APPENDIX E - STATION ATMOSPHERIC RELEASE LIMIT CALCULATIONS

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APPENDIX E STATION ATMOSPHERIC RELEASE LIMIT CALCULATIONS

The doses, models, and assumptions presented in this section were utilized to determine the maximum release rates allowable by the offsite dose limitations of 10CFR20. A realistic assessment of offsite doses from expected annual releases showing conformance with the design objectives of 10CFR50, Appendix I, is presented in Radioactive Effluent Dose Assessment, Peach Bottom Atomic Power Station Units 2 and 3, Enclosure A, September 30, 1976 (Appendix I evaluation). This report is made part of this document by reference.

The meteorological dispersion model used at Peach Bottom has been modified due to the results of the Unit 2 Vent Plume Behavior Study for Peach Bottom Atomic Power Station, March, 1974. This report is made part of this document by reference. This has resulted in a change in the iodine Technical Specification release limits; however, noble gas Technical Specification limits were not modified. These Technical Specification release limits were subsequently relocated to the Offsite Dose Calculation Manual in Amendments 210 and 214 for Peach Bottom Atomic Power Station Units 2 and 3 respectively.

Note: The material presented in Appendix E is historical and describes the analysis for the original plant design.

E.1 ANALYTICAL MODEL

The model described below is primarily concerned with calculating the annual gamma dose rate at ground level resulting from a continuous release of radioactive materials. As a direct consequence, a method is also obtained for calculating the annual average concentration at ground level.

In essence, the gamma dose model considers the integrated dose rate from a continuously distributed gaseous source (the plume). The source distribution is treated by a standard dispersion model that relates the dispersion of airborne particles to downwind distance and to the meteorological conditions that exist during the release intervals. The annual gamma dose is obtained by weighting the gamma dose rate associated with a given meteorological condition by the frequency of occurrence of that condition. The height of terrain and the height of release are considered in the model.

E.1.1 Meteorological Factors

The air concentration per unit amount released at a point (x,y,z) in the cloud at any instant is given by Equation (E.1) which is

Sutton's equation corrected by Cramer[1] for depletion by ground deposition and radioactive decay:

$$(X) = \frac{Q_o}{2\pi\sigma_y\sigma_z\bar{u}_h} \exp \left(-\frac{y^2}{2\sigma^2_y} - \frac{x^2}{2\sigma^2{}_z} \right) \frac{Q}{Q_o} \exp[-\lambda t] \qquad (E.1)$$

where:

(X)	= average air concentration (Ci/cu m or μCi/cc)
Q_o	= release rate (Ci/sec)
$\bar{u}_h$	= average wind speed at height of release (m/sec)
σ_z, σ_y	= standard deviation of cloud width in vertical and horizontal direction, respectively (m)
t	= time after release
λ	= radioactive decay constant (sec^{-1})

The factor Q/Q_o is the correction for cloud depletion due to deposition and is equal to the fraction of the initial amount released which is present at a down wind distance x. According to Watson and Gamertsfelder[(2)], Q/Q_o is given by:

$$Q/Q_o = \exp - \frac{v_d(\bar{u}_o/\bar{u}_h)}{\bar{u}_o\pi/2} \int_o^t \frac{\bar{u}_h}{\sigma z} \exp - \frac{z^2}{2\sigma_z{}^2} dt \qquad (E.2)$$

where:

V_d	= deposition velocity (m/sec)
u_o	= mean wind speed at ground level (m/s)

Values of the deposition "velocity" (V_d) are obtained from Table E.1.1.

It is considered a reasonable approximation to assume that throughout the year all the plumes which travel anywhere within a given sector direction do not have a skewed frequency distribution within the sector. Then, the average cloud concentration in the sector is found by integrating Equation (E.1) in the crosswind direction and dividing by the sector width.

$$(X)_{ave} = \frac{\int_{-\infty}^{\infty} x \, dy}{\Theta x} \tag{E.3}$$

(Θx sector width)

Equation (E.3) cannot be integrated since the interrelationship between the variables σ_y, σ_z, and $\bar{u}_h$ with respect to their average values is not generally known. However, for any specific combination of wind speed and stability at a given downwind distance all these variables are known and can be treated as constants, and the integration can then be performed. Thus, the average concentration in the sector for all occurrences of any specific condition is given by:

$$(\chi)_{ave}^{ij} = \frac{Q_o[Q/Q_0]}{\sqrt{2\pi}\theta x \sigma_z \bar{u}_h} \exp\left[\frac{-z}{2\sigma_z^2}\right] \exp[-\lambda t] \tag{E.4}$$

where:

- θ = sector angle ($\pi/8$ or 22 1/2° is used in this report)
- x = downwind distance and is equal to $\bar{u}_h t$
- σ_z = a function of stability, wind speed, and downwind distance (x)

Thus, the average cloud is seen to have a uniform concentration distribution vertically which is of the Gaussian form.

The standard deviation in the vertical direction is described by Watson and Gamertsfelder(2) as:

$$\sigma_z^2 = [1 - \exp(-k^2t^2) + bt] \text{ stable condition} \tag{E.5}$$

$$\sigma_z^2 = \frac{C^2{}_z \chi(2-n)}{2} \text{ neutral, unstable conditions} \tag{E.6}$$

The expression for σ_z in Equation (E.6) is the standard Sutton equation. The expression for σ_z in Equation (E.5) was derived from Hanford field measurements of the vertical concentration taken at several downwind locations under stable conditions. The constants for Equation (E.5) and (E.6) were evaluated from the Hanford measurements for a source height of 200 ft and correlated with vertical temperature gradients at the point of emission.

Since the concentration measurements were averaged over 30-to-60 min intervals, the constants used to evaluate σ_z are considered to be more appropriate for long-term releases rather than the shorter term or "puff" releases. Figures E.1.1 to E.1.4 show vertical cloud width (σ_z) as a function of distance for each stability category.

The following stability classification is used along with vertical temperature lapse rates for each:

Very stable	$\Delta T \geq 1.5$ °C/100 m
Moderately stable	$-0.5 \leq \Delta T < 1.5$
Neutral	$-1.5 \leq \Delta T < -0.5$
Unstable	$\Delta T < -1.5$

Table E.1.1 shows the deposition velocity coefficients for each stability category. Table E.1.2 shows the appropriate values of a,b,k^2, C_z, and n used with each stability condition and wind speed. Such values are used to calculate the vertical dimensions of the plume (σ_z) and, as stated earlier, were constants derived from the Hanford field measurements.

The conventional "reflection" factor of two usually applied for releases is not included. For the passing cloud, which is primarily a gamma dose, the entire plume volume is integrated as an "infinite" number of point sources to plus and minus infinity in the z direction. This ignores the interception by the ground so that the entire cloud volume is included.

Inhalation doses are a function of concentration at the ground and subject to "reflection" effects if they exist. Since the materials of interest in inhalation effects deposit on the ground, it is doubtful that "perfect" reflection will occur, but rather that the cloud will expand, distorting the Gaussian mass distribution of the cloud resulting in, at most, a small increase in concentration. In addition, no account was taken of the better diffusion at the ground (effective on the portion of the cloud near the ground) compared to the stack exit elevation used. Meteorology and Atomic Energy (AECU 3066) shows that compared to an elevation of 200 m, ground level diffusion coefficients are larger by about a factor of 2 plus proportionally increasing dispersion. In any event, an increase by a factor of slightly more than 1.0 but less than 2 would account for this "reflection" effect.

