ATTACHMENT 1

PLG-0433

TMI-1 CONTROL ROOM HABITABILITY STUDY: ANALYSIS OF RADIOLOGICAL AND CHEMICAL ACCIDENTS FOR ABNORMAL FLOW PATHS TO THE CONTROL ROOM

PREPARED FOR
GENERAL PUBLIC UTILITIES

FINAL REPORT

AUGUST 28, 1985

BY
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1. INTRODUCTION

For reasons of safety, both of the general public and of control room personnel, the Nuclear Regulatory Commission requires that, for a variety of potential accident situations, the control rooms of nuclear reactors be maintained in a habitable condition. These accidents include the range of design basis radiological accidents as well as spills of chemicals which may result in injurious levels of toxic gases in the control room. The NRC has promulgated standards for the evaluation of these potential hazards in section 6.4 of the Standard Review Plan[1] and Regulatory Guide 1.4[2] which deals primarily with the radiological hazard; Regulatory Guide 1.78[3] which deals with the evaluation of chemical hazards; and Regulatory Guide 1.95[4] which deals specifically with the chlorine hazard. The analysis methods used in this report comply with those in the above documents insofar as they are complete and applicable to the TMI-1 control room; where methods are not specified or are, for some reason, inapplicable, appropriately conservative methodologies were developed for this analysis.

The accidents considered in this report all consider flow through pathways other than the normal control room intake system. It is postulated that these pathways could occur due to leaks or damper failures. The same accident sources have been considered, postulating all flow through the normal control room intake system (in either normal or emergency mode), in previous studies.

2. SCOPE OF THIS STUDY

In this study, several accident source terms (both chemical and radiological) are studied in conjunction with pathways other than the control building air intake system. Accidents with the same source terms but with flow paths through the air intake system have been considered in previous studies. It was felt that, for the sake of completeness, leakage of contaminated air by alternate pathways into the control building envelope should be considered.

The source terms considered in this study are:

1. design basis loss of coolant accident (LOCA)
2. rupture of the Unit 1 ammonium hydroxide storage tank
3. rupture of a one-ton cylinder of liquid chlorine at the river the Unit 1 chlorinator

For all three of these sources, the possibility of leakage through the exhaust damper (AH-D-37) was considered. In the first two cases the concern was the proximity of the damper to the source of contaimination. For the last case, the concern was the lack of a chlorine detector at either the Unit 1 chlorinator or the exhaust damper. Additionally, the design basis LOCA was analyzed assuming that the entire design leakage went into the auxiliary building, and a portion of this activity le[illegible] into the control room via the fuel handling building, level 306' of the control building, the control building elevators and stairways, and the patio area, and finally into the control building isolation zone.

The radiological accidents assume that ES actuation results in the closing of the intake dampers while the detectors in the control room cause automatic shutdown of normal ventilation in the control building envelope, followed by activation of the ventilation system in the emergency mode. The applicable portions of the Murphy-Campe method are applied to the radioactive releases. The ammonium hydroxide and chlorine releases are treated using k factors determined by Dr. James Halitsky in Appendix A, using the 5% worst meteorology. The ammonium hydroxide tank is considered surrounded by a dike which contains the spill. No emergency response to the chemical accidents is assumed.

3. METHODOLOGY

The assumptions and methodology used in this study are in accordance with the Standard Review Plan 6.4[1] and Regulatory Guides 1.4,[2] 1.78[3] and 1.95.[4] Where no specification was made of the models to be used in the analysis, appropriate models were developed as described in the following sections.

3.1 MODELING THE LARGE BREAK LOCA

The release of radioactive material resulting from a large break LOCA was calculated using the assumptions of paragraph c.1 of Reg. Guide 1.4. Credit was taken for the removal of iodines by the Containment Spray System using Sodium Hydroxide spray solution. The assumptions and models used in this analysis are presented in a previous report entitled, "Dose Estimates for Three Mile Island Unit 1: Spray Solution".[5] This report describes the HYDROS computer code and all data input needed to calculate the leakage rate for all radionuclides considered. For this study, the HYDROS code was modified to output the containment release rates as a function of time up to 30 days after postulated releases begin. These were needed as input to the Emergency Building Concentration and Dosimetry models described in Section 3.6.

The dilution of the plume of radioactive material between the containment and the intake vent was computed by using the Murphy-Campe method[6] described in Section 3.5. This should lead to conservative results.

3.2 MODELING AMMONIUM HYDROXIDE TANK RUPTURES

Aqueous ammonium hydroxide solution is a liquid at normal ambient temperatures and pressures. Upon release from the storage container the solution spills to the ground and ammonia (NH_3) and water vapor (H_2O) evaporate from the spill to form a continuous plume. Only ammonia impacts the habitability of the control building.

