SEABROOK STATION

OFFSITE DOSE CALCULATION MANUAL

ATMOSPHERIC DIFFUSION AND DEPOSITION FACTORS

by

Robert B. Harvey, Jr.

January 1990

Yankee Atomic Electric Company
Nuclear Services Division
580 Main Street
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1.0 INTRODUCTION

The purpose of the Seabrook Station Offsite Dose Calculation Manual (ODCM) is to identify the equipment, methods, equations, and data used to verify compliance with the effluent release limits specified in the Seabrook Station Technical Specifications. Included as part of Section 7.0 of the ODCM is a table of the atmospheric diffusion and deposition factors used to calculate the offsite doses and radionuclide concentrations necessary to determine compliance with the dose and dose rate requirements of the Technical Specifications which implement 10CFR20 and 10CFR50 Appendix I dose criteria. The intent of this document is to present a technical description of the methodology used to generate the Seabrook Station ODCM atmospheric diffusion and deposition factors.

2.0 DETAILS OF CALCULATION

Seabrook Station Offsite Dose Calculation Manual (ODCM) atmospheric diffusion and deposition factors were computed for routine continuous and randomly distributed batch releases using the AEOLUS-2 computer code (Reference 1). AEOLUS-2 is based, in part, on the constant mean wind direction model with Gaussian diffusion as presented in Regulatory Guide 1.111 (Reference 2) and as implemented by the NRC XOQDOQ computer code (Reference 3).

Four types of atmospheric diffusion and deposition factors were generated by AEOLUS-2 for use within the Seabrook Station ODCM:

1. *Undepleted CHI/Q factors* which convert noble release rates (Ci/sec) to ground level concentrations (Ci/m^3).
2. *Depleted CHI/Q factors* which convert iodine and particulate release rates (Ci/sec) to ground level concentrations (Ci/m^3).
3. *D/Q factors* which convert iodine and particulate releases (Ci) to ground deposition per unit area (Ci/m^2).
4. *Gamma CHI/Q factors* which are used to convert noble gas release rates (Ci/sec) to whole body gamma dose rates (mrem/sec) utilizing the sector-average gamma dose model presented in Section 7-5 of Meteorology and Atomic Energy - 1968 (Reference 4). [The standard gamma dose rate equation for a semi-infinite cloud can be converted to a finite cloud gamma dose rate equation by replacing undepleted CHI/Q factors in the semi-infinite cloud dose rate equation with gamma CHI/Q factors.]

Two categories of potential release pathways were considered: (i) a 'generic' ground-level release pathway (indicative of Condenser Air Evacuation and Chemistry Lab Hood Vents releases); and, (ii) a Primary Vent Stack release pathway. The following assumptions were used in generating diffusion and deposition factors for each of the two release pathways:

- Sector-average atmospheric diffusion and deposition factors were used (e.g., the plume was assumed to be distributed evenly horizontally across a 22.5-degree wide direction sector).
- Recirculation correction factors were applied to consider the effects of spatial and temporal variations in airflow which can occur during prolonged periods of atmospheric stagnation and during the onset and decay of seabreezes.
- The ground-level release pathway was treated as a Regulatory Guide 1.111 ground-mode release occurring below the height of adjacent buildings.
- The Primary Vent Stack release pathway was treated as a Regulatory Guide 1.111 mix-mode release occurring above (but less than 2 times above) the height of adjacent buildings.
- Onsite lower level wind speed data were used to evaluate diffusion and deposition conditions for both release pathways. These data were used 'as is' to disperse the plume for the ground-level release pathway and the ground-mode portion of the Primary Vent Stack release pathway. These data were extrapolated upwards to the Primary Vent Stack release height for evaluating the potential for plume entrainment and for determining plume rise and dispersion for the elevated-mode portion of the Primary Vent Stack release pathway.
- Onsite lower level wind direction data were used to determine plume transport (e.g., affected downwind sector) for both release pathways.
- Atmospheric stability was determined as a function of vertical temperature difference using the onsite 209'-43' delta-temperature measurements.

- The effect of the Thermal Internal Boundary Layer (TIBL) coastal site phenomenon on plume dispersion was evaluated for both release pathways. TIBLs were assumed to occur from April through September between the hours of 08:00 and 18:00 whenever solar radiation was above 0.35 langley/min, wind speed was between 2 and 10 m/sec, and the wind was from the northeast clockwise through south-southeast.
- The Regulatory Guide 1.111 depletion/deposition model was used for determining depleted CHI/Q and D/Q values for both release pathways.
- Wet depletion/deposition and decay-in-transit were not considered.
- The gamma energy spectrum used to generate the gamma CHI/Q values was derived using the gamma energy spectrum associated with the projected annual noble gas release rates for each release pathway as presented in Section 3.5 of the Seabrook Station Environmental Report - Operating License Stage (ER-OLS).

Average diffusion and deposition factors were generated using on-site meteorological data from the six-year period January 1980 through December 1983 and January 1987 through December 1988 (with the exception that April 1980 and May 1980 data were substituted with April 1979 and May 1979 data because of low data recovery rates) by compiling a joint frequency distribution of wind speed, wind direction, and atmospheric stability for both TIBL and TIBL/non-TIBL conditions. Corresponding diffusion and deposition factors for each wind speed/wind direction/stability class combination were generated. Average diffusion and deposition factors were then calculated for each receptor as a function of the frequency of wind speed/wind direction/stability combinations applicable to the receptor's location.

Specific details on the compilation of the meteorological data joint frequency distributions and the resulting average diffusion and deposition factors are provided in the subsections which follow.

2.1 Meteorological Data Joint Frequency Distributions

Hourly meteorological data records consisting of lower level wind speed, lower level wind direction, and 209'-43' vertical temperature difference (delta-temperature) data were used to generate joint frequency summaries of stability class i, wind speed group j, and wind direction sector k for both TIBL and TIBL/non-TIBL conditions as follows:

2.1.1 Atmospheric Stability Classes

Atmospheric stability classes (Pasquill Categories A through G) were determined as a function of vertical temperature difference using the onsite 209'-43' delta-temperature measurements and the atmospheric stability classification criteria outlined in Regulatory Guide 1.23 (Reference 5).