E.1.2 Radiological Factors

The ground level gamma dose rate from an elevated plume of radioactive materials having a spatial distribution as given in Equation (E.3) may be considered as the sum of the dose rates from all the points in the plume. The source strength of each point is (χ)dV and the total source is:

$$S = \int_{-\infty}^{\infty} (\chi)^{dV} \tag{E.7}$$

where:

dV = dxdydz

The flux from a point source, considering buildup in the air is given by Glasstone[3] as:

$$\Phi = \frac{SB\ e^{-\mu R}}{4\pi R^2}\ \frac{\text{photons per}}{m^2 \text{ per sec}} \tag{E.8}$$

where:

S	= source strength
B	= buildup factor = 1 + kμR (see Figure E.1.6)
k	= $\frac{\mu-\mu_a}{\mu_a}$
μ	= Total linear attenuation coefficient $(m)^{-1}$
μ_a	= Energy absorption coefficient $(m)^{-1}$
R	= distance from source equal to $(x^2 + y^2 + z^2)^{1/2}$
x_1, y_1, z_1	= coordinates of dose point at ground level relative to the incremental volume (dV)

The gamma dose rate from a flux of a given energy (E) from Glasstone is:

$$(DR)_\gamma = 5 \times 10^{-3}\ \Phi\ E\mu_a \text{ (units of mR/hr)} \tag{E.9}$$

so that the total dose-rate from the plume at any point is found by combining Equations (E.7), (E.8), and (E.9). Hence, the gamma dose rate:

$$(DR)\gamma = \frac{5 \times 10^{-3}}{4\pi} E\mu_a \int_{-\infty}^{\infty} \frac{(\chi)_{ave} B_e^{-\mu R}}{R^2} dV;\ (mR/hr) \tag{E.10}$$

As Equation (E.10) is written, it assumes a monoenergetic source. For a mixture of isotopes, it is proper to perform the calculation for each gamma energy present considering its abundance. Since μ and μ_a are energy dependent and appear in an exponential term, care must be exercised if any average energy is to be used. A listing of each of the noble gas isotopes and significant particulate daughter products is shown in Tables E.1.3 and E.1.4; also shown are the gamma energies, total attenuation, and linear absorption coefficients. This analysis used an "average" isotope representing the mixture at 30 min decay. Values used for E, μ, and μ_a are shown in Table E.1.4.

In general, Equation (E.10) cannot be solved analytically and must be solved numerically. While integration to infinity is indicated, in practice finite bounds are placed on the cloud. Integrating Equation (E.10) to $\pm 3\ \sigma_z$ includes more than 99.97 percent of the entire matter per unit length; hence, the dose contributions from points in the cloud when vertical displacement is more than three standard deviations from the plume center line can be ignored. Likewise, due to the geometric and material attenuation shown in Equation (E.8), one can usually ignore the dose contribution from source points that are more than 400-500 m downwind or upwind of the receptor point without significant error. The integration proceeds by reducing the distributed source (the plume) into a large array of point sources. This is done by dividing the cloud into cubical volume elements. The assumption is made that the concentration at the center of the cube is average for the volume element.

The total source strength is preserved by multiplying the concentration at the center (μCi/cc) by the volume of the element (cc). The dose rate from each point source is calculated by Equation (E.10) and summed over all points. Equation (E.10) then becomes a finite series.

Mathematically the numerical integration can be expressed as:

$$DR^{ij}(P) = \sum_{P'} \sum_{I} G^{ij}(1, P'; P) \qquad \text{(E.11)}$$

where $G^{ij}(I,P';P)$ is the dose rate contribution from isotope(I) to point (P') from a source at (P) as described by Equation (E.10).

Equation (E.10) or (E.11) gives the average dose rate for the (ij)th meteorological condition for a point (P) which may be immersed in the cloud or at some point outside the cloud. This is a significant item since the gamma dose at ground level from a stack plume is not merely existent when the receptor is immersed in the plume. Dose is also received when the plume is traveling in some other sector than the one in which the receptor point is located. The effect is particularly important at points close to the stack where the receptor remains at a nearly constant distance from the plume regardless of angular separation.

E.1.3 Engineering Factors

From Equations (E.4) and (E.10) it is evident that the dose rate is significantly affected by the height of the plume above ground level. This height is made up of the physical stack height plus plume rise due to exit velocity and buoyancy. Many formulae are available to calculate plume rise. The method used here is the Holland formula as modified by Moses, et al[4].

$$\Delta H = \frac{K\,(1.5 V_s d + 4 \text{ X } 10^{-5} Q_h)}{\overline{u}_h} \qquad \text{(E.12)}$$

where:

V_s = exit velocity (m/sec)

d = stack diameter (m)

Q_h = heat emission of effluent (cal/sec)

$\overline{u}_h$ = wind speed at stack exit (m/sec)

K = correction factor for stack diameter[4] (Stumke regression coefficient)

In proposing the correction factor "K" in the plume rise formula, Moses used data from an experimental stack at Argonne with a diameter of about 0.46 m and from a stack at Duisburg, Germany, which has a diameter of 3.5 m. His conclusions are that a value of 3 for the correction factor is proper for large stacks with appreciable buoyancy, whereas a factor of 2 is recommended for small stacks with modest buoyancy. In applying the Moses correction to individual situations, a linear interpolation is made from the actual stack diameter compared to those from which data were obtained (Figure E.1.5).

The AEC/NRC document "Meteorology and Atomic Energy - 1968"[5] points out similar results in Section 5.2 discussed by Gary A. Briggs. He states that "both the Stumke formula and Holland formula times a factor of 3 seem to give good agreement (calculated versus observed plume rise) for the moderate-sized sources (heat emissions of about 10^6 cal/sec) but grossly underestimate rise in the case of the large Colbert plant (heat emissions of about 7×10^6 cal/sec)."

E.1.4 Averaging Techniques

One is usually interested in the cumulative dose over some appropriate time interval, such as a year. To compute the annual gamma dose, the gamma dose rate for a given meteorological condition must be weighted by the frequency distribution F^{ijk}. F^{ijk} describes the frequency of the i^{th} stability condition with j^{th} wind speed occurring in direction sector k. The average annual gamma dose rate in sector k is given by:

$$DR_\gamma^{ij}(P) = C \sum_{k'} \left[\sum_{k} DR_\gamma^{ijk;k'}(P)\ F^{ijk} \right] \tag{E.13}$$

where:

$DR_\gamma^{ijk;k'}(P)$ = the gamma dose rate at a point (P) in sector k from a plume traveling in sector k'

C = 8,760 hr/yr.

Equation (E.13) indicates a finite summation over the variables of stability, wind speed, and direction. For stability and direction it has already been indicated how these variables can be grouped into four stability classes and 16 directions. The spectrum of wind speeds can also be grouped into representative ranges. One such grouping that has proven useful, especially when using U.S. Weather Bureau summaries, is as follows:

Wind Speed Range (mph)	Average Wind Speed (m/sec)
0 - 3	1
4 - 7	2
8 - 12	5
13 - 18	7
19 - 24	10
>25	>13

Also included is the average wind speed that is representative of each speed range.

E.1.5 Average Air Concentration

For doses other than the whole-body gamma dose, the annual average concentration at ground level is of interest. This is easily obtained from the preceding material presented by substituting plume height for z. The air concentration during any meteorological condition has been described by Equation (E.4). However, for materials other than noble gases, the depletion factor (Q/Q_o) is not unity and must be accounted for. For the calculations made in the report, the deposition rates shown in Table E.1.1 were used.

Using the joint frequency distribution F^{ijk} defined previously, computations of the annual average concentration at the ground can be made from:

$$(\chi)^{k}_{gr} = \sum_{ij} (\chi)^{ij}_{gr} F^{ijk} \qquad \text{(E.14)}$$

E.1.6 Shielding and Occupancy Factors

Radiation doses calculated are usually performed for certain distances from the point of release and often are calculated for locations where no actual dose would be received by a human receptor. In fact, it is not too uncommon to see radiation doses from the passing cloud calculated as if the dose receptors were out-of-doors day and night. This is certainly possible, but it does not lead to particularly accurate dose estimates for the great majority of people. For this reason, occupancy by individuals should be considered in arriving at reasonable dose estimates. Credit for this is allowed by the AEC/NRC's 10CFR20.

Additionally, it seems rather incongruous to assume that a person would stay in one place all of the time without being inside some type of shelter. For this reason, the shielding effect for various types of structures was evaluated.

It is easily seen that the error introduced by omitting this effect can be a factor of 2 or more. Where larger urban complexes are concerned, such an error may be far greater.

E.1 ANALYTICAL MODEL

REFERENCES

1. Cramer, H. E., "A Brief Survey of the Meteorological Aspects of Atmospheric Pollution," Bulletin of the American Meteorological Society 40(4): pp 165-171.

2. Watson, H. C. and Gamertsfelder, C. C., "Environmental Radioactive Contamination as a Factor in Nuclear Plant Siting Criteria," HW-SA2809, February, 1963.