Since ammonia is more volatile than water, ammonia evaporates from the spill at a faster rate than the water. As a result, the fraction of ammonia in the spill decreases as evaporation proceeds. Since the NH_3 evaporation rate is proportional to the partial pressure of NH_3 above the liquid spill and since the partial pressure decreases as the weight fraction of NH_3 in the spill decreases, the ammonia evaporation rate decreases with time.

The ratio of evaporation of a chemical species i from a liquid mixture is given by:

$$\dot{M}_{vi} = h_{di} M_{wi} A(t) (P_{si} - P_{ai})/RT_a \quad (3.1)$$

where

$\dot{M}_{vi}$ = rate of evaporation of chemical i, gm/sec

h_{di} = forced convection mass transfer coefficient for chemical i, cm/sec

M_{wi} = molecular weight of chemical i, gm/gm mole

$A(t)$ = area of spill at time t, cm^2

P_{si} = saturated partial pressure of chemical's vapor above liquid mixture, atm

P_{ai} = partial pressure of chemical's vapor in ambient air, atm

T_a = ambient temperature, °K

R = gas constant = 82.05 cm^3-atm/g-mole, °K

t = time, sec

The forced convection mass transfer coefficient is given by:

$$h_{di} = 0.037 \frac{D_i}{L} Re^{0.8} Sc_i^{0.33} \quad (3.2)$$

where

D_i = mass diffusivity of chemical species i in air, cm^2/sec

L = characteristic length of liquid spill, cm

Re = $L \overline{U} \rho_a/\mu_a$ = Reynolds Number, dimensionless

Sc_i = $\mu_a/\rho_a D_i$ = Schmidt Number of chemical species i, dimensionless

$\overline{U}$ = mean wind velocity, cm/sec

ρ_a = density of ambient air, gm/cm^3

μ_a = viscosity of ambient air, gm/cm-sec

The characteristic length of the spill is taken as the spill diameter. Therefore:

$$L(t) = \left(\frac{4A(t)}{\pi}\right)^{1/2} \tag{3.3}$$

The liquid spill area, A(t), is given by

$$A(t) = \pi\left[r_o^2 + 2\left(\frac{gV_o}{\pi}\right)^{1/2} t\right] \tag{3.4}$$

where the density of air has been neglected. Here

g = acceleration due to gravity, 980 cm/sec^2

V_o = initial volume of liquid, cm^3

r_o = initial radius of spill, cm

t = elapsed time since rupture, sec

It is assumed that the pool reaches its maximum size when A(t) equals the dike area or the thickness of the pool is 1 cm, whichever occurs first.

To account for the depletion of ammonia in the spill, the model is applied as follows. At any time t, the mass of ammonia and water in the spill are $M_1(t)$ and $M_2(t)$, respectively. The mass fraction of ammonia in the spill is

$$f(t) = \frac{M_1(t)}{M_1(t) + M_2(t)} \qquad (3.5)$$

The saturation partial pressure of ammonia, $P_{s1}(t)$ and water $P_{s2}(t)$ are functions of f(t) only and are given over a wide temperature and composition range in Reference 9. At time Δt later

$$M_1(t + \Delta t) = M_1(t) - M_{v1}(t) \qquad (3.6)$$

$$M_2(t + \Delta t) = M_2(t) - M_{v2}(t) \qquad (3.7)$$

$$f(t + \Delta t) = \frac{M_1(t + \Delta t)}{M_1(t + \Delta t) + M_2(t + \Delta t)} \qquad (3.8)$$

when $M_{v1}(t)$ and $M_{v2}(t)$ are calculated from (3.1) to (3.3). Therefore, beginning at time 0, it is possible to update this amount of each species in the spill and their saturation partial pressures. The model allows f(t) to fall to zero as time proceeds. The model is run with a background (ambient) partial pressure of zero for NH_3 and one corresponding to 50% relative humidity for H_2O.

This model has been implemented as the PLG code NH3VAP, which produces a time history of the evaporation rate of ammonia in grams per second from a pool of ammonium hydroxide for specified accident conditions.

3.3 MODELING CHLORINE TANK RUPTURES

According to NUREG-0570,[8] the mass of chemical which is instantaneously flashed to form a puff release is

$$M_{vo} = M_T C_p (T_a - T_b)/H_v \qquad (3.9)$$

M_{vo} = mass of instantaneously vaporized (flashed) chemical, gm

M_T = total initial mass of spilled chemical, gm

C_p = liquid heat capacity of chemical, cal/gm-°C

T_a = ambient temperature, °C

T_b = normal boiling point of chemical, °C

H_v = heat of vaporization of chemical at normal boiling point, cal/gm

The portion of the release which does not flash to puff will form a liquid pool whose surface area is given by equation (3.4). This liquid (M_t - M_{vo}) will vaporize by absorption of atmospheric and solar radiation, convection of air and ground conduction. NUREG-0570 gives the following formula for calculating the vaporization (boil-off) rate:

$$\dot{M}_v(t) = \frac{A(t)}{H_v}\left[q_r + h_c\,(T_a - T_b) + S\,(T_a - T_b)/t^{1/2}\right] \tag{3.10}$$