2.1.2 Wind Speed Groups

Lower level wind speed data were utilized to generate wind speed frequency distributions for both the ground-level and Primary Vent Stack release pathways. In accordance with Regulatory Guide 1.111 guidance, the wind speed data were divided into 12 wind speed classes which approximated the Beafort wind scale. The lowest wind speed group represented calm conditions, defined as wind speeds less than the anemometer/wind vane threshold wind speed of 0.5 mph. A group-average wind speed of 0.25 mph (half the anemometer/wind vane threshold wind speed) was assigned to this first wind speed group. For all other wind speed groups, the average wind speed was determined for each wind speed group j as a function of stability class i. These group-average ground-level wind speeds $u_g(i,j)$ were used to disperse the plume for the ground-level release pathway and the ground-mode portion of the Primary Vent Stack mix-mode release pathway.

In order to perform dispersion analysis for the elevated-mode portion of the Primary Vent Stack release pathway, the group-average ground-level wind speeds $u_g(i,j)$ were extrapolated to the Primary Vent Stack release height of 57.9 m above plant grade as follows:

$$u_e(i,j) = u_g(i,j) * [57.9m/10.0m]^{q(i)}$$

where $u_e(i,j)$ is the group-average elevated wind speed (considered to be representative of conditions at the Primary Vent Stack release height) and $q(i)$ is a stability-dependent power coefficient. In line with the XOQDOQ computer code, $q(i)$ was defined as 0.25 for stability classes A, B, C, and D and 0.50 for stability classes E, F, and G.

2.1.3 Wind Direction Sectors

The hourly wind direction data were classified into 16 compass point sectors (e.g., 22.5-degree wide sectors) centered on true north, north-northeast, etc. Wind directions during calm conditions (e.g., hours with wind speeds less than 0.5 mph) for any given stability were distributed to the various sectors in proportion to the sector-dependent observations in the second wind speed group for that stability.

2.1.4 TIBL Conditions

For coastal sites such as Seabrook, a Thermal Internal Boundary Layer (TIBL) can form under conditions of seabreeze or onshore gradient flow which can limit the vertical mixing depth of the plume. During certain times of the year when offshore water temperatures are relatively low, a cool and stable air mass can form over the cold water surface. During an onshore flow, this cool and stable marine air can be heated from below by a warmer land surface and become unstable in the lower levels. The layer of unstable air beneath the stable marine air is known as the TIBL and tends to increase in depth with inland distance. For releases occurring within the TIBL, the material is trapped within the TIBL. This lid will limit the mixing volume to a greater extent than the average mixing depth for the area around the site and can result in higher ground-level concentrations.

The following criteria were established for the formation of TIBLs:

- TIBLs were assumed to occur only during the time of year when the land-water temperature difference was assumed suitable for TIBL formation. A TIBL season from April through September was assumed appropriate for the Seabrook site.
- TIBLs can occur only during daytime when there is sufficient solar intensity to generate a TIBL. Consequently, TIBL occurrence was limited to between the hours of 08:00 and 18:00.
- The wind direction must be onshore with an overwater fetch sufficiently long to stabilize the marine air mass. Consequently, TIBL occurrence was limited to time periods where the wind direction was from the northeast clockwise to south-southeast sectors.
- The wind speed must be in an appropriate range. Too low a wind speed will not support a TIBL; too high a wind speed will result in generating mechanical turbulence which will overcome any thermal effects resulting in a TIBL. Consequently, TIBL occurrence was limited to time periods where wind speeds were between 2 and 10 m/sec. (Note that the check on wind-speed for the identification of TIBLs was applied to the data in the hourly meteorological file, not to the group-average wind speed values).
- Solar radiation must be sufficiently strong since it is the heating of the land which causes the development of a TIBL. Consequently, TIBL occurrence was limited to time periods when a minimum of 0.35 langley/min were recorded.

A separate joint frequency distribution $f_s(i,j,k)$ representing the number of observations of stability class i, wind speed group j, and wind direction sector k during TIBL conditions was compiled. Since one of the parameters needed in TIBL analysis is the intensity of solar radiation for determining TIBL height, average solar radiation values were compiled for each array position in the $f_s(i,j,k)$ joint frequency distribution.

2.2 Diffusion and Deposition Factor Averages

Average diffusion and deposition factors for each receptor location were determined as follows:

$$\overline{DF}(k,x) = [C(x)/f_t] \sum_{i,j} ([f(i,j,k) - f_s(i,j,k)] * DF(i,j,k,x))$$

$$+ [C(x)/f_t] \sum_{i,j} (f_s(i,j,k) * DF_s(i,j,k,x))$$

where:

$\overline{DF}(k,x)$ = average diffusion factor of interest (e.g., undepleted CHI/Q, depleted CHI/Q, D/Q, or gamma CHI/Q) for receptor located at in directional sector k at downwind distance x

$C(x)$ = recirculation correction factor for downwind distance x

f_t = total number of observations in the joint frequency distribution $f(i,j,k)$

$f(i,j,k)$ = number of observations in the joint frequency distribution with stability class i, wind speed group j, and wind direction sector k (TIBL and non-TIBL conditions)

$f_s(i,j,k)$ = number of observations in the joint frequency distribution with stability class i, wind speed group j, and wind direction sector k (TIBL conditions only)

DF(i,j,k,x) = diffusion factor of interest in directional sector k at downwind distance x in directional sector k for stability class i and wind speed group j during non-TIBL conditions

$DF_s(i,j,k,x)$ = diffusion factor of interest at downwind distance x in directional sector k for stability class i and wind speed group j during TIBL conditions

The fundamental equations used to determine the diffusion factors DF(i,j,k,x) and $DF_s(i,j,k,x)$ are described in the subsections which follow. A description of the recirculation correction factors C(x) is provided in Subsection 2.3.9.

2.3 Diffusion and Deposition Factor Models

2.3.1 Undepleted CHI/Q

The equation used to determine undepleted diffusion factors $CHI/Q_u(i,j,k,x)$ (sec/m^3) in direction sector k at a downwind distance x for stability class i and wind speed class j was as follows:

$$CHI/Q_u(i,j,k,x) = E_t(i,j) * CHI/Q_{ug}(i,j,k,x) + [1-E_t(i,j)] * CHI/Q_{ue}(i,j,k,x)$$

where the subscripts "g" and "e" stand for "ground-mode" and "elevated-mode" releases and $E_t(i,j)$ is the plume entrainment coefficient. The ground-mode and elevated-mode undepleted diffusion factors $CHI/Q_{ug}(i,j,k,x)$ and $CHI/Q_{ue}(i,j,k,x)$ were defined as follows:

$$CHI/Q_{ug}(i,j,k,x) = \frac{2.032}{u_g(i,j)*\Sigma_z(i,x)*x}$$

$$* \sum_{J=-5}^{5} \exp - ([2]^{0.5} * J * L(i,j,k,x)/\Sigma_z(i,x))^2$$

$$CHI/Q_{ue}(i,j,k,x) = \frac{2.032}{u_e(i,j) * \sigma_z(i,x) * x}$$

$$* \sum_{J=-5}^{5} \exp - ([2]^{-0.5} * h_e(i,j,k,x)/\sigma_z(i,x) + [2]^{0.5} * J * L(i,j,k,x)/\sigma_z(i,x))^2$$

where:

x = downwind distance (m) from the release point

$u_g(i,j)$ = group average ground-level wind speed (m/sec) for stability class i and wind speed group j

