8500 9.50E-01	1.1243 3.10E-02			
	.6715 6.00E-02		.8600 4.00E-02	1.1316 1.75E-01			
	.7270 3.20E-02		.8900 7.00E-01	1.1691 7.90E-03			
	.7290 3.20E-02		.9600 2.00E-02	1.2604 2.58E-01			
	.7729 8.30E-01		1.0000 5.00E-02	1.4575 7.10E-02			
	.9547 1.94E-01		1.0700 1.89E-01	1.5029 1.20E-02			
	1.1390 2.60E-02		1.1500 1.20E-01	1.5659 1.40E-02			
	1.1400 4.00E-02		1.2800 1.00E-02	1.6785 9.50E-02			
	1.2230 7.60E-03		1.3400 2.00E-02	1.7070 3.80E-02			
	1.2430 6.00E-02		1.4600 4.00E-02	1.7919 7.60E-02			
	1.3630 2.60E-02		1.4900 1.00E-02	1.8314 6.40E-03			
	1.3980 8.00E-02		1.6200 5.00E-02	2.0467 8.30E-03			
	1.4400 3.00E-02		1.7900 5.00E-02	2.2567 6.30E-03			
	1.7200 3.40E-03			2.4079 9.00E-03			
	1.7700 5.00E-03						
	1.9100 1.30E-02						
	1.9930 1.30E-02						
	2.0450 3.00E-03						
	2.1600 2.00E-03						
	2.2230 2.00E-03						
	2.3900 2.00E-03						
	2.5500 5.00E-04						
	2.6800 2.00E-04						

TABLE C-3 (continued)

ISOTOPIC GAMMA ENERGIES AND DECAY FRACTIONS (Ref. 6)

ISOTOPES, GAMMA ENERGIES AND FRACTIONS

XE-135M	XE-135	XE-138	KR-83M	KR-85M	KR-85	KR-87	KR-88
.0045 4.00E-04	.0310 4.50E-02	.0300 3.00E-02	.0016 8.00E-02	.0016 6.50E-04	.5140 4.35E-03	.4030 5.90E-01	.1660 6.93E-02
.0298 1.35E-01	.1585 2.10E-03	.1550 7.80E-02	.0093 8.00E-02	.0128 5.20E-02		.6743 2.50E-02	.1961 3.61E-01
.5270 8.20E-01	.1999 2.00E-04	.2430 3.60E-02	.0128 1.60E-01	.1495 7.70E-01		.8360 8.00E-03	.3626 3.03E-02
	.2498 9.16E-01	.2590 3.70E-01		.3050 1.35E-01		.8459 8.10E-02	.3903 6.53E-03
	.3586 2.20E-03	.3970 7.40E-02				1.1755 1.40E-02	.4723 6.33E-03
	.3731 1.10E-04	.4020 2.80E-02				1.3380 7.50E-03	.8337 1.31E-01
	.4082 3.10E-03	.4340 2.30E-01				1.3840 5.50E-03	.8624 5.00E-03
	.5733 5.00E-05	1.7700 2.00E-01				1.7410 2.00E-02	.9867 1.63E-02
	.6066 2.40E-02	2.0000 1.60E-01				2.0120 2.60E-02	1.1417 1.63E-02
	.6546 3.20E-04					2.5560 9.50E-02	1.1853 9.06E-03
	.7319 4.60E-04					2.5590 5.10E-02	1.2503 1.16E-02
	.8126 5.06E-04					2.8112 4.00E-03	1.5135 1.56E-02
	1.0630 3.66E-05					3.3098 6.00E-03	1.5293 1.14E-01
							2.0295 4.63E-02
							2.0353 4.83E-02
							2.1959 1.51E-01
							2.2316 3.63E-02
							2.3524 2.06E-03
							2.3920 3.82E-01

TABLE C-4

ABSORPTION COEFFICIENTS FOR AIR (Ref.9)

E MeV	μ/ρ [(a)] (cm^2/gm)	μ_a/ρ [(b)] (cm^2/gm)
0.01	4.99	4.61
0.015	1.55	1.27
0.02	0.752	0.511
0.03	0.349	0.148
0.04	0.248	0.0669
0.05	0.208	0.0406
0.06	0.188	0.0305
0.08	0.167	0.0243
0.1	0.154	0.0234
0.15	0.136	0.0250
0.2	0.123	0.0268
0.3	0.107	0.0288
0.4	0.0954	0.0295
0.5	0.0870	0.0297
0.6	0.0805	0.0290
0.8	0.0707	0.0289
1.0	0.0636	0.0280
1.5	0.0518	0.0257
2.0	0.0445	0.0238
3.0	0.358	0.0212
4.0	0.0308	0.0194

[a] From Table 3.-27, NSRDS-NBS 29.
[b] From Table 1.-7, NSRDS-NBS 29.