$\dot{M}_v(t)$ = vaporization rate, gm/sec

q_r = solar and atmospheric radiation fluxes, cal/m^2-sec

h_c = heat transfer coefficient for wind convection, cal/m^2-sec-°C

T_a = ambient temperature, assumed for both atmospheric and ground, °C

T_b = chemical's normal boiling point, °C

$A(t)$ = liquid spill surface area, m^2

H_v = heat of vaporization, cal/gm

S = 197 cal/m^2-°C-sec$^{0.5}$

t = time after tank rupture, sec

The wind convection heat transfer coefficient is conservatively assumed to equal 1.6 cal/m^2-sec-°C as suggested in NUREG-0570. Since radiation flux data were not available, q_r was conservatively assumed to equal 275 cal/m^2sec. The values used for h_c and q_r do not significantly affect the calculations since evaporation due to ground conduction (last term in brackets in equation 3.4) far outweighs that due to radiation and wind convection except at extremely long times after release. At these long times the concentration in the control room has usually passed its maximum.

If (3.4) is substituted into (3.10), the resulting equation may be integrated to yield the mass remaining at time t, M(t):

$$M(t) = M_T - M_{vo} - at^{0.5} - bt - ct^{1.5} - dt^2 \qquad (3.11)$$

where

$$a = 2\pi S r_o^2 \, (T_a - T_b) \, H_v^{-1}$$

$$b = \pi r_o^2 \, [q_r + h_c \, (T_a - T_b)] \, H_v^{-1}$$

$$c = \frac{4S(\pi g V_o)^{0.5} \, (T_a - T_b)}{3H_v}$$

and

$$d = (\pi g V_o)^{0.5} \, [q_r + h_c \, (T_a - T_b)] \, H_v^{-1}$$

until the pool reaches its maximum extent and thereafter by:

$$M(t) = et^{0.5} + ft \qquad (3.12)$$

where

$$e = 2SA_{max} \, (T_a - T_b) \, H_v^{-1}$$

$$f = A_{max} \, [q_r + h_c \, (T_a - T_b)] \, H_v^{-1}$$

and where A_{max} is the maximum extent of the pool.

This model has beem implemented as the PLG code CL2VAP, which produces a time history of chlorine evaporation rate in grams per second for specified accident conditions.

3.4 MODELING ATMOSPHERIC DISPERSION

The dispersion of an effluent is generally modeled with the equation

$$\chi = \frac{CQ}{U} \tag{3.13}$$

where

χ = effluent concentration at receptor, in Ci/m^3 for radioactive materials and g/m^3 for non-radioactive materials

C = proportionality constant, which is a function of source position, receptor position, wind direction, atmospheric stability, and the structure of the terrain surrounding and between the source and receptor, in m^{-2}.

Q = effluent release rate, in Ci/sec or g/sec as appropriate

U = wind speed in m/sec

For the large break LOCA, Murphy and Campe propose[6]

$$C = [\pi \sigma_y \sigma_z + a\ (K + 2)^{-1}]^{-1} \tag{3.14}$$

where

σ_y, σ_z = standard deviation of the effluent concentration in the horizontal crosswind and vertical directions respectively at distance s from a point source, m.

a = projected area of containment building, m^2

K = $3(d/s)^{1.4}$

s = distance between source and receptor locations, m

d = containment diameter, m

The values for σ_y and σ_z are based on the most stable case excluding the worst 5% (i.e., 5% of all hours as or more stable than the stability chosen, 95% are as or less stable). This is known as the 5% stability. Similarly, the windspeed used for the first 8 hours is the 5% windspeed, for the next 16 hours is the 10% windspeed, for the following three days is the 20% windspeed, while the 40% windspeed is used thereafter. The Murphy-Campe method also allows a correction for wind meander of (.75 + .25F) from 8 to 24 hours, (.5 + .5F) for 1 to 3 days, and F thereafter. Here F is the fraction of time that the wind direction results in exposure. Credit was also taken for the occupancy factor as allowed in the Murphy-Campe method.

For releases of toxic chemicals, values of C in equation (3.13) were derived from wind tunnel studies by Dr. James Halitsky (Appendix A). These values are similar to Murphy-Campe results for the point-source and point receptor case when credit is taken for the finite size of the spill and receptor. For both chemical releases, the 5% worst meteorology was used.