3. Glasstone, S. and Sesonske, A., "Nuclear Reactor Engineering," D. VanNostrand Company, 1963.

4. Moses, H.; Strom, G. H.; and Carson, J. E., "Effects of Meteorological and Engineering Factors on Stack Plume Rise," Nuclear Safety, Vol. 6(1), Fall, 1964.

5. Slade, David H. (editor), "Meteorology and Atomic Energy 1968," TID-24190, pp 189-198, July, 1968.

TABLE E.1.1

DEPOSITION VELOCITY COEFFICIENTS

Stability Condition	Particulates	Halogens
	$V_d/\square_o$ *	
Very Stable	1.5×10^{-4}	2.4×10^{-3}
Moderately Stable	2.2×10^{-4}	3.4×10^{-3}
Neutral	3.0×10^{-4}	4.6×10^{-3}
Unstable	6.0×10^{-4}	8.0×10^{-3}

*To obtain the deposition velocity, multiply this ratio of deposition velocity to ground wind speed by the ground speed ($\square_o$).

TABLE E.1.2

DIFFUSION COEFFICIENTS

Constants	Very Stable	Moderately Stable	Neutral	Unstable
a(sq m)	34	97	--	--
b(sq m/sec)	0.025	0.33	--	--
$K^2(sec^{-2})$	8.8×10^{-4}	2.5×10^{-4}	--	--
C_z($\square$=1 m/sec)	--	--	0.15	0.30
($\square$=5 m/sec)	--	--	0.12	0.26
($\square$=10 m/sec)	--	--	0.11	0.24
n	--	--	0.25	0.20

TABLE E.1.3

NOBLE GAS ISOTOPES

CONSTITUTING MIXTURE

Isotope Name	Half-Life	Eγ(Mev)	μ	μ_a
Noble Gases				
Kr-83m	1.86h	0.032	0.045	0.015
		0.009	0.8	0.7
Kr-85m	4.4h	0.15	0.016	0.0032
		0.305	0.013	0.0038
Kr-85	10.76y	0.522	0.011	0.004
Kr-87	76m	2.05	0.006	0.0028
		2.57	0.005	0.0026
		0.847	0.009	0.0038
		0.347	0.013	0.0039
Kr-88	2.8h	2.4	0.0055	0.0027
		2.21	0.006	0.0028
		0.19	0.015	0.0034
		1.55	0.007	0.0032
		0.85	0.009	0.0038
		0.17	0.015	0.0032
		0.02	0.1	0.063
Xe-131m	12d	0.164	0.015	0.0032
Xe-133m	2.3m	0.233	0.014	0.0037
Xe-133	5.27d	0.081	0.02	0.0032
Xe-135m	16m	0.53	0.011	0.004

TABLE E.1.3 (Continued)

Isotope Name	Half-Life	Eγ(Mev)	μ	μ_a
Xe-135	9.2h	0.604	0.01	0.004
		0.36	0.013	0.0039
		0.244	0.014	0.0037
Xe-138	14m	0.42	0.012	0.004

TABLE E.1.4

PARTICULATE DAUGHTER PRODUCTS AND "AVERAGE" ISOTOPE

Isotope Name	Half-Life	$E\gamma$(Mev)	μ	μ_a
Particulate Daughters				
Rb-88	18m	0.91	0.0085	0.0037
		1.28	0.0072	0.0034
		1.85	0.0060	0.0032
		2.18	0.0050	0.0030
		4.2	0.0038	0.0024
Cs-138	32.2m	0.14	0.018	0.0033
		0.19	0.016	0.0035
		0.23	0.015	0.0037
		0.41	0.0122	0.0037
		0.46	0.0116	0.0038
		0.55	0.0108	0.0038
		0.87	0.0088	0.0037
		1.01	0.0082	0.0036
		1.43	0.0068	0.0034
		2.21	0.0055	0.003
		2.63	0.0050	0.0039
		3.34	0.0043	0.0026

TABLE E.1.4 (Continued)

Isotope Name	Half-Life	Eγ(Mev)	μ	μ_a
"Average" Isotope				
0-12 hr decay		0.62	0.0099	0.0039
12-48 hr decay		0.30	0.0135	0.0038
>48 hr decay		0.020	0.092	0.059

E.2 VERIFICATION OF ANALYTICAL MODEL

E.2.1 Meteorology Data

Micrometeorological data for 1963 were obtained from Brookhaven National Laboratory. The data were in the form of computer input cards containing hourly observations of average wind speed and direction at the 37, 150, and 355-ft levels and the air temperature at the 37, 75, 150, 300,and 410-ft levels. The measurements at the 355-ft level were summarized in terms of frequency of occurrence according to wind speeds, direction, and atmospheric stability. The stability was determined according to the method described in subsection E.1 by using the temperature gradient measured between the 410-ft and 37-ft levels.

The summaries are presented in Tables E.2.1 through E.2.6. The frequency of occurrence was based on 6,464 hr of good observations. Of the missing 2,296 hr of 1963, August and September account for 1,464 missing hr, the rest being scattered throughout the year. A total of 12 hr was observed to have a wind speed less than 0.5 mph. These "calm" conditions were included in the wind speed category (0-3) mph.

E.2.2 Radiological Data

As is discussed in Hull[1], the radiation dose was measured at several stations around the Brookhaven Graphite Research Reactor (BGRR) in 1963 using 6-liter, atmospheric pressure ion chambers. The dose rate from the release of Ar-41 (Argon) was determined from the total dose measurement by subtracting from it the contribution from natural background and operation of the forest ecology station. The resultant dose rate is shown in Table E.2.7.

It was necessary to adjust the measured values of annual gamma dose to account for the absence of meteorological data during August and September. The average dose rate (mR/wk) was averaged over the 10 months for which meteorological data were available and multiplied by 52 to get the annual dose (mR/yr). The exception to this is station E-2 which was moved in December. For this station, 9 months were used to determine the annual dose. These normalized values are shown in comparison with calculated values in Table E.2.8.

E.2.3 Gamma Dose Calculations

The methods described in subsection E.1 were used to analyze the effects of the BGRR stack effluent in the Brookhaven environs. The following is a discussion of the calculations leading to the gamma dose rate matrix, $DR_{\gamma}^{ijk;k'}$.

E.2.3.1 Plume Rise

The BGRR has a 350-ft stack (107 m) with an exit velocity of 6 m/sec and an effluent temperature difference of 50°C above ambient. For use in Equation (E.12) these values correspond to:

Q_h	$= 1.62 \times 10^6$ cal/sec	- Heat rate
d	= 5.18	- Stack exit diameter
K	= 3.47	- Correction factor in equation

Using these values in Equation (E.12), the plume rise formula becomes:

$$\Delta H = \frac{377}{\bar{u}_h} \text{ meters} \tag{E.15}$$

Using the six standard wind speed groups described earlier, the effective stack heights were computed and are shown below.

BGRR Plume Rises for Various Wind Speeds

Wind Speed Range (mph)	Average Speed (m/sec)	Plume Rise (m)	Effective Height (m)
0 - 3	1	377	484
4 - 7	2	189	295
8 - 12	5	75	182
13 - 18	7	54	161
19 - 24	10	38	145
>25	>13	29	136

E.2.3.2 Isotopic Data

The BGRR during full power operation releases about 12,960 Ci of Ar-41 per day (0.15 Ci/sec). However, the actual average release rate during 1963 was 0.127 Ci/sec as determined from personal communications with the BGRR staff, which represents an 85 percent operation factor.

Pertinent radiological properties of Ar-41 are:

$E = 1.29$ Mev	Gamma energy
$\mu = 6.93 \times 10^{-3}\ M^{-1}$	Total attentuation coefficient
$\mu_a = 3.3 \times 10^{-3}\ M^{-1}$	Energy absorption coefficient
$\gamma = 1.1 \times 10^{-4}\ sec^{-1}$	Decay constant

E.2.3.3 Dose Rate Calculations

From the above information, the gamma dose rate as given by Equations (E.10) and (E.11) was evaluated using a digital computer program to evaluate Equation (E.10). The dose rate was evaluated for downwind distances of 10, 100, 400, 1,400, 2,400, 3,200, and 6,400 m, using the six wind speeds shown earlier and all four stability conditions. The results are shown in Figure E.2.1. The dose rates for the very stable and moderately stable conditions are essentially identical because, for the distances used here, the vertical spread of the plume is small in each case. Hence, the difference in cloud dimensions between the two stable conditions are not great compared to the attenuation distances involved.