$u_e(i,j)$ = group average elevated wind speed (m/sec) for stability class i and wind speed group j (representative of conditions at the Primary Vent Stack release height)

$\sigma_z(i,x)$ = vertical plume standard deviation (m) at downwind distance x and stability class i

$\Sigma_z(i,x)$ = vertical plume standard deviation (m) at downwind distance x and stability class i corrected for building wake effects

$h_e(i,j,k,x)$ = effective plume height above ground (m) as a function of stability class i and wind speed class j in direction sector k at a downwind distance x

$L(i,j,k,x)$ = mixing layer depth (m) as a function of stability class i and wind speed class j in direction sector k at a downwind distance x

The generation of the group average wind speeds $u_g(i,j)$ and $u_e(i,j)$ was discussed in Section 2.1.2. Details on the definitions of the remaining parameters are given in the subsections that follow.

2.3.2 Depleted CHI/Q

The equation used to determine depleted diffusion factors $CHI/Q_d(i,j,k,x)$ (sec/m^3) for downwind distance x in direction sector k for stability class i and wind speed group j was as follows:

$$CHI/Q_d(i,j,k,x) = E_t(i,j) * CHI/Q_{ug}(i,j,k,x) * D_g(x)$$
$$+ [1-E_t(i,j)] * CHI/Q_{ue}(i,j,k) * D_e(i,j,k,x)$$

where $D_g(x)$ and $D_e(i,j,k,x)$ were the dry depletion factors for ground-mode and elevated-mode portions of the plume, respectively, for downwind distance x in direction sector k for stability class i and wind speed group j.

The dry depletion factors $D_g(x)$ and $D_e(i,j,k,x)$ used were based on the dry depletion factors presented in Figures 2 through 5 of Regulatory Guide 1.111 as represented by analytical expressions provided in the XOQDOQ computer code. (Regulatory Guide 1.111 Figures 2 through 5 represent depletion factors for release heights of 0 m, 30 m, 60 m, and 100 m, respectively.) A description of the procedure employed for determining the appropriate depletion correction factors $D_g(x)$ and $D_e(i,j,k,x)$ from Regulatory Guide 1.111 Figures 2 through 5 follows.

The ground-mode dry deposition correction factors $D_g(x)$ were computed at the downwind distance of interest x using a stability-independent analytical expression corresponding to the single curve in Figure 2 of Regulatory Guide 1.111.

The elevated-mode dry deposition correction factors $D_e(i,j,k,x)$ were computed at downwind distance x in direction sector k for stability class i and wind speed group j using a modified effective plume height $h_e'(i,j,k,x)$

defined as:

$$h_e'(i,j,k,x) = [h_s + h_{pr}(i,j,x) - c(i,j)] - 0.5*h_t(k,x)$$

where the parameters stack height h_s, plume rise $h_{pr}(i,j,x)$, downwash correction factor $c(i,j)$, and maximum terrain height $h_t(k,x)$ are discussed in Subsection 2.3.7.

The above expression represents the use of an average terrain height between the release point and the receptor. This expression was used with the limiting conditions that $0\ m \leq h_e'(i,j,k,x) \leq 100\ m$. Dry depletion correction factors for three different plume heights h were computed for the downwind distance of interest x using the stability-dependent analytical expressions for Figures 2 through 5 of Regulatory Guide 1.111 as follows:

if $h_e'(i,j,k,x) \leq 30$ m, h = 0, 30, and 60 m

if $h_e'(i,j,k,x) > 30$ m, h = 30, 60, and 100 m

The three computed depletion correction factors were then converted to logarithms and subjected to parabolic interpolation for computation of the correct factor $D_e(i,j,k,x)$ at the desired height $h_e'(i,j,k,x)$. Due to the limiting condition that $h_e'(i,j,k,x) \leq 100$ m, extrapolation of the data to effective plume heights greater than 100 m was not allowed.

2.3.3 D/Q

The equation used to determine deposition factors D/Q(i,j,k,x) ($1/m^2$) in direction sector k at downwind distance x for atmospheric stability class i and wind speed group j was as follows:

$$D/Q(i,j,k,x) = \frac{8}{\pi*x} * (E_t(i,j)*P_g(x) + [1-E_t(i,j)]*P_e(i,j,k,x))$$

where $P_g(x)$ and $P_e(i,j,k,x)$ are the relative deposition rates (1/m) for ground-mode and elevated-mode portions of the plume, respectively, for downwind distance x in direction sector k for stability class i and wind speed group j. The relative deposition rates $P_g(x)$ and $P_e(i,j,k,x)$ used were based on the relative deposition rates presented in Figures 6 through 9 of Regulatory Guide 1.111 as represented by analytical expressions provided in the XOQDOQ computer code. (Regulatory Guide 1.111 Figures 6 through 9 represent relative deposition rates for release heights of 0 m, 30 m, 60 m, and 100 m, respectively.) The procedure employed for determining the appropriate relative deposition rates $P_g(x)$ and $P_e(i,j,k,x)$ from Regulatory Guide 1.111 Figures 6 through 9 was similar to the procedure used to determine the appropriate dry deposition factors $D_g(x)$ and $D_e(i,j,k,x)$ from Regulatory Guide 1.111 Figures 2 through 5 as described in Section 2.3.2.