3.5 MODELING FLOW IN THE AUXILIARY AND FUEL HANDLING BUILDINGS AND THE PORTION OF THE CONTROL BUILDING OUTSIDE THE CONTROL BUILDING ENVELOPE

The flow path including the Auxiliary Building, the Fuel Handling Building and the portion of the Control Building outside the isolation zone is modeled as shown in Figure 3-1. The quantity of each of the 18 radionuclides considered by HYDROS, described in Section 3.1, is determined in each compartment as a function of time by the PLG code AUXFLOW, and the amount leaked into the control building envelope is determined for each radionuclide at each time step. The input to AUXFLOW consists of the volume of each compartment (V_i) and the 5 flow values (U_j) shown in Figure 3-1, along with the release quantities from HYDROS. The governing equations for radionuclide;

$$C_{oj}(t) = u_o^{-1} Q_{oj}(t) \tag{3.15}$$

$$\frac{dC_{1j}}{dt} = u_o V_1^{-1} C_{oj}(t) - (u_o V_1^{-1} + \lambda_j) C_{1j}(t) \tag{3.16}$$

$$\frac{dC_{2j}}{dt} = u_1 V_2^{-1} C_{1j}(t) - (u_1 V_2^{-1} + \lambda_j) C_{2j}(t) \tag{3.17}$$

$$\frac{dC_{3j}}{dt} = u_2 V_3^{-1} C_{2j}(t) - [(u_2 + u_3) V_3^{-1} + \lambda_j] C_{3j}(t) \tag{3.18}$$

and

$$Q_{1j}(t) = u_4 C_{3j}(t) \tag{3.19}$$

where $C_{ij}(t)$ is the concentration of radionuclide j in compartment i, and $Q_{oj}(t)$ and $Q_{1j}(t)$ and the input and output quantities, respectively, of radionuclide j. The identity of the compartments is given in Figure 3-1.

The equations are solved exactly in each time step. It is assumed that $Q_{oj}(t)$ may be treated as an exponential in each time step.

3.6 MODELING DOSES TO CONTROL ROOM PERSONNEL

The Control Building Envelope may be modeled as a flow system as shown in Figure 3-2. The time dependent concentrations of eighteen radionuclides in each of the three compartments shown in Figure 3-2 are computed by the PLG code CRDOSE, using the methods described below. The dose rates and integral doses received by personnel in the control room are also computed by CRDOSE.

The CRDOSE code uses time-dependent containment release rates for eighteen radionuclides produced by HYDROS, described in Section 3.1 or AUXFLOW, described in Section 3.5. The remaining data is input by the user, and consists of the volume (V_i) of each compartment, the volumetric flow rate (u_j) into that compartment, the volumetric flow rate from that compartment into the recirculation loop (u_j), the intake volumetric flow rate (u_o), the filter efficiency (η), and the volume of the intake duct (V_D). For a given isotope, other pertinent variables are the intake concentration measured after decay in the intake duct ($C_o(t)$), the concentration of the radionuclide in each compartment as a function of time ($C_i(t)$), and the decay constant λ_D. The concentrations are then governed by the equations

$$\frac{dC_i}{dt} = \sum_{j=1}^{3} \gamma_{ij} C_j(t) + v_i C_o(t) \tag{3.20}$$

where

$$\lambda_i = u_i/V_i \tag{3.21}$$

$$U_r = \sum_{i=1}^{3} u_r' \tag{3.22}$$

$$u_R = \sum_{i=1}^{3} u_r' \tag{3.23}$$

$$\alpha_i = u_i/u_R' \tag{3.24}$$

$$\beta = \frac{u_R}{u_R + u_o} \tag{3.25}$$

$$\gamma_{ij} = (1-\eta)\,\beta\gamma_i\,\alpha_j - (\lambda_i + \lambda_D)\,\sigma_{ij} \tag{3.26}$$

and

$$v_i = (1-\eta)\,(1-\beta)\,\lambda_i. \tag{3.27}$$

The set of equations (3.20) has a particular solution and three linearly independent homogeneous solutions. It is assumed the $C_o(t)$ may be adequately represented in some time interval k beginning at t_k by

$$C_o(t) = A_k e\,[\lambda_k\,(t-t_k)] \qquad t_k < t < t_{k+1} \tag{3.28}$$

The particular solution then has the form

$$C_{Ii}(t) = F_i e\,\lambda_k\,[(t-t_k)] \tag{3.29}$$

Substituting this expression into equation (3.20) at t_k yields

$$\sum_{j=1}^{3} (\gamma_{ij} - \lambda_k\,\sigma_{ij})\,F_j = v_i A_k \tag{3.30}$$

This set of linear equations is solved in CRDOSE by Gauss-Jordan elimination. In order to find the homogeneous solution which matches the boundary conditions (the concentration in each compartment at time t_k, computed in the previous time step), the characteristic equation of the matrix $[\gamma_{ij}]$ is first solved for the eigenvalues of $[\gamma_{ij}]$, W_j, and the corresponding eigenvectors. Let E_{ij} be the element of eigenvector j corresponding to compartment i. The solution in interval k is then given by

$$C_i(t) = \sum_{j=1}^{3} E_{ij}^{-1} \left[B_j e^{W_j\,(t-t_k)} \right] + F\,e^{\lambda_k (t-t_k)} \tag{3.31}$$

Using the known concentrations at time t_k, the unknown values B_j may be found by solving the set of linear equations

$$\sum_{j=1}^{3} E_{ij} B_j = C_i(t_k) - F_i \tag{3.32}$$

In CRDOSE, since the operation is carried out many times for each matrix E_{ij}, the inverse matrix E_{ij}^{-1} is found, and the unknowns B_j are found in each time step by using

$$B_j = \sum_{i=1}^{3} E_{ji}^{-1} [C_i(t_k) - F_i] \tag{3.33}$$

This process is repeated for each isotope at each time step, yielding the time dependent concentration of each isotope.