Another important feature to notice is that there is very little variation in dose rate between any of the stability classes for the plume height considered here. Figure E.2.2 illustrates this point more clearly by showing the dose rate for a 5 m/sec wind speed for each of the stability conditions. The variation of dose rate between stability conditions is very small for downwind distances less than 400 m, and is less than a factor of 2 even to a distance of 6 mi. From the shape of the dose rate curves, it can be seen that the maximum usually occurs within 1,000 m and decreases rapidly thereafter.

Rates shown in Figure E.2.1 are for points on the ground directly below the centerline of the sector averaged plume. As previously mentioned, significant dose contributions can also occur in sectors other than the one in which the plume is traveling. Due to symmetry, there are only nine unique sectors for which dose rate calculations can be made.

If the sector in which the plume is traveling is designated as Sector 1 (Figure E.2.4), then the dose to Sector 16 from the plume is equal to the dose to Sector 2; the dose to Sector 15 is the same as the dose to Sector 3, and so on. In terms of the dose rate matrix the following equalities can be listed:

$$DR_{\gamma}^{ij1,1} = Dr_{\gamma}^{ij1,1}$$

$$DR_{\gamma}^{ij16,1} = Dr_{\gamma}^{ij2,1}$$

$$DR_{\gamma}^{ij15,1} = Dr_{\gamma}^{ij3,1}$$

$$\vdots \qquad \vdots$$

$$DR_{\gamma}^{ij9,1} = DR_{\gamma}^{ij9,1}$$

However, for distances greater than 100 m, the dose rate to adjacent sectors is very small because of the large separation distances. This is illustrated by Figure E.2.3 which shows the sector variation of dose rate with distance for one particular meteorological condition. In practice, the dose rate to a point in Sector k is not calculated if the dose rate is less than 0.1 percent of the dose rate to a point at the same downwind distance in Sector 1.

Figure E.2.1 indicates how the dose rate matrix $DR_{\gamma}^{ijk,k'}$ is constructed. It now remains to find the joint frequency distribution F^{ijk} to calculate the annual dose rate.

E.2.3.4 Conclusions About Gamma Dose Calculations

From the data presented in Figure E.2.5 it is concluded that the analytical model provides a fairly precise correlation between stack release rate and ground level gamma radiation dose. It is seen that the maximum dose is at the closest point to the stack. This should not be surprising since at the base of the stack, for example, the dose rate is continuous and independent of plume direction travel. This would be expected from the dose rate curves presented in Figure E.2.1.

Further examination of Figures E.2.1 through E.2.3 showing dose rate during each meteorological condition leads to additional interesting conclusions. The dose rate does not seem to be very sensitive to the atmospheric stability condition. This is markedly in contrast to the air concentration differences at ground level during the various stability regimes. It is widely known that, during very stable conditions, near zero air concentration exists at ground level from an elevated plume since it remains very narrow and highly concentrated aloft. On the other hand, unstable conditions promote rapid effluent growth and dispersion and highest ground level air concentrations.

It appears that, while the gamma dose rate is quite insensitive to atmospheric stability, it is quite dependent on plume height and wind speed. This is to be expected intuitively from Equation (E.4), where the average concentration which is used to obtain dose rate is inversely proportional to wind speed and the attenuation distances increase with plume height. In practice, buoyant effluents are typical (although not universal) so that effluent buoyance enters the calculations. That is to say, plume height is made up of stack height plus plume rise due to buoyancy. The latter is greatest for smallest wind speeds. Thus, the smallest wind speed conditions do not a priori yield the largest dose rates. In fact, experience with calculations using this analytical model verifies this.

Calculations have also shown that most of the dose over a long period of time comes from the conditions where the wind speed is about at the average speed of 4-7 m/sec (9-16 mph), which most locations are observed to have. The calculation for Brookhaven is no exception. This can partially be explained by the fact that for elevations considered here (300-400 ft) low winds speeds, for example, are rather infrequent, accounting for about 3 percent of the time.

A final conclusion drawn from the comparison of calculated and measured doses refers to the dose pattern depicted in Figure E.2.5. It is observed that for distances out to about 1/2 mi (typical large reactor site), the isodose contours exhibit a smooth rather than a peaked pattern. This is quite different from the wind direction distribution (wind rose, see Table E.2.5) where total direction frequency is indicated. However, the smooth gamma dose pattern, as indicated in Figure E.2.5 is attributed to the fact that the total dose at each point is made up of the dose from plumes traveling in all directions. At distances of 2 mi and beyond, the gamma dose contours exhibit a peak pattern similar to the wind rose. At these distances, only plumes traveling in the direction of a dose point contribute significantly to the gamma dose at the point.

E.2.3.5 Ground Level Air Concentration Calculations

For some kinds of radiation dose only the ground level air concentration is of interest. Examples of these are dose from inhalation, external beta dose, and deposition. In each of these, concentration at the dose point determines the dose regardless of the concentration at other points in the plume. This method of calculating the correlation between stack emission rate and ground level air concentration is also of interest in assessing environmental effects of a stack effluent.

Some limited air concentration measurements are also made at Brookhaven (BNL-915). These are measurements of small quantities of iodine released from the BGRR. Three monitoring stations were operated in 1963, although since then the scope of this program has been augmented. The release of Iodine-131 from the BGRR was about 0.1 μCi/sec continuously.

As indicated previously, the analytical model used calculates average air concentration at any point in the cloud, including ground level. Thus, the calculation is similar to that done for the gamma dose, but only at the dose point (ground level) can the calculation be performed.

The calculation of long-term, average, ground level air concentration is as described in paragraph E.1.1. This involves weighting each calculated average concentration during each meteorological condition by its frequency of occurrence and summing over all conditions.

The highest concentration calculated for the Brookhaven case is 0.6×10^{-15} μCi/cc. As indicated previously, only three iodine monitoring points existed during the year 1963. All of these locations showed annual concentrations below detectable limits of about 2×10^{-15} μCi/cc. Thus, only a qualitative comparison of the analytical mode and the data can be made at this time for this type of calculation. The calculated values, however, appear to be about the correct order of magnitude, but the comparison is inconclusive.

E.2 VERIFICATION OF ANALYTICAL MODEL

REFERENCE

1. Hull, A.P., "1963 Environmental Radiation Levels at Brookhaven National Laboratory," BNL -915, November, 1964.

TABLE E.2.1

PERCENT OCCURRENCE OF GOOD OBSERVATIONS FROM THE BNL SITE

FOR VARIOUS DIRECTIONS AND WIND SPEEDS (VERY STABLE)

(6,464 hr during 1963)
Atmospheric stability: Very Stable
Stability based temp. diff. taken at 410 ft and 37 ft

Speed (mph) at 355 ft

Direction	0-3	4-7	8-12	13-18	19-24	>24	All Speeds
N	0.0619	0.108	0.433	0.449	0	0	1.05
NNE	0.0619	0.139	0.155	0.124	0	0	0.48
NE	0.0309	0.0464	0.155	0.0309	0	0	0.26
ENE	0	0.0928	0.124	0.0309	0	0	0.25
E	0.0464	0.0774	0.155	0.0774	0.0619	0	0.42
ESE	0.108	0.201	0.263	0.0155	0	0	0.59
SE	0.0464	0.0309	0.0464	0.0155	0.0155	0	0.15
SSE	0.0619	0.139	0.201	0.124	0	0	0.53
S	0.0464	0.201	0.248	0.356	0.232	0.0309	1.11
SSW	0.0619	0.294	0.665	1.13	1.01	0.0928	3.25
SW	0.108	0.170	0.433	1.22	0.897	0	2.83
WSW	0.0928	0.124	0.340	1.11	0.557	0.0155	2.24
W	0.0464	0.186	0.804	0.712	0.541	0.309	2.32
WNW	0.0774	0.186	0.572	0.433	0.139	0	1.41
NW	0.0309	0.186	0.433	0.603	0.186	0	1.44
NNW	0.0155	0.124	0.433	0.789	0.0774	0	1.44
All Directions	0.90	2.31	5.46	7.22	3.71	0.17	19.77