2.3.4 Gamma CHI/Q

Gamma diffusion factors $CHI/Q_\gamma(i,j,k,x)$ were generated for downwind distance x in direction sector k for stability class i and wind speed group j using the following expression:

$$CHI/Q_\gamma(i,j,k,x) = \frac{\sum_r E(r) * A(r) * CHI/Q_\gamma(i,j,k,r,x)}{\sum_r E(r) * A(r)}$$

$$A(r) = \frac{\sum_n Q'(n) * A(r,n)}{\sum_n Q'(n)}$$

where:

$Q'(n)$ = release rate (e.g., Ci/yr) of nuclide n (used to indicate the relative concentration of nuclide n in the plume)

$E(r)$ = median energy level (Mev) of gamma photon energy group r

$A(r,n)$ = photon yield (photo/dis) of gamma-ray photons in energy group r due to the decay of nuclide n in the plume

$A(r)$ = photon yield (photo/dis) of gamma-ray photons in energy group r due to the decay of all nuclides in the plume (used to indicate the relative abundance of energy group r photons in the plume)

The plume nuclide/mixture was derived from the estimates of annual noble gas releases as presented in Section 3.5 of the Seabrook Station Environmental Report - Operating License Stage (ER-OLS). These annual isotopic release rates (Ci/yr) are provided in Exhibit 1. A table of isotope-dependent photon production rates for 16 different energy groups was then used along with the plume's estimated nuclide mixture to determine the relative abundance A(r) of each energy group's photons in the plume. The resulting 16 energy group spectrum was then reduced to an eight group energy spectrum for the purposes of calculating the energy-dependent gamma diffusion factor $CHI/Q_\gamma(i,j,k,r,x)$.

The energy-dependent gamma diffusion factors $CHI/Q_\gamma(i,j,k,r,x)$ were determined as follows:

$$CHI/Q_\gamma(i,j,k,r,x) = E_t(i,j) * CHI/Q_{\gamma g}(i,j,k,r,x) + [1-E_t(i,j)] * CHI/Q_{\gamma e}(i,j,k,r,x)$$

where the ground-mode and elevated-mode energy-dependent gamma diffusion factors $CHI/Q_{\gamma g}(i,j,k,r,x)$ and $CHI/Q_{\gamma e}(i,j,k,r,x)$ were defined as:

$$CHI/Q_{\gamma g}(i,j,k,r,x) = \frac{2 * \mu_a(r) * [I_{1g}(i,r,x) + K(r)*I_{2g}(i,r,x)]}{[\pi]^{0.5} * u_g(i,j) * x * [\pi/8]}$$

$$* \sum_{J=-5}^{5} \exp - ([2]^{0.5} * J * L(i,j,k,x)/\Sigma_z(i,x))^2$$

$$CHI/Q_{\gamma e}(i,j,k,r,x) = \frac{2 * \mu_a(r) * [I_{1e}(i,j,k,r,x) + K(r)*I_2(i,j,k,r,x)]}{[\pi]^{0.5} * u_e(i,j) * x * [\pi/8]}$$

$$* \exp ([2]^{-0.5} * h_e(i,j,k,x)/\sigma_z(i,x))$$

$$* \sum_{J=-5}^{5} \exp - ([2]^{-0.5} * h_e(i,j,k,x)/\sigma_z(i,x) + [2]^{0.5} * J * L(i,j,k,x)/\sigma_z(i,x))^2$$

where $\mu_a(r)$ is the linear energy absorption coefficient for air (1/m) at energy E(r) and K(r) is the buildup factor for air defined as $[\mu(r) - \mu_a(r)]/\mu_a(r)$ where $\mu(r)$ is the linear attenuation coefficient for air (1/m) at energy E(r).

Parameters $I_{1g}(i,r,x)$, $I_{2g}(i,r,x)$, $I_{1e}(i,j,k,r,x)$, and $I_{2e}(i,j,k,r,x)$ are integrals defined by Healy and Baker in Section 7-5.2.5 in Meteorology and Atomic Energy - 1968 (Reference 4). These integrals account for the dispersion of the plume and are functions of vertical plume standard deviation (σ_z for I_{1g} and I_{2g}; Σ_z for I_{1e} and I_{2e}), effective plume height h_e, and photon energy E(r).

Further details on the derivation of the gamma diffusion factor and the calculation of the I_1 and I_2 intervals can be found in References 1 and 6.

2.3.5 Plume Standard Deviations and Building Wake Effects

The algorithms used to determine vertical plume standard deviation $\sigma_z(i,x)$ were the same as those utilized by computer code XOQDOQ for non-desert conditions.

For ground-mode portion of any release, consideration was also given to additional dispersion of the effluent plume within the wake caused by the buildings adjacent to the release point. In such cases, use was made of an adjusted vertical standard deviation $\Sigma_z(i,x)$ defined as:

$$\Sigma_z(i,x) = [\sigma_z(i,x)^2 + 0.5*h_b^2/\pi]^{0.5}$$

where h_b is the height of the building causing additional dispersion. A value of 23.8 m was used representing the Heater Bay and Control Building roof heights. The maximum value of $\Sigma_z(i,x)$ was restricted by the condition:

$$\Sigma_z(i,x) \leq [3]^{0.5}*\sigma_z(i,x)$$

2.1.6 Entrainment

According to Regulatory Guide 1.111, effluents can be considered to be ground-mode releases $[E_t(i,j) = 1]$, elevated-mode releases $[E_t(i,j) = 0]$, or mixed-mode releases $[0 < E_t(i,j) < 1]$ depending on: (a) the elevation of the release point relative to the height of adjacent solid structures, and (b) the effluent vertical exit velocity relative to the speed of the prevailing wind at the height of release.

Releases from the ground-level release pathway were assumed to occur below the tops of adjacent buildings. Consequently, $E_t(i,j) = 1$ for ground-level releases.

Primary Vent Stack releases occur at a height of approximately 3.4 m above the height of the containment structure, the highest building on-site. Consequently, Primary Vent Stack releases qualified as a mixed-mode release pathway based on Regulatory Guide 1.111 criteria. The entrainment coefficient for Primary Vent Stack releases was therefore defined as follows:

$$E_t(i,j) = 1.0 \quad \text{when} \quad W_o/u_e(i,j) \le 1.0$$

$$E_t(i,j) = 2.58 - 1.58\, W_o/u_e(i,j) \quad \text{when} \quad 1.0 < W_o/u_e(i,j) \le 1.5$$

$$E_t(i,j) = 0.30 - 0.06\, W_o/u_e(i,j) \quad \text{when} \quad 1.5 < W_o/u_e(i,j) \le 5.0$$

$$E_t(i,j) = 0.0 \quad \text{when} \quad 5.0 < W_o/u_e(i,j)$$

where W_o is the Primary Vent Stack effluent exit velocity. An exit velocity of 12.9 m/sec (representing a flow rate of 272,665 cfm) was used to represent W_o.