Two types of doses are computed by CRDOSE: beta skin dose and gamma whole body dose. These are treated in the manner outlined in Regulatory Guide 1.4[2] for infinite plumes, with two exceptions. For beta skin dose, a user-input protective factor for clothing may be input. Also, for gamma whole body dose, a correction is made for the finite size of the control room, rather than using the infinite plume value. The Goldstein buildup factor of

$$B(\mu r) = (1 + K\mu r) \tag{3.34}$$

is used, where

$$K = \frac{\mu}{\mu_a} - 1 \tag{3.35}$$

A correction factor is derived which is the fraction of the dose from an infinite plume resulting from gamma rays emitted within a distance R of the source point. This is

$$\begin{aligned} F_c &= \mu_a \int_0^R (1 + K\mu r) \; e^{-\mu r} dr \\ &= (1-e^{-\mu R}) - (\mu-\mu_a) \, Re^{-\mu R} \end{aligned} \tag{3.36}$$

The radius R is that of an hemisphere of equivalent volume to the control room volume V,

$$R = \left(\frac{3V}{2\pi} \right)^{1/3} \tag{3.37}$$

The walls, ceilings and floors in the Control Building are of a great enough thickness that the contribution of external shine to the dose may be neglected.

It should be noted that both the control room flow model and the finite plume gamma dose model are more sophisticated versions of approaches suggested in the Murphy-Campe model.[6]

3.7 MODELING OF TOXIC GAS CONCENTRATIONS IN THE CONTROL BUILDING ENVELOPE

The model for toxic gas concentrations in the control building envelope is shown in Figure 3-3. While the radioactive decay problem does not occur, the flow path is different in this model.

At the intake damper, a portion of the flow, U_B, is diverted to the halls and machine shop, while the remainder, U_1 is used in a manner entirely analogous to U_o in Section 3.6. With this substitution, and with the decay constant λ_D set to zero, equations (3.20) to (3.33) are used to model the concentration as a function of time.

A further modification is used to correct for the fact that the intake tunnel may be drawing air from a volume over which the concentration varies greatly. If no correction is performed, the amount of toxic gas can be, under some circumstances, be overestimated to the point that more gas would be taken in than was actually released. To alleviate this problem, the conservative approach shown below was used.

It is assumed that a cross-section of the plume taken in the crosswind plane at the intake has a gaussian distribution with standard deviations σ_y in the horizontal direction and σ_z in the vertical direction traveling at windspeed $\bar{V}$. Since the plume is reflected by the ground, it will have a dilution factor as a function of horizontal distance y and vertical distance z of

$$\frac{X}{Q} = \frac{1}{\pi \bar{V} \sigma_y \sigma_z} \exp - \left(\frac{y^2}{2\sigma_y{}^2} + \frac{z^2}{2\sigma_z{}^2} \right) . \qquad (3.38)$$

Isopleths of constant concentration will thus be given by

$$\left(\frac{y}{\sigma_y} \right)^2 + \left(\frac{z}{\sigma_z} \right)^2 = s^2. \qquad (3.39)$$

Bearing in mind that $z \geq 0$, this isopleth is a semiellipse with an area of

$$A = 0.5\pi\sigma_y\sigma_z s^2 \tag{3.40}$$

It is assumed that the intake flow is taken from the area bounded by such an isopleth, thus conservatively maximizing the amount of toxic gas taken in. The required area is

$$A = U/\bar{v} \tag{3.41}$$

where U is the intake flow rate. Setting the areas in (3.40) and (3.41) equal,

$$s^2 = \frac{2U}{\pi\bar{v}\sigma_y\sigma_z} = \frac{2\chi_o U}{Q} \tag{3.42}$$

where χ_o/Q is the value of (3.38) at y=z=o, the centerline atmospheric dilution factor. Integrating (3.38) over the area bounded by the isopleth (3.39) and multiplying by the windspeed $\bar{v}$ yields the fraction R of toxic gas which is introduced into the vent:

$$R = 1 - \exp(-s^2/2) = 1 - \exp(-\chi_o U/Q). \tag{3.43}$$

It is seen that, in accordance with physical reality, this fraction varies from zero to one as U increases from zero to infinity. Dividing R by the uncorrected flow rate into the tunnel gives the required correction factor

$$F_c = \frac{1-\exp(-\chi_o U/Q)}{(\chi_o U/Q)} \tag{3.44}$$

which reduces to unity for small flow rates.