TABLE E.2.2

PERCENT OCCURRENCE OF GOOD OBSERVATIONS FROM THE BNL SITE

FOR VARIOUS DIRECTIONS AND WIND SPEEDS (MODERATELY STABLE)

(6,464 hr during 1963)
Atmospheric stability: Moderately Stable
Stability based temp. diff. taken at 410 ft and 37 ft

Speed (mph) at 355 ft

Direction	0-3	4-8	8-12	13-18	19-24	>24	All Speeds
N	0	0.186	0.433	0.433	0.232	0.0464	1.33
NNE	0.0464	0.278	0.557	0.464	0.186	0.0309	1.56
NE	0.0774	0.232	0.557	0.124	0.0928	0	1.08
ENE	0.0309	0.139	0.139	0.201	0.155	0	0.66
E	0.0309	0.186	0.263	0.278	0.232	0.0619	1.05
ESE	0.0928	0.139	0.371	0.278	0.186	0.0619	1.13
SE	0.0309	0.0774	0.155	0.387	0.0619	0	0.71
SSE	0.0309	0.0619	0.495	0.696	0.418	0.449	2.15
S	0.0928	0.108	0.402	1.08	0.804	0.201	2.69
SSW	0.139	0.232	0.913	1.90	1.36	0.108	4.66
SW	0.0464	0.232	0.495	1.53	0.572	0.0619	2.94
WSW	0.0464	0.108	0.449	1.44	0.480	0.0774	2.60
W	0	0.139	0.387	1.42	1.01	0.170	3.12
WNW	0.0464	0.139	0.371	0.727	1.07	0.0464	2.40
NW	0.0464	0.139	0.371	0.743	0.727	0.0309	2.06
NNW	0.0464	0.155	0.655	1.25	0.309	0.0619	2.49
All Directions	0.80	2.55	7.02	12.96	7.89	1.41	32.63

TABLE E.2.3

PERCENT OCCURRENCE OF GOOD OBSERVATIONS FROM THE BNL SITE

FOR VARIOUS DIRECTIONS AND WIND SPEEDS (NEUTRAL)

(6,464 hr during 1963)
Atmospheric stability: Neutral
Stability based temp. diff. taken at 410 ft and 37 ft

Speeds (mph) at 355 ft

Direction	0-3	4-7	8-12	13-18	19-24	>24	All Speeds
N	0.0619	0.217	0.526	0.325	0.170	0.0309	1.331
NNE	0.0928	0.340	0.495	0.774	0.0464	0.0155	1.764
NE	0.0774	0.480	0.526	0.217	0.0155	0	1.316
ENE	0.0928	0.186	0.371	0.325	0.155	0.0155	1.145
E	0.0464	0.0928	0.263	0.155	0	0	0.557
ESE	0.139	0.449	0.743	0.278	0.0774	0.0155	1.702
SE	0.0309	0.217	0.464	0.124	0.0309	0.0155	0.882
SSE	0.0309	0.248	1.45	0.665	0.232	0.201	2.827
S	0.155	0.402	1.58	1.42	0.603	0.0774	4.237
SSW	0.186	0.172	1.67	0.93	0.774	0.0619	5.334
SW	0.139	0.294	0.712	0.804	0.433	0.139	2.521
WSW	0.124	0.263	0.882	1.18	0.990	0.325	3.764
W	0.155	0.248	0.789	1.39	1.73	0.975	5.287
WNW	0.124	0.248	0.851	1.01	1.30	0.619	4.152
NW	0.0464	0.294	0.511	0.851	0.866	0.263	2.831
NNW	0.0619	0.464	0.619	0.990	0.402	0.928	2.630
All Directions	1.56	5.15	12.45	12.44	7.83	2.85	42.28

TABLE E.2.4

PERCENT OCCURRENCE OF GOOD OBSERVATIONS FROM THE BNL SITE

FOR VARIOUS DIRECTIONS AND WIND SPEEDS (UNSTABLE)

(6,464 hr during 1963)
Atmospheric stability: Unstable
Stability based temp. diff. taken at 410 ft and 37 ft

Speeds (mph) at 355 ft

Direction	0-3	4-7	8-12	13-18	19-24	>24	All Speeds
N	0	0	0.0928	0.0464	0	0	0.1392
NNE	0	0	0.0464	0.0155	0	0	0.0619
NE	0	0	0.0619	0	0	0	0.0619
ENE	0	0	0	0	0.0619	0.0155	0.0774
E	0	0	0	0.0155	0.0155	0	0.031
ESE	0	0	0.0155	0	0	0	0.0155
SE	0	0	0	0	0	0	0
SSE	0	0	0.0155	0.0309	0	0	0.0464
S	0	0	0.0928	0.248	0.232	0.0464	0.6192
SSW	0	0	0.0155	0.217	0.0774	0	0.3099
SW	0	0	0.0619	0.0619	0	0.0155	0.1393
WSW	0	0	0.0309	0.155	0.170	0.0928	0.4487
W	0	0	0.0619	0.402	0.541	0.186	0.1909
WNW	0	0.0309	0.0619	0.495	0.402	0.201	1.1908
NW	0	0	0.186	0.309	0.139	0.0155	0.6495
NNW	0	0.0155	0.0928	0.155	0.0619	0	0.3252
All Directions	0.046	0.835	2.15	1.70	0.5724	0.5737	5.87

TABLE E.2.5

PERCENT OCCURRENCE OF ALL WIND SPEEDS FOR 16 DIRECTIONS

AND 4 ATMOSPHERIC STABILITY CONDITIONS AT 355 FT (FROM BNL DATA - 1963)

(Wind Rose)

Stability (ΔT = T410-T37)

Direction	VS	MS	N	U	All Stabilities
N	1.05	1.33	1.33	0.14	3.86
NNE	0.48	1.56	1.76	0.06	3.86
NE	0.26	1.08	1.31	0.06	2.73
ENE	0.25	0.66	1.14	0.08	2.13
E	0.42	1.05	0.56	0.03	2.06
ESE	0.59	1.13	1.70	0.01	3.43
SE	0.15	0.71	0.88	0.00	1.75
SSE	0.52	2.15	2.83	0.05	5.55
S	1.11	2.69	4.24	0.62	8.66
SSW	3.25	4.66	5.34	0.31	13.55
SW	2.83	2.94	2.52	0.14	8.43
WSW	2.24	2.60	3.76	0.45	9.05
W	2.32	3.12	5.29	1.19	11.92
WNW	1.41	2.40	4.15	1.19	9.14
NW	1.44	2.06	2.83	0.65	6.98

TABLE E.2.5 (Continued)

Direction	VS	MS	N	U	All Stabilities
NNW	1.44	2.49	2.63	0.32	6.88
All Directions	19.77	32.64	42.28	5.31	100.00

NOTES: 1. 6,464 Total Hours
2. 12 hr of calm (less than 0.5 mph)

KEY: VS = very stable
MS = moderately stable
N = neutral
U = unstable

TABLE E.2.6

PERCENT OCCURRENCE OF GOOD OBSERVATIONS FROM THE BNL SITE

FOR VARIOUS DIRECTIONS AND WIND SPEEDS

(6,464 hr during 1963)
All Stabilities

Speed (mph) at 355 ft

Direction	0-3	4-7	8-12	13-18	19-24	>24	All Speeds
N	0.124	0.510	1.48	1.25	0.402	0.077	3.85
NNE	0.201	0.758	1.25	1.38	0.232	0.046	3.87
NE	0.186	0.758	1.30	0.371	0.108	0	2.72
ENE	0.124	0.418	0.634	0.557	0.371	0.031	2.13
E	0.124	0.356	0.681	0.526	0.303	0.062	2.06
ESE	0.340	0.789	1.39	0.572	0.263	0.077	3.43
SE	0.108	0.325	0.665	0.526	0.108	0.015	1.75
SSE	0.124	0.449	2.16	1.52	0.650	0.650	5.55
S	0.294	0.712	2.32	3.11	1.87	0.356	8.66
SSW	0.387	1.24	3.26	5.18	3.22	0.263	13.55
SW	0.294	0.696	1.70	3.62	1.90	0.216	8.43
WSW	0.263	0.495	1.70	3.98	2.20	0.510	9.05
W	0.201	0.572	2.04	3.93	3.82	1.36	11.93
WNW	0.247	0.603	1.86	2.66	2.91	0.866	9.14
NW	0.124	0.619	1.50	2.51	1.92	0.309	6.98
NNW	0.124	0.758	1.81	3.19	0.851	0.155	6.88
All Directions	3.42	10.05	25.77	34.78	21.13	5.00	100.00