2.3.7 Effective Plume Height

Ground-level releases and the ground-mode portion of the Primary Vent Stack releases were assumed to have effective plume heights equal to zero. In accordance with Regulatory Guide 1.111, the effective plume height for the elevated portion of Primary Vent Stack release was defined as:

$$h_e(i,j,k,x) = h_s + h_{pr}(i,j,x) - h_t(k,x) - c(i,j)$$

where:

$h_e(i,j,k,x)$ = effective plume height (m above receptor grade) at distance x in downwind sector k for stability class i and wind speed group j

h_s = Primary Vent Stack height (57.9 m above plant grade)

$h_{pr}(i,j,x)$ = plume rise above the release point (m) at distance x for stability class i and wind speed group j

$h_t(k,x)$ = maximum terrain height (m above plant grade) between the release point and the receptor located at downwind distance x in direction sector k [$h_t \ge 0$]

$c(i,j)$ = downwash correction factor (m) for low relative exit velocity as a function of stability class i and wind speed group j

The downwash correction factor c(i,j) is defined as:

$$c(i,j) = 3*[1.5 - W_o/u_e(i,j)]*d \quad \text{when} \quad W_o/u_e(i,j) < 1.5$$

$$c(i,j) = 0 \quad \text{when} \quad W_o/u_e(i,j) \geq 1.5$$

where d is the effective inside diameter of the Primary Vent Stack (3.57 m).

Only non-buoyant plumes were assumed to emanate from the Primary Vent Stack. Consequently, the momentum jet equations adopted from the XOQDOQ computer code were utilized as outlined below to determine plume rise h_{pr}.

For neutral and unstable conditions, plume rise was computed from the following two equations:

$$h_{pr}(i,j,x) = 1.44 * [W_o/u_e(i,j)]^{0.667} * [x/d]^{0.333} * d$$

$$h_{pr}(i,j) = 3 * [W_o/u_e(i,j)] * d$$

and the lesser (more conservative) value used.

For stable conditions, the results of the previous two equations were compared with the results from the following two equations:

$$h_{pr}(i,j) = 4 * [F_m/S_m(i)]^{0.25}$$

$$h_{pr}(i,j) = 1.5 * [F_m/u_e(i,j)]^{0.333} * S_m(i)^{-0.167}$$

and the smallest value of h_{pr} was used. In the last two equations, F_m is the momentum flux parameter defined as:

$$F_m = (W_o*d/2)^2$$

and $S_m(i)$ is the restoring acceleration per unit vertical displacement for adiabatic motion in the atmosphere (sec^{-2}). In line with the XOQDOQ computer code, $S_m(i)$ is defined as 8.7×10^{-4} for E stability, 1.75×10^{-3} for F stability, and 2.45×10^{-3} for G stability.

2.3.8 Mixing Depths

Vertical diffusion of the plume can be inhibited by the existence of a stable atmospheric layer (an elevated inversion) aloft. The rate of vertical mixing is reduced in such cases and the stable layer can be considered as an effective lid on vertical transport of pollutants.

For the determination of diffusion factors during non-TIBL conditions, the mixing layer height L(i,j,k,x) was assigned a value of 900 m based on the average of the mean annual morning and mean annual afternoon mixing layer heights for the Seabrook site region as reported by Holzworth (Reference 7).

For TIBL conditions, the mixing layer height L(i,j,k,x) was assigned a value equal to the height of the TIBL as predicted by the following relationship:

$$L(i,j,k,x) = h_{tibl}(i,j,k,x)$$
$$= 1.79\ [(x+x_s(k)) * SR(i,j,k)]^{0.5} + 83.33$$

where $h_{tibl}(i,j,k,x)$ is the height (m) of the TIBL layer above ground in direction sector k at distance x for stability class i and wind speed group j, $x_s(k)$ is the upwind distance from the shoreline to the release point whenever the wind is blowing towards direction sector k, and SR(i,j,k) is the average solar radiation intensity (langley/min) for stability class i, wind speed group j, and direction sector k.

This relationship for $h_{tibl}(i,j,k,x)$ was derived from a field study conducted by Lebeis and Foltman at the Fermi-2 Nuclear Power Plant site on the western shore of Lake Erie (References 8 and 9). Lebeis and Foltman tested several different parameters to account for observed TIBL height variation (including overland fetch, land/water temperature differences, solar radiation, wind direction, wind direction standard deviation, wind speed, frictional velocity, and overwater vertical temperature gradient) and found that overland fetch and solar radiation were the top ranked parameters. Support for an equation of this form can also be found in NUREG/CR-3542 (Reference 10).

Note that the above equation defines a TIBL height of 83.33 m at the coastline, due to the heating of the onshore flow by warmer water near the coastline. Consequently, all releases (including those from the 57.9 m high Primary Vent Stack) are assumed to occur beneath the TIBL. The plume is not allowed to punch through the TIBL even though the plume rise equations may predict so. Also note that TIBLs are assume to follow the terrain and are not allowed to exceed the 900 m mixing layer height discussed previously.

2.3.9 Recirculation Correction Factors

In order to consider the effects of spatial and temporal variations in airflow such as recirculation which can occur during prolonged periods of atmospheric stagnation and during the onset and decay of seabreezes, recirculation correction factors C(x) were applied in defining each type of diffusion factor as a function of downwind distance x. The recirculation correction factors used were based on the 'open terrain' correction factors published in Rev. 0 to Regulatory Guide 1.111 (Reference 11) (See Exhibit 2). These recirculation correction factors are compatible with site-specific factors generated at other coastal sites (e.g., Perry and St. Lucie No. 2).

3.0 RESULTING DIFFUSION AND DEPOSITION FACTORS

Diffusion and deposition factors for the ground-level and Primary Vent Stack release pathways were calculated for the Site Boundary and two onsite locations: 'The Rocks' and the Ed Center. In order to determine the maximum offsite diffusion and deposition factors for the mixed-mode Primary Vent Stack release pathway, diffusion and deposition factors were also calculated at 0.25 mile increments from the stack starting beyond the site boundary out to five miles. The following criteria were used to determine receptor downwind distances and direction sectors:

1. Ground-Level Release Pathway
   - *'The Rocks' and Ed Center:* The minimum distances from the nearest point on the Administration Building/Turbine Building complex to 'The Rocks' and Ed Center as measured from a site aerial photograph were used.
   - *Site Boundary:* For the south-southeast clockwise to north downwind sectors, the minimum distances from the nearest point on the Administration Building/Turbine Building complex to the site boundary within a 45-degree sector centered on the compass direction of interest as measured from Seabrook Station FSAR Figure 2.1-4A were used (see Exhibit 3). The site boundary for the remaining six sectors, north-northeast clockwise to southeast, is located over marsh. Consequently, for these remaining six sectors, the minimum distances from the center of the Unit 1 Containment Building to the nearest dry land beyond the site boundary as measured from a site aerial photograph were used.