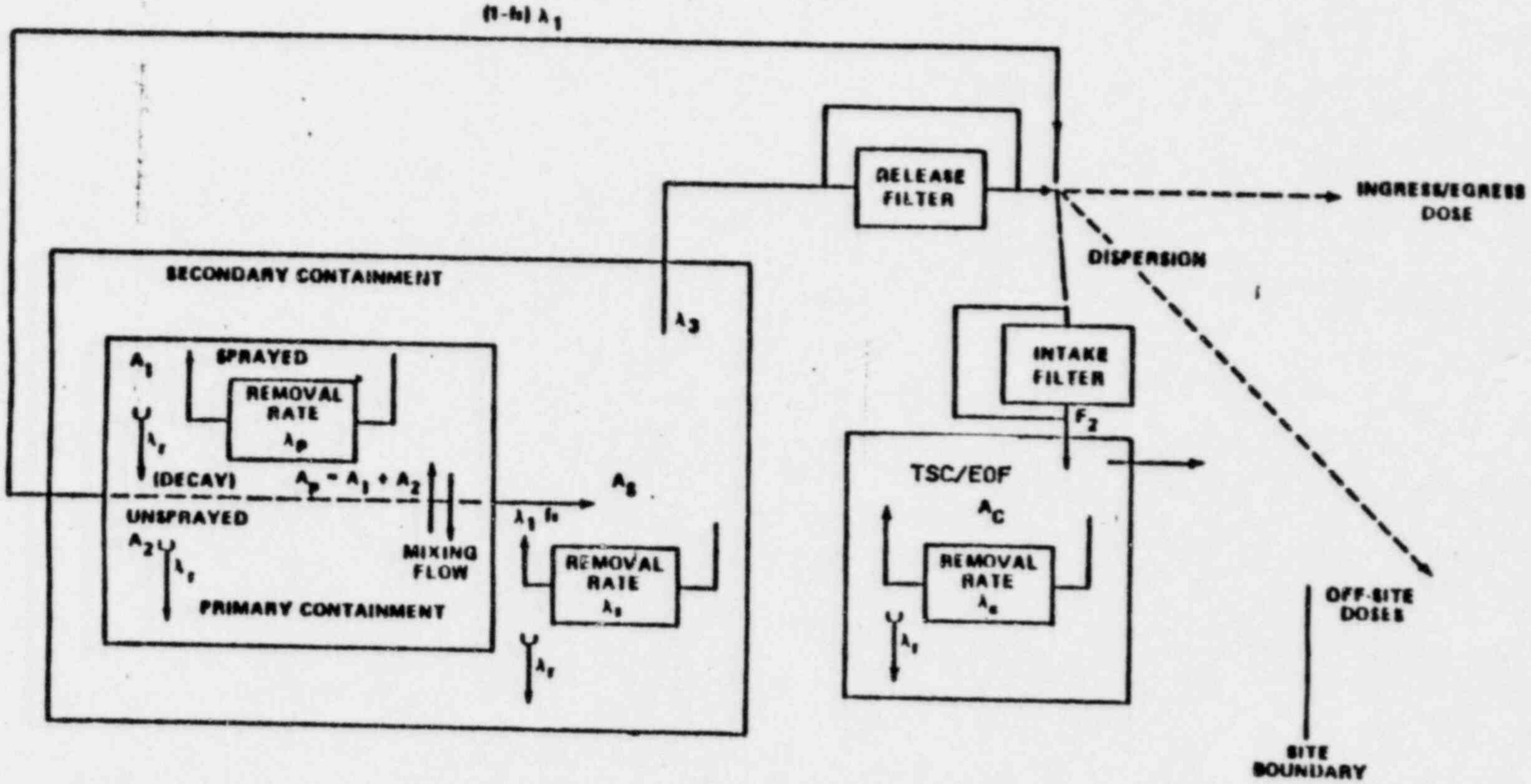

FIGURE C-1

DOSE MODEL ACTIVITY FLOW SCHEMATIC