TABLE E.2.7

1963 BNL ENVIRONMENTAL MONITORING

Monthly Average Ar-41 Radiation Levels, mR/wk*
Station Locations

	On-Site			Perimeter				Off-Site
Month	E-10	E-11	E-12	E-2	E-4	E-7	E-9	0-6
January	1.46	2.08	2.59	0.45	0.26	0.28	0.76	0
February	0.06	2.22	2.92	0.06	0.11	0.76	0.76	0.02
March	0.68	2.58	2.25	0.58	0.05	0.57	0.57	0.03
April	0.78	1.94	2.59	0.14	0.19	1.08	0.74	0.01
May	0.44	6.55	5.19	0.43	0.24	0.41	1.86	0.01
June	0.85	2.31	2.43	0.82	0.32	0.57	0.74	0.02
July	0.35	2.56	4.30	0.47	0.25	0.42	1.49	0.03
August	0.64	3.18	5.02	0.17	0.01	0.48	1.02	0
September	1.63	3.07	3.83	0.21	0.70	0.27	0.55	0.03
October	1.51	2.68	3.46	0.41	0.57	0.53	0.80	0.02
November	0.90	2.16	3.40	0.31	0.39	0.45	0.58	0.04
December	0.58	1.60	1.17	0.19	0.25	0.39	0.35	0.04
Average	0.82	2.74	3.26	0.35	0.28	0.52	0.85	0.02
Peak weekly average	3.23	12.91	7.57	1.97	1.94	1.63	2.29	1.08

NOTE: Estimated error at 90 percent confidence level, ±0.25 mR/wk.

*From Brookhaven National Laboratory Publication BNL 915.

TABLE E.2.8

AVERAGE ANNUAL GAMMA DOSE(mRad/yr) FOR

BGRR 1963 - PREDICTED AND OBSERVED

			Dose (mRad/yr)	
Station	Sector Calculated[3]	Distance (m)	Measured[1]	
E-2	NW	1,100	21[2]	20
E-4	WSW	2,200	14	13
E-7	SE	2,500	28	30
E-9	NE	2,750	45	34
E-10	W	520	40	42
E-11	S	420	140	122
E-12	NNE	460	158	156

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(1) Based on a 10-month average
(2) Based on a 9-month average
(3) Based on an 85 percent operation factor giving a release rate of 0.127 Ci/sec

E.3 STACK RELEASE LIMIT CALCULATIONS FOR PEACH BOTTOM SITE

The methods described previously were used in the calculations for the Peach Bottom site.

Each stack monitor consists of four channels -- a low range channel, a mid-range channel, a high range channel, and a derived effluent channel. The HIGH and HIGH-HIGH alarm set points, discussed below, fall within the range of the low range channel. The low range, mid-range, and high range channel provide their read-outs in μCi/cc, however, the derived effluent channel provides its read-out directly in μCi/sec. This relates the equivalence of the μCi/sec release rate to the resultant offsite dose rate in mrem/hr.

The stack gas radiation monitors are provided with two radiological alarm level set points -- HIGH-HIGH and HIGH. The upper set point (HIGH-HIGH), calculated in units of μCi/cc with a corresponding conversion factor in units of CPM per μCi/cc, is based on 30% of the instantaneous release rate corresponding to the annual offsite dose limits of 10 CFR Part 20 as specified in Offsite Dose Calculation Manual Specification 3.8.C.1.a, those limits being 500 mrem/yr to the whole body or 3000 mrem/yr to the skin, whichever of the two is more restrictive. The lower set point (HIGH), being a warning alarm, is based on 1% of the HIGH-HIGH alarm set point

E.3.1 Plume Rise

Characteristics of the stack off-gas exhaust system design are significant to the calculation of ground level doses. Plume height above the stack is a function of vertical momentum and buoyancy effects. Greater plume heights result in lower ground level dose effects. Credit was taken for momentum effects only since relatively little heat would be discharged through the stack.

The following values were used as input to the Holland plume rise model (modified) Equation (E.12):

Stack height (H)	500 ft (152 m); above 265 ft MSL stack grade
Inside Diameter	2.5 ft (0.762 m)
Exit Velocity	50 ft/sec (15.2 m/sec)
Correction factor (K)	1.0

Using the above data, the effective plume rise above the stack exit was calculated for various wind speeds at stack height as follows:

Wind Speed (□) (mph)	(m/sec)	Plume Rise (ΔH) (m)
0-3	1	17.4
4-7	2	8.7
8-12	5	3.5
13-18	7	2.5
>19	>10	1.7

E.3.2 Terrain Effects

In calculating downwind ground level concentrations and doses, the effective plume height above the ground must be known. As the overhead plume travels downwind toward rising terrain, the plume tends to follow the general contours of the ground. Usually, the plume would flow over and/or around any significant obstacle. However, for the sake of conservatism, the height of the terrain (Z) is subtracted from the stack height (H) plus plume rise height (ΔH). This is done for the 16 wind directions and for various distances. Table E.3.1 illustrates terrain elevations around the site.

It is from these values that the plume height above the ground was determined.

E.3.3 Whole-Body Dose Calculations

E.3.3.1 Gamma Dose

The procedure for calculating annual gamma dose consists of calculating the dose rate at various points during each different meteorological condition, weighting the dose rate by the frequency of occurrence and summing over the year to determine total dose. Calculations have shown that gamma dose rate results are not strongly dependent on atmospheric stability. This is in contrast to ground level air concentration calculations where stability is important (Figure E.3.1). As an example, Figure E.3.2 shows the difference in gamma dose rate at distances beyond 100 m. This difference does not exceed a factor of about 2. Figure E.3.2 is for an average wind speed of 5 m/sec and a plume height of 100 m, and a continuous stack release rate of 1 Ci/sec of noble gases.

Gamma dose rates as a function of wind speed for stable, neutral, and unstable conditions are shown in Figures E.3.3 through E.3.5. All curves assume a continuous stack release rate of 1 Ci/sec of noble gases. For distances less than about 800-1,000 m, the dose rate contribution from adjacent sectors should be considered. Figure E.3.6 shows such dose rates for the direction in which the plume is traveling (Sector 1) and for the adjacent directions to the right (Sectors 2,3, etc). As previously discussed, dose rates in Sectors 2 and 3 are equivalent to dose rates in Sectors 16 and 15, respectively (Figure E.2.4).

Gamma dose rate calculations were done for many downwind dose points. These dose rates were weighted by frequency of occurrence of wind speed, direction, and atmospheric stability in accordance with the observed meteorological data (subsection 2.3, Appendix N) applicable for a stack release and summed to give a total "air dose" for the year. Gamma dose rate calculations and integrated doses over a 1-yr period resulting from the radioactive source in the off-gas stack were calculated as a function of distance from the base of the stack. A tabulation of the sum of these doses is included in Table E.3.2. In all cases, dose is calculated for a fixed point (air dose) with no consideration of human occupancy or shielding. However, credit is taken for such effects in defining the actual "stack release rate limit" in the results below (paragraph E.3.3.3).

The closest site boundary in the direction of the highest dose is usually taken as the basis for determining the continuous stack release rate limit. The direction of the "maximum" calculated "fence post" dose may or may not be in the direction of existing population centers. For the Peach Bottom site, the maximum off-site dose occurs 1,060 m away from the stack towards the south-southeast (Table E.3.2). Terrain effects were considered by reducing the effective plume height for each distance and direction.

The meteorological conditions with respect to annual radioactive effluent releases from the plant stack and reactor building roof vents have been evaluated for all points on the site land boundary and along the waterline. Based on that evaluation it was determined that the point on this site boundary described above receives the maximum annual dose. Therefore, for normal plant operation, the pond can be considered as an unrestricted area.

E.3.3.2 Beta Dose

The range of beta particles in air is only a few meters. Hence, for beta calculations, a cloud of material released via a stack which expands to large dimensions at downwind distances where the cloud has reached ground level is frequently considered an "infinite" cloud. In such a cloud, the air dose rate is calculated assuming that the rate of energy release per unit volume in the cloud is equal to the rate of absorption in that volume (no buildup). The body is considered a small volume within the flux of the cloud and causes no perturbation in the flux.