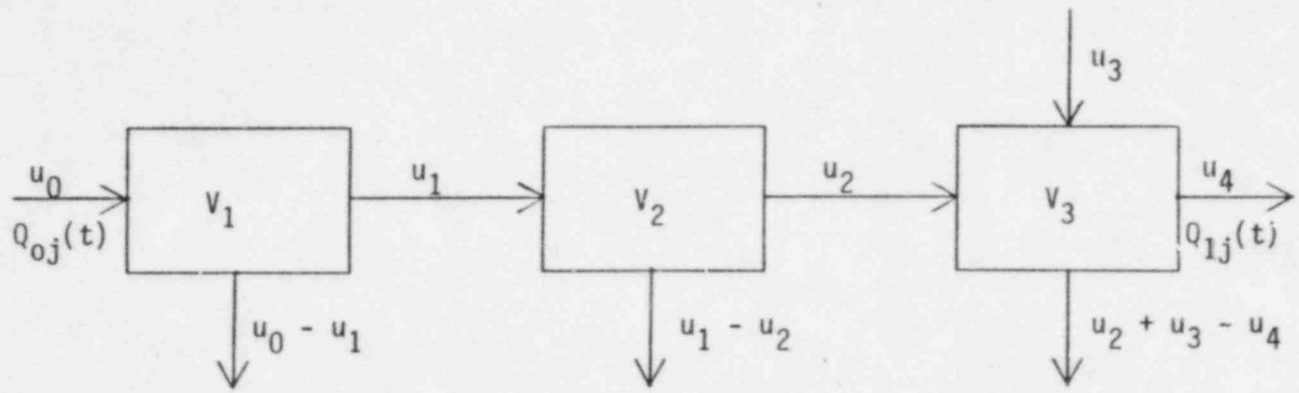

FIGURE 3-1. MODEL FOR FLOW THROUGH THE AUXILIARY, FUEL HANDLING AND CONTROL BUILDINGS

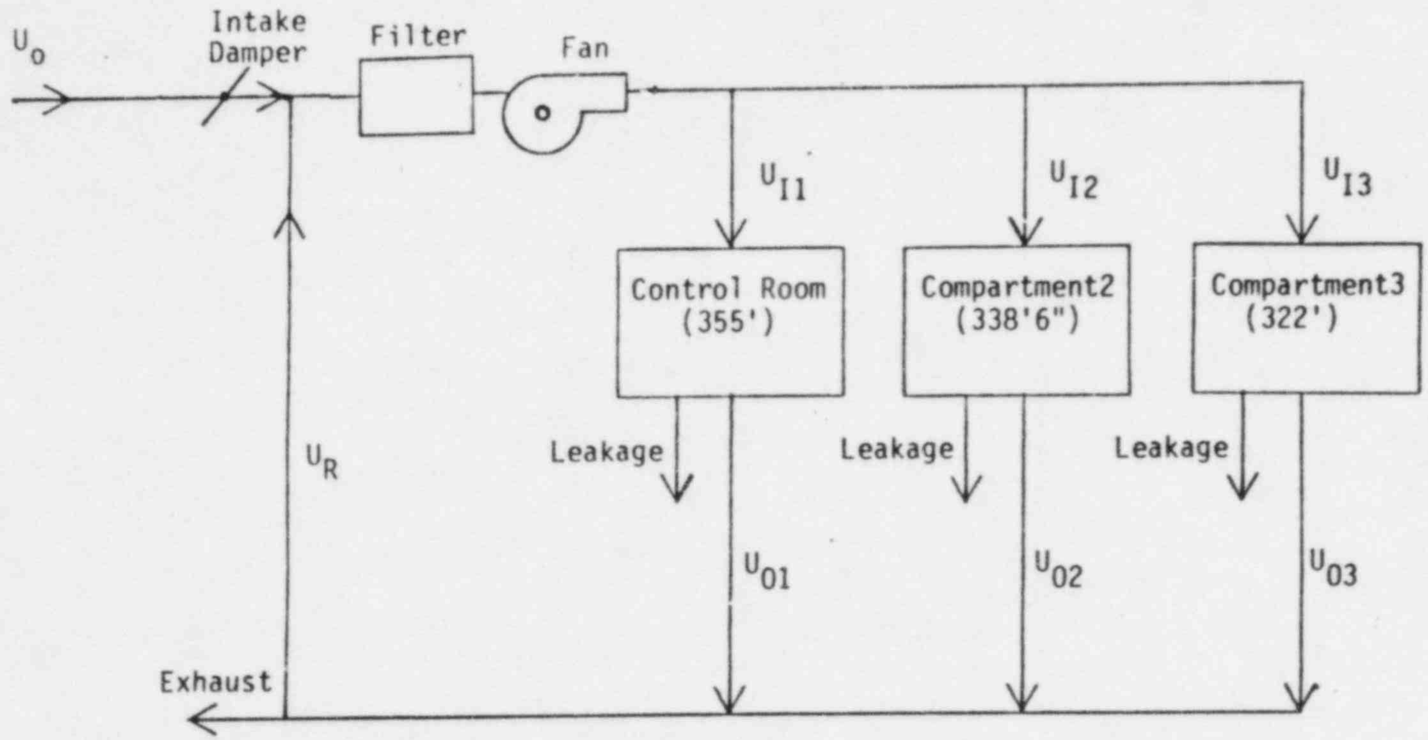

FIGURE 3-2. MODEL FOR CONTROL ROOM DOSES

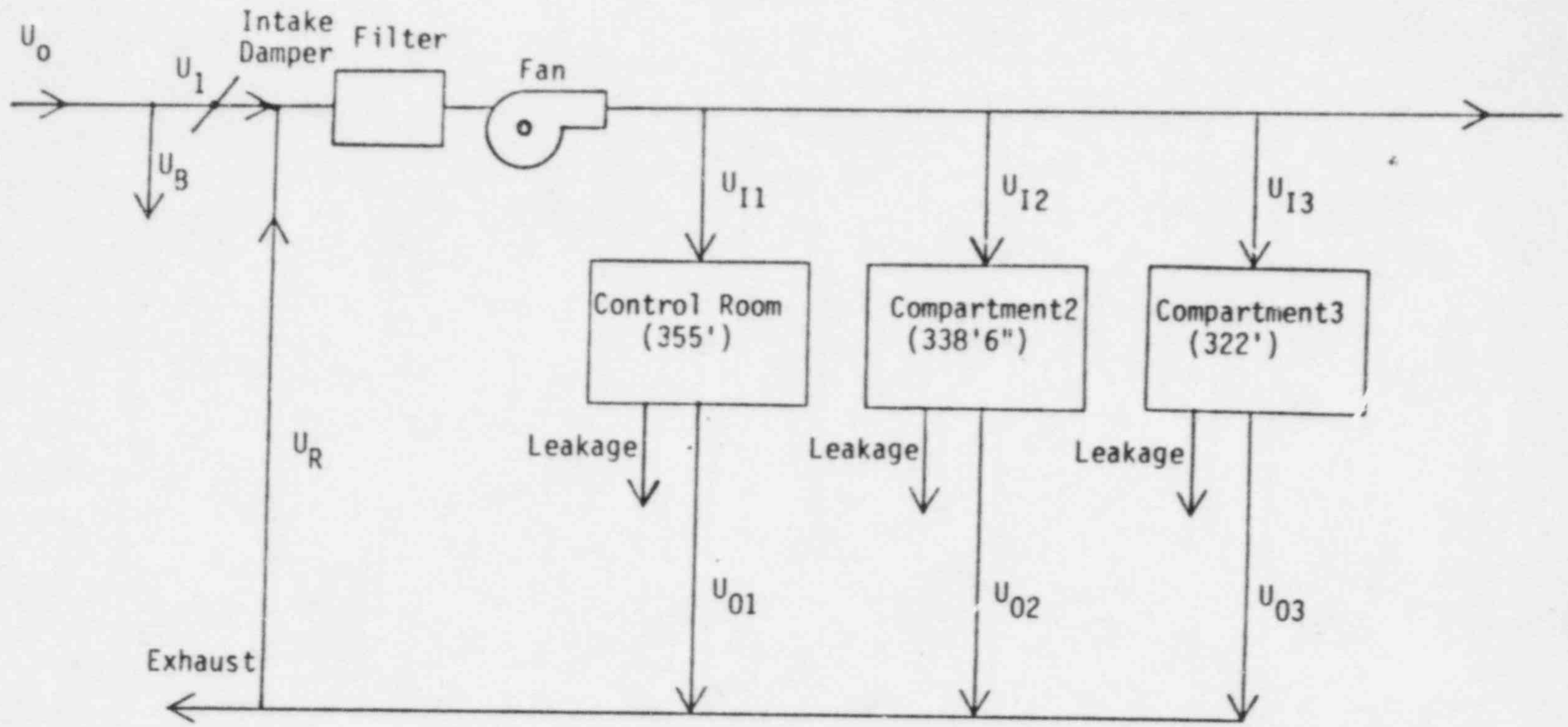

FIGURE 3-3. MODEL FOR TOXIC GAS CONCENTRATION

4. DATA

In this section, the data required for the analysis is discussed. The values used are tabulated herein, and the sources of the data are referenced.

4.1 HYDROS INPUT DATA

The HYDROS code used containment flow, spray and leakage models to find the release rates of eighteen radionuclides from containment as a function of time, given a Design Basis Loss of Coolant Accident.