2. Primary Vent Stack Release Pathway

- *'The Rocks' and Ed Center:* The minimum distances from the center of the Unit 1 Containment Building to 'The Rocks' and Ed Center as measured from a site aerial photograph were used.
- *Site Boundary:* For the south-southeast clockwise to north downwind sectors, the minimum distances from the center of the Unit 1 Containment Building to the site boundary within a 45-degree sector centered on the compass direction of interest as measured from Seabrook Station FSAR Figure 2.1-4A were used (see Exhibit 4). The site boundary for the remaining six sectors, north-northeast clockwise to southeast, is located over marsh. Consequently, for these remaining six sectors, the minimum distances from the center of the Unit 1 Containment Building to the nearest dry land beyond the site boundary as measured from a site aerial photograph were used.

A list of the resulting receptor coordinates (downwind distance and sector) is provided in Exhibit 5.

Six-year average diffusion and deposition factors were calculated for 'The Rocks' and the Ed Center during the time period January 1980 through December 1983 and January 1987 through December 1988. For the site boundary and offsite receptors, both six-year growing season (April through September) and year-round (January through December) diffusion and deposition factors were generated, with the higher of the two chosen to represent the site boundary and offsite receptor diffusion and deposition factors.

The resulting diffusion and deposition factors for the two onsite receptors ('The Rocks' and Ed Center) and the location and resulting diffusion and deposition factors for the highest site boundary/offsite receptors are provided in Table 1 for both the ground-level and the Primary

Vent Stack release pathways. These are the diffusion and deposition values incorporated into the Seabrook Station Offsite Dose Calculation Manual.

4.0 REFERENCES

1. JN Hamawi, "AEOLUS-2 - Technical Description", Entech Engineering P100-R13-A, dated March 1988.

2. US Nuclear Regulatory Commission, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors", Regulatory Guide 1.111, Rev. 1, dated July 1977.

3. JF Sagendorf, JT Goll, and WF Sandusky, "XOQDOQ: Computer Program for the Meteorological Evaluation of Routine Effluent Releases at Nuclear Power Stations", NUREG/CR-2919, dated September 1982.

4. JW Healy and RE Baker, "Radioactive Cloud-dose Calculations", Chapter 7 of Meteorology and Atomic Energy - 1968, DH Slade, Editor, US Atomic Energy Commission, dated July 1968.

5. US Nuclear Regulatory Commission, "Onsite Meteorological Programs", Regulatory Guide 1.23 (Safety Guide 23), Rev. 0, dated February 1972.

6. JN Hamawi, "A Method for Computer the Gamma-Dose Integrals I_1 and I_2 for the Finite Cloud Sector-Average Model", Yankee Atomic Electric Report YAEC-1105, dated March 1975.

7. GC Holzworth, "Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution throughout the Continuous United States", US EPA Office of Air Programs PB-207 103, dated January 1972.

8. MP Lebeis and RA Foltman, "Development of a Site Specific Empirical Equation to Estimate TIBL Heights at the Fermi-2 Power Plant Site", Paper 85-25A.3 presented at the 78th Annual Meeting of the Air Pollution Control Association, Detroit, Michigan, June 16-21, 1985.

9. MP Lebeis, "Use of Monostatic Acoustic Radars to Determine Thermal Internal Boundary Layer Heights Along the Western Lake Erie Shoreline",

Paper 85-25B.4 presented at the 78th Annual Meeting of the Air Pollution Control Association, Detroit, Michigan, June 16-21, 1985.

10. WA Lyons, CS Keen, and JA Schuh, "Modeling Mesoscale Diffusion and Transport Processes for Releases within Coastal Zones During Land/Sea Breezes", NUREG/CR-3542, dated December 1983.

11. US Nuclear Regulatory Commission, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors", Regulatory Guide 1.111, Rev. 0, dated March 1976.

TABLE 1

Seabrook Station ODCM

Atmospheric Diffusion and Deposition Factors

A. Ground-Level Release Pathway

Diffusion Factor	Receptor: The Rocks	Receptor: Ed Center	Receptor: Site Bndy[a]
Undepleted CHI/Q, sec/m^3	1.6×10^{-4} (244m ENE)	2.3×10^{-5} (406m SW)	1.0×10^{-5} (823m W)
Depleted CHI/Q, sec/m^3	1.5×10^{-4} (244m ENE)	2.1×10^{-5} (406m SW)	9.4×10^{-6} (823m W)
D/Q, m^{-2}	5.1×10^{-7} (244m ENE)	1.0×10^{-7} (406m SW)	5.1×10^{-8} (823m W)
Gamma CHI/Q, sec/m^3	2.6×10^{-5} (244m ENE)	5.3×10^{-6} (406m SW)	3.4×10^{-6} (823m W)

2. Primary Vent Stack Release Pathway

Diffusion Factor	Receptor: The Rocks	Receptor: Ed Center	Receptor: Site Bndy[a]
Undepleted CHI/Q, sec/m^3	1.7×10^{-5} (244m ENE)	1.6×10^{-6} (488m SW)	8.2×10^{-7} (974m W)
Depleted CHI/Q, sec/m^3	1.6×10^{-5} (244m ENE)	1.5×10^{-6} (488m SW)	7.5×10^{-7} (974m W)
D/Q, m^{-2}	1.1×10^{-7} (244m ENE)	2.7×10^{-8} (488m SW)	1.5×10^{-8} (914m NW)
Gamma CHI/Q, sec/m^3	5.0×10^{-6} (244m ENE)	1.1×10^{-6} (488m SW)	8.5×10^{-7} (974m W)

[a] The highest site boundary diffusion and deposition factors occurred during the Apr-Sep growing season. Note that for the Primary Vent Stack Release Pathway, none of the offsite receptor diffusion and deposition factors (located at 0.25-mile increments beyond the site boundary) exceeded the site boundary diffusion and deposition factors.

EXHIBIT 1

Projected Annual Noble Gas Effluent Releases (Ci/yr)

Radionuclide	Ground-Level Release Pathway	Primary Vent Stack Release Pathway
Ar-41	0[a]	2.5×10^1
Kr-83M	0[a]	0[a]
Kr-85M	1.0×10^0	1.0×10^1
Kr-85	0[a]	2.6×10^2
Kr-87	0[a]	3.0×10^0
Kr-88	2.0×10^0	1.6×10^1
Kr-89	0[a]	0[a]
Xe-131M	0[a]	2.3×10^1
Xe-133M	0[a]	1.6×10^1
Xe-133	2.1×10^1	9.9×10^2
Xe-135M	0[a]	0[a]
Xe-135	3.0×10^0	3.8×10^1
Xe-137	0[a]	0[a]
Xe-138	0[a]	1.0×10^0

[a]Less than 1.0 Ci/yr.