Beta flux incident on the human body comes from one direction only, so that the air dose rate at the surface of the body is only one-half of that in the air. In addition, the cloud is not infinite since the ground represents a boundary to the cloud such that at the ground the cloud is a hemisphere of "infinite" radius. It approaches the "infinite" cloud at some height above the ground equal to the range of the betas in air. There is a variation in the dose rate from the head to the foot of an individual with the highest dose rate at the head. This factor varies from 1/2 at the ground to 1 at heights greater than the range of betas in air. Taylor[1] has computed this effect to show that the average dose to the body of a person 1.8 m tall is about 0.64 times the semi-infinite cloud dose. This factor applies for fixed fission products with maximum energies of about 1-2 Mev.

The following beta dose equation[2] is used and modified:

$$D_\beta = 0.457\ \overline{E}_\beta\ \chi \tag{E.16}$$

This equation is multiplied by 0.5 for the beta flux factor discussed above and by 0.64 to account for the average dose to the body. Converting Equation (E.16) into a dose rate yields the equation used in the analysis.

$$(DR)_\beta = 0.53 \times 10^6\ (\chi)\ \overline{E}\ (\text{mRad / hr}) \tag{E.17}$$

Substituting (χ^i_{avg}) for (χ) gives the average beta dose rate for the i^{th} meteorological condition. Since the range of betas in air is quite short, the annual total beta dose in a given direction is the sum of the dose rates (in mRad/hr) during each i^{th} condition accompanied by wind blowing in that direction weighted by annual frequency (in hours) of occurrence. Conversion of this dose into a dose delivered to an individual requires adjustments to take the shielding effect of clothing into account.

Table E.3.2 shows the beta dose calculated for the direction having the highest gamma dose (southeast sector) which is the direction in which the stack release limit is based. There is no dose contribution from adjacent sectors due to the short range of betas in air.

E.3.3.3 <u>Results</u>

Utilizing the site meteorological data (subsection 2.3, Appendix N), the maximum off-site dose to a fixed point can be seen on Table E.3.2 to be south-southeastward. The total ground level, whole-body radiation dose in air from a continuous stack release of 1.0 Ci/sec all year is shown in Table E.3.3. The total represents the sum of gamma and beta doses for a year to fixed point.

The stack release limit is based on the total dose to an individual from all dose contributions at a distance of 1,060 m towards the south-southeast. The maximum dose (in air) at this point is calculated to be 500 mRem/yr from a 0.42 Ci/sec continuous stack release rate. The 500 mRem/yr value is established by 10 CFR Part 20.

If an individual were present at the maximum dose point for every hour of a year, he would receive a whole-body dose of 500 mRem from the calculated stack release rate. It is incongruous to assume that an individual would be at such a location all of the time. Nevertheless, no credit has been taken for occupancy factors.

Since the 500 mRem off-site dose is a cumulative yearly dose, the stack release rate of 500 mRem/yr is an average. In order to ensure that the range of release rates averaged over 1 yr are not excessive, an upper bound to the release rate is applied for short time periods. A factor of 10 times the annual average stack release rate for a period not to exceed 15 min is used.

The following summarizes the stack release rate limits for the emission of noble radiogases:

Release Period	Stack Release Rate
Annual average continuous	0.42 Ci/sec
Short term (not to exceed 15 min)	4.2 Ci/sec

E.3.4 Internal Dose Calculations

E.3.4.1 Internal Dose from Inhalation

Internal dose from inhalation may be related directly to an annual average ground level air concentration. The average air concentration at ground level is as given in Equation (E.4) for any specific meteorological condition. Figure E.3.1 illustrates this for a 5-m/sec wind speed for various stability conditions. The annual average concentration is the sum of each of the averages for various wind speeds and stabilities weighted by their frequency of occurrence. This weighted concentration may then be compared to the maximum permissible concentration in air (MPC) given in 10CFR20, Appendix B, Table II for the isotope or mixture of isotopes of interest. These MPC values are equivalent to an annual dose to an individual of 500 mRem.

The annual average ground level air concentrations were calculated for I-131 using the site meteorological data. Table E.3.4 shows the results of calculations for eight distances (ranging from the nearest site boundary to 16,000 m) and for 16 directions.

E.3.4.2 Internal Dose from Ingestion

Radioactive materials which deposit on vegetation and on the ground can cause radiation dose from consumption of certain agricultural products. For certain food chains, concentration effects exist. One radioisotope which exhibits such effects is I-131. The appropriate food chain is air-pasture-cow-milk-infant thyroid.

On the other hand, the MPC for I-131 in air is based on exposure via the air-lung-thyroid route. The milk exposure mode is far more limiting. That is, the thyroid dose from breathing air of any given I-131 content is much less than the thyroid dose to an infant drinking milk solely from cows feeding from pastures exposed to the same air. This is a result of deposition of iodine on pasture grass, concentrating the iodine due to the large area of grass eaten by the cow, and relatively efficient transfer to the milk. This effect must be considered when relating an emission rate for iodine to an environmental dose where there are cows involved. Current U.S. practice, in context of AEC/NRC licenses associated with stack emission, assigns a reconcentration factor of 700 to I-131. Thus, for example, the MPC for I-131 in 10CFR20 is 1×10^{-10} μCi/cc for inhalation but is

$$\frac{1 \times 10^{-10}}{700}$$

for ingestion consideration for a baby, with an assumed 2-g thyroid, drinking 1 liter of milk per day.

The maximum annual average off-site air concentration is calculated to occur in a direction east of the stack at the site boundary distance of 650 m. Since this region is actually Conowingo Pond, no cows can be present. The highest site boundary ground level concentration in a direction where cows can be present is calculated to be 11.7×10^{-8} μCi/cc at 1.10 km to the southeast. I-131 establishes the maximum permissible I-131 stack release rate as 1.34 μCi/sec.

E.3 STACK RELEASE LIMIT CALCULATIONS FOR PEACH BOTTOM SITE

REFERENCES

1. "Meteorology and Atomic Energy," AECU-3066, 1955, p 100.

2. Slade, David H. (editor), "Meteorology and Atomic Energy 1968," TID-24190, July, 1968, p 100.

TABLE E.3.1

TERRAIN HEIGHT (mMSL) AROUND SITE FOR

VARIOUS DISTANCES FROM OFF-GAS STACK

Direction From Stack	Site Boundary	Distance (km) 1.6	3.2	4.8	6.4	8.0
N	76	33	33	159	177	206
NNE	33	33	122	157	152	180
NE	33	33	113	143	168	174
ENE	33	33	125	131	131	149
E	33	33	98	101	125	125
ESE	40	33	33	122	149	107
SE	91	116	101	56	116	121
SSE	104	123	116	125	125	122
S	122	125	131	140	122	99
SSW	104	131	145	140	125	159
SW	98	137	152	180	204	213
WSW	85	125	140	165	189	168
W	101	122	131	119	151	171
WNW	110	127	149	149	168	186
NW	107	119	149	143	171	165
NNW	68	122	33	137	162	171

NOTE: Tabulated terrain heights in meters mean sea level (mMSL) are subtracted from the sum of the physical stack height (in mMSL) and plume rise above the stack (m).

TABLE E.3.2

ANNUAL AVERAGE GAMMA DOSE AT GROUND LEVEL FROM CONTINUOUS

RELEASE RATE OF 1.0 Ci/sec - PEACH BOTTOM SITE

(mRem/yr)

Direction From Stack	Site Boundary (Distance)	Site Boundary (Dose)	Distance from Stack (km) 1.6	3.2	4.8	6.4	8.0
N	(0.64)*	390	262	147	165	115	90
NNE	(0.57)	245	156	166	114	68	55
NE	(0.60)	235	153	156	104	77	51
ENE	(0.62)	178	113	130	75	44	36
E	(0.65)	248	162	163	78	54	34
ESE	(0.84)	279	149	101	90	61	31
SE	(1.10)	730	479	219	98	74	47
SSE	(1.06)	940	669	277	140	81	50
S	(0.98)	740	513	207	111	60	38
SSW	(0.92)	446	370	150	75	41	32
SW	(0.72)	525	355	177	109	77	55
WSW	(0.75)	470	302	139	83	55	31
W	(0.97)	498	375	168	78	53	39
WNW	(0.92)	550	390	185	93	62	49
NW	(0.80)	660	547	247	116	90	53
NNW	(0.92)	550	384	92	93	70	51

*Numbers in parentheses are site boundary distances in km.