The radionuclides considered and the data required to calculate the release rate for a period of 30 days is presented in Tables 1 to 5 and Figures 1 and 2 of Reference 5. Iodine removal was calculated with one spray header operating. The study of Reference 5 focused on dose estimates at the exclusion boundary at 2 hours after the accident. For this study it was therefore necessary to replace entries 1 to 4 and entry 6 of Table 4 of Reference 5 with values relevant to this study. These are discussed in Section 4.8.

4.2 AMMONIUM HYDROXIDE AND RELATED DATA

The relevant chemical data was taken from an earlier habitability study for TMI-1[10], as were the tank volume and the distance from the tank to the intake vent. The data are given in Table 4-2.

4.3 CHLORINE AND RELATED DATA

The relevant physical properties of chlorine, as well as tank capacity and position data, were taken from the study mentioned in the previous section.[10] The data are reproduced in Table 4-3.

4.4 VOLUME AND FLOW DATA FOR THE AUXILIARY, FUEL HANDLING AND CONTROL INTERMEDIATE TURBINE BUILDINGS

The volumetric data was computed from a set of drawing furnished by GPU Nuclear.[12] The flow data was taken from 2 ventilation flow diagrams furnished by GPU Nuclear.[13] The data used is given in Table 4.4.

4.5 CONTROL ROOM ISOLATION ZONE FLOW DATA

The control room ventilation system may be run in a variety of modes, each of which has a unique set of flow rates. The flow rates were taken from a variety of sources, primarily a ventilation drawing,[13] measurements at the plant,[14] and calculations by Burns & Roe.[15] The relevant values are given in Table 4-5.

4.6 DOSE LIMITS

The dose limits are taken from Section 6.4 of the Standard Review Plan. Gamma whole body dose to an operator must be no greater than 5 rem, while beta skin dose must not exceed 30 rem. *

4.7 TOXICITY LIMITS

The potential for ammonia and chlorine to incapacitate control room operators is based upon short term exposure limits recommended by the Commonwealth of Pennsylvania, Dept. of Environmental Resources, Title 25, Article IV, Chapter 201 (1971). These are reported in Reference 16. Exposures in excess of the following are considered to incapacitate the operators.

Ammonia: 1. 100 ppm for 30 minutes
2. 500 ppm for 10 minutes

Chlorine: 1. 3 ppm for 5 minutes
2. 15 ppm for 2 minutes

---

* The thyroid dose was not considered because the iodine source terms are being re-evaluated by the NRC.

For both ammonia and chlorine, the calculations showed that if the second criterion is violated, the first is also violated. Therefore, criterion 1 is limiting and the toxicity model is actually based on 100 ppm for 30 min for ammonia and 3 ppm for 5 min for chlorine.

4.8 METEOROLOGICAL AND DISPERSION DATA

Meteorological data from the period July 1976 to June 1977 taken at the TMI site was used to determine the relevant meteorological conditions at the plant. The joint frequency tables are given in Table 4-6. The data required for the calculations in the Murphy-Campe method and the resulting atmospheric dispersion factors are given in Table 4-7. The atmospheric dispersion factors for the 2 chemical spill sites are given in Table 4-8.

TABLE 4-1. DATA FOR DESIGN BASIS LOCA ACCIDENT

		Dose Conversion Factors, Rem/hr per Ci/m^3	
Isotope *	Curies Released	Beta, Skin	Gamma, Whole Body
I-131	4.74E+3	2.11E+2	3.14E+2
I-132	3.36E+2	5.64E+3	1.85E+3
I-133	8.32E+3	4.46E+2	5.58E+2
I-134	3.99E+2	6.82E+2	1.92E+3
I-135	9.01E+2	3.31E+2	1.52E+3
Kr-83m	7.80E+3	3.86E+1	2.70E-1
Kr-85m	6.90E+3	2.68E+2	1.31E+2
Kr-85	7.78E+4	2.45E+2	1.71E+0
Kr-87	3.79E+3	1.36E+3	6.48E+2
Kr-88	1.21E+4	3.59E+2	1.68E+3
Kr-89	2.81E+2	N/A[a]	N/A[a]
Xe-131m	4.75E+3	1.44E+2	9.92E+0
Xe-133m	7.97E+3	1.94E+2	2.69E+1
Xe-133	5.94E+5	1.51E+2	3.26E+1
Xe-135m	5.92E+2	9.96E+1	3.54E+2
Xe-135	1.93E+4	2.49E+2	2.04E+2
Xe-137	4.36E+2	1.86E+3	1.51E+2
Xe-138	2.30E+2	7.19E+2	6.81E+2

a. Not available

* Iodine Source terms are used only to Calculate Gamma Whole Body and Beta Skin doses. This was to account for doses associated with iodine and is conservative.

TABLE 4-2. PROPERTIES AND STORAGE OF AMMONIUM HYDROXIDE

Density of 29.4 wt. % aqueous solution		.897 gm/cm^3
Molecular Weight of Ammonia		