Reference: Seabrook Station ER-OLS Table 3.5-10

EXHIBIT 2

Regulatory Guide 1.111 (Rev. 0)

Open Terrain Recirculation Correction Factors

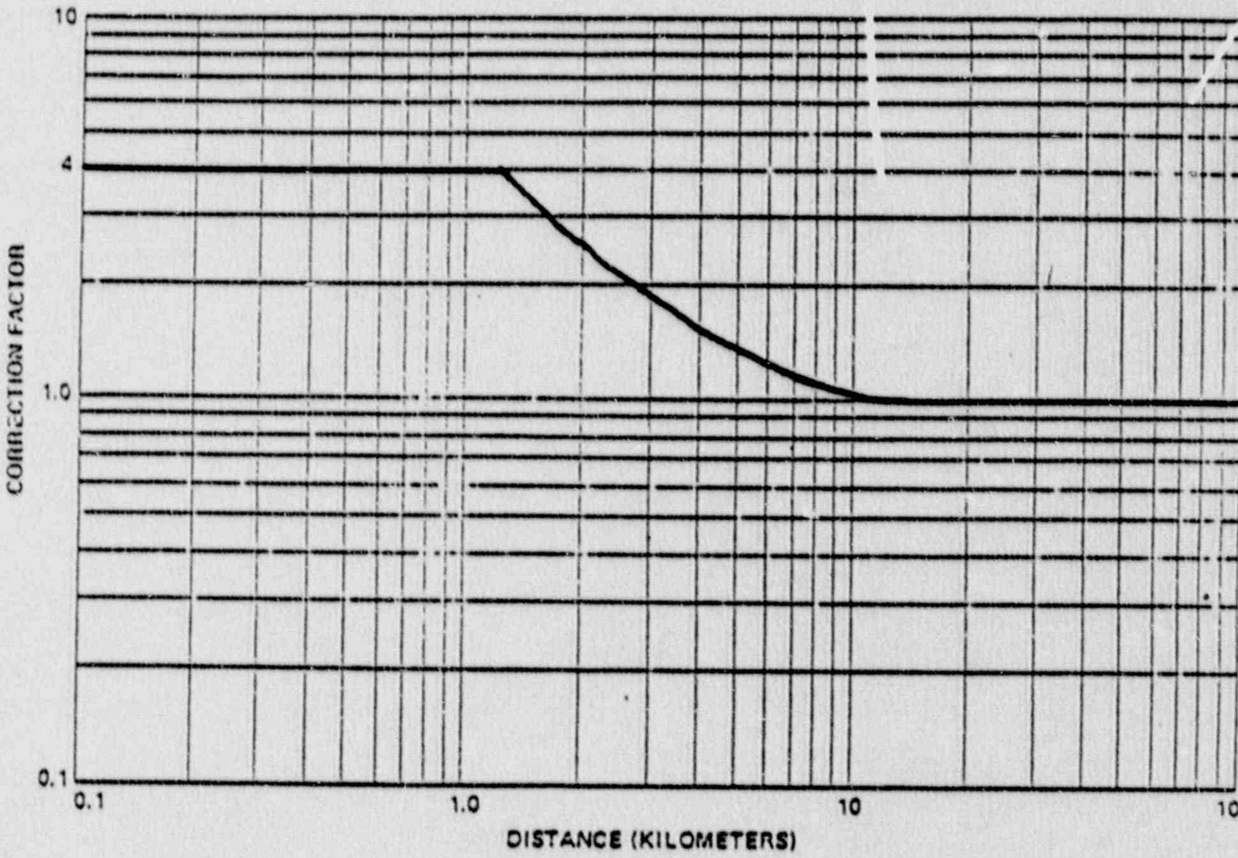

EXHIBIT 3

Site Map Showing Locations of the

Administration Building/Turbine Building Complex

and the Site Boundary

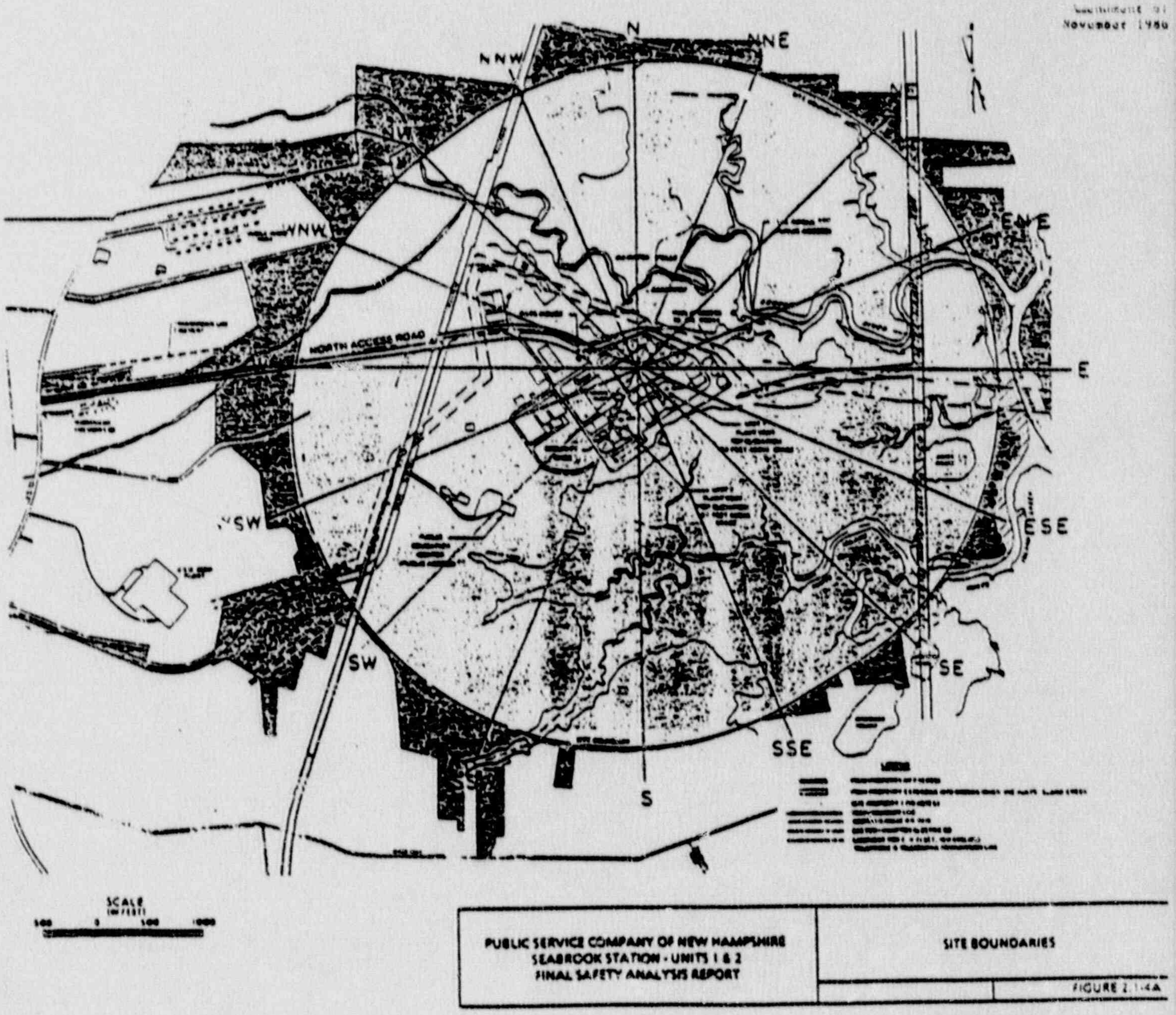

EXHIBIT 4

Site Map Showing Locations of the Primary Vent Stack and the Site Boundary

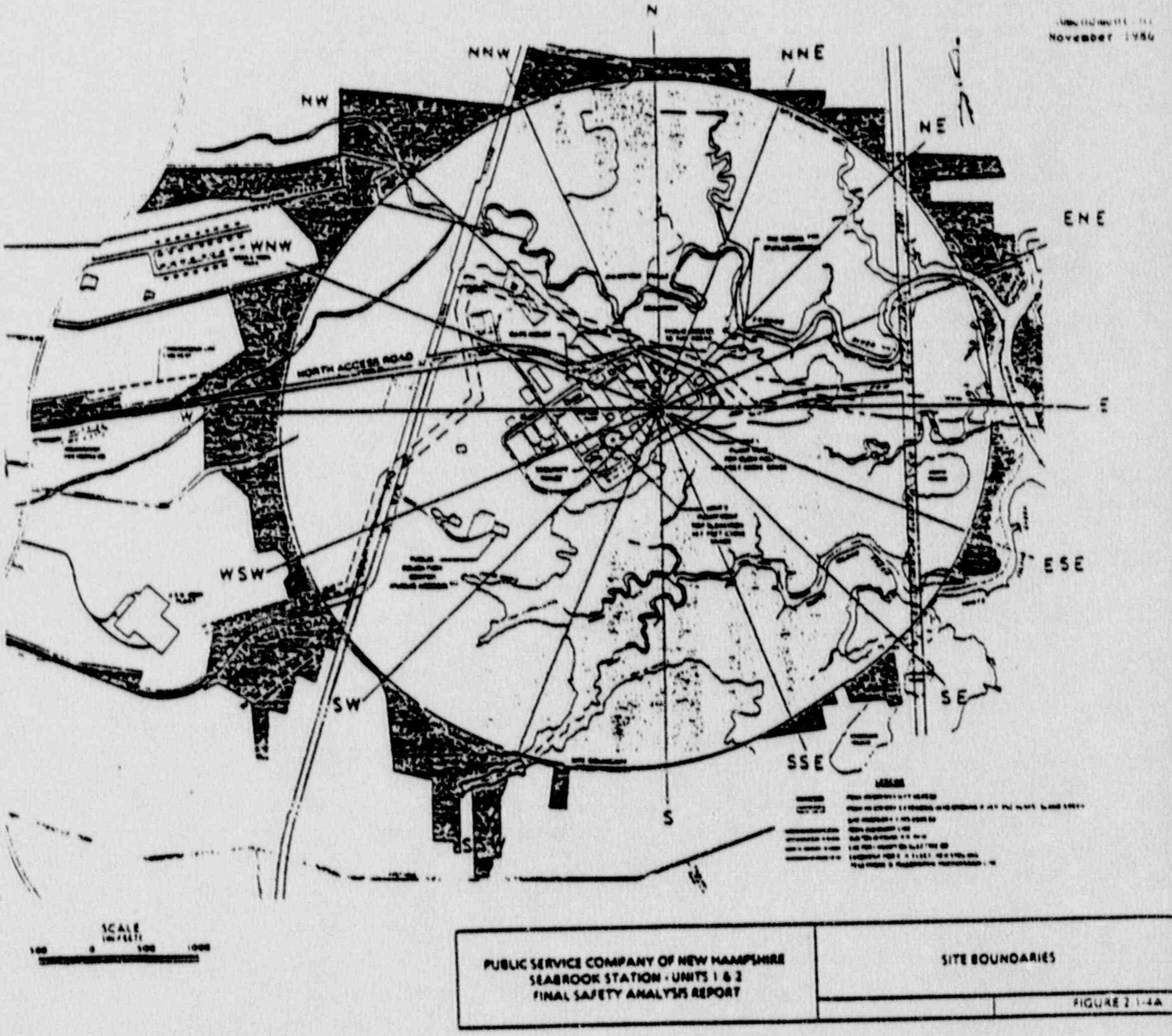

EXHIBIT 5

Receptor Locations

Receptor	Ground-Level Release Pathway	Primary Vent Stack Release Pathway
The Rocks	244m ENE	244m NE 244m ENE
Ed Center	406m SW	488m SW
Site Bndy	780m N 2926m NNE[a] 2276m NE[a] 2276m ENE[a] 2438m E[a] 2276m ESE[a] 2276m SE[a] 952m SSE 968m S 968m SSW 941m SW 871m WSW 823m W 775m WNW 775m NW 775m NNW	914m N 2926m NNE[a] 2276m NE[a] 2276m ENE[a] 2438m E[a] 2276m ESE[a] 2276m SE[a] 914m SSE 930m S 990m SSW 1022m SW 1022m WSW 974m W 930m WNW 914m NW 914m NNW
Offsite	None	(b)

(a) The site boundary in the NNE through SE sectors is located over marsh (e.g., water). Consequently, the site boundary distances for these six direction sectors represent the nearest dry land beyond the site boundary.

(b) Because the maximum offsite dispersion and deposition factors for the Primary Vent Stack Release Pathway may occur beyond the site boundary, diffusion and deposition factors were determined at 0.25-mile increments from the stack starting beyond the site boundary out to five miles.