TABLE E.3.3

TOTAL ANNUAL GROUND LEVEL RADIATION DOSE* IN AIR

FROM STACK RELEASE RATE OF 1.0 Ci/sec - PEACH BOTTOM SITE

Distance		Dose (mRad/yr)		
Miles	Meters	Gamma (γ)	Beta (ß)	Total
0.66	1,060	940	240	1180
1	1,600	669	144	813
2	3,200	277	84	361
3	4,800	140	72	212
4	6,400	81	45	126
5	8,000	50	30	80

*The doses shown are for the direction south-southeast of the stack which give the maximum values for the closest off-site locations.

TABLE E.3.4

ANNUAL AVERAGE INTEGRATED GROUND LEVEL AIR CONCENTRATIONS

OF I-131 PEACH BOTTOM SITE

(10^{-8} μCi/cc per Ci/sec released)

Direction From Stack	Site Boundary		Distance From Stack (km)						
			0.8	1.6	3.2	4.8	6.4	8.0	16.0 [3]
N	(0.64) [1]	4.0 [2]	2.8	1.4	1.1	2.0	1.4	1.1	1.6
NNE	(0.57)	3.6	1.9	0.67	2.2	1.3	0.92	0.75	1.2
NE	(0.60)	5.3	3.1	1.2	1.1	0.93	0.86	0.73	1.3
ENE	(0.62)	3.1	1.9	0.58	0.62	0.43	0.29	0.25	1.2
E	(0.65)	15.0	10.1	3.3	2.1	1.1	0.72	0.51	1.4
ESE	(0.84)	14.0	---	4.7	1.7	1.5	0.93	0.60	1.3
SE	(1.10)	11.7	---	6.7	3.6	1.6	1.2	0.87	1.8
SSE	(1.06)	8.0	---	4.8	2.8	2.4	1.5	1.0	1.5
S	(0.98)	4.6	---	3.8	2.2	1.2	0.81	0.60	1.3
SSW	(0.92)	2.0	---	2.5	1.6	0.92	0.60	0.44	0.70
SW	(0.72)	2.2	2.1	2.4	1.8	1.0	0.71	1.0	0.74
WSW	(0.75)	2.1	2.1	2.2	1.4	0.93	0.65	0.51	0.64
W	(0.97)	2.3	---	2.8	1.7	1.0	0.66	0.62	0.76
WNW	(0.92)	1.2	---	2.4	1.7	0.98	0.84	0.66	0.96
NW	(0.80)	1.5	---	3.2	2.2	1.3	1.1	0.89	1.3
NNW	(0.92)	1.1	---	1.3	0.57	1.0	0.95	0.77	1.2

[1] Numbers in parentheses are site boundary distances in km.
[2] Each number is to be multiplied by 10^{-8}. Example: 4.0×10^{-8} μCi/cc.
[3] Assumption made that stack plume and terrain height are equal at 16 km. In all cases the concentration decreases beyond this distance. However, terrain would not equal or exceed plume height in every direction, but was conservatively assumed.

E.4 BUILDING EXHAUST VENT RELEASE

The ventilation air from a reactor building is routed to a common release location just higher than the top of the reactor building. The air within the secondary containment reactor building is designed to be relatively free from radioactive material. In this case the ventilation air leaving such a clean environment would contribute nothing to the annual average doses beyond the site perimeter. However, recent licensing trends by the AEC/DRL have required that an analysis be performed for such a "potential" release. Such an analysis has been done assuming that the roof top release of "clean" air contained a certain amount of activity resulting in an off-site dose of 500 mRem/yr.

In performing this analysis, it was assumed that one-half of the time the "plume" traveled horizontally downwind from the duct top; the rest of the time the plume experienced downwash in the turbulent wake of the reactor building complex. This certainly is conservative since the plume would rise above the duct top prior to bending over and traveling downwind. The resulting release rate over the year could amount to 0.22 Ci/sec without exceeding the 10CFR20 annual dose to people. This release rate, in combination with the stack release rate of 0.42 Ci/sec, would not exceed 500 mRem/yr when combined as shown in subsection E.5.

E.5 ALL SOURCES OF AIRBORNE RADIOACTIVITY

See paragraphs 9.4.4.2 and 9.4.4.5 and 9.2.4.5.

E.6 SUMMARY

The method of calculating a stack release limit is given along with partial verification of the method using data from Brookhaven National Laboratory. The whole-body gamma dose calculations are quite close to that observed at Brookhaven. The ground level integrated air concentration calculations give an order of magnitude type of verification due to the lack of sensitive field measurements.

Table E.6.1 shows the release limits from all the release points of Units 2 and 3. Each release point is monitored as described in subsection 7.12 for Units 2 and 3.

The alarm set points are set so that the total release satisfies the conditions of Table E.6.1 even if all release points were to be discharging at their alarm set points.

Radioactive releases are documented through analyses of filter depositions, analyses of grab samples, and strip chart recorder records.

The stack release limit calculation was performed for the Peach Bottom site using the Peach Bottom Site meteorological data. Calculations include whole-body dose from the noble gases and internal dose from I-131. It is concluded that the noble gases dominate and that the control of emission should be on these constituents of the stack effluent.

The calculated annual average stack release rate limits are conservative since human occupancy and shielding factors are not included. Table E.6.1 shows the stack release rates for Units 2 and 3 combined (Q_2+Q_3) and the Unit 2 and 3 roof vents (Q_{RS_2} and Q_{RS_3})

The annual average release rate of I-131 for consideration of postulated exposure via the milk production and consumption mode is calculated to be 1.34 μCi/sec. Table E.6.2 shows the I-131 release rates for the off-gas stack and roof vents.

It is recognized that precise determination of dose from a certain emission from the stack is only possible by direct measurement. Such information is provided by the environmental monitoring program conducted at and around the site. If the stack emission ever reaches a level such that it is measureable in the environment, such measurements will provide a basis for adjusting the proposed stack limit long before the effect in the environment is of any safety concern. In this regard, it is important to realize that averaging the emission rate over a period of 1 year as permitted by 10CFR20 represents a very large safety margin between conditions existing at any one instant (any minute, hour, or day) and the long-term dose of interest.

TABLE E.6.1

NOBLE GAS RELEASE RATE LIMITS

Release Period	
Annual Average continuous	$$\frac{Q_2 + Q_3}{0.42} + \frac{Q_{RS2}}{0.22} + \frac{Q_{RS3}}{0.22} \leq 1$$
Short term not to exceed 15 min	$$\frac{Q_2 + Q_3}{4.2} + \frac{Q_{RS2}}{2.2} + \frac{Q_{RS3}}{2.2} \leq 1$$

NOTES:

1. Vent release limits do not correspond with current PBAPS Technical Specifications based on results of Unit 2 Vent Plume Behavior Study for PBAPS, March, 1974.

2. Terms on left side of inequality sign are in units of Ci/sec of noble gases.

3. $Q_2 + Q_3$ is the off-gas stack release rate for Units 2 and 3 combined.

4. Q_{RS_2} and Q_{RS_3} are the release rates for the roof vents on Units 2 and 3, respectively.

5. Annual average continuous release rates for gases are equivalent to a "fence post dose" of 500 mRem/yr (10CFR20.105a).

TABLE E.6.2

I-131 RELEASE RATE LIMITS

Release Period	
Annual average continuous	$\frac{Q_2 + Q_3}{1.34} + \frac{Q_{RS_2}}{0.0143} + \frac{Q_{RS_3}}{0.0143} \leq 1$

NOTES:

1. Vent release limits do not correspond with current PBAPS Technical Specifications based on results of Unit 2 Vent Plume Behavior Study for PBAPS, March, 1974.

2. Terms on left side of inequality sign are in units of μCi/sec of I-131.

3. Annual average continuous release rates are equivalent to the adjusted MPC for I-131 considering the milk consumption mode of exposure, i.e., $\frac{1x10^{-10}}{700}$ μCi/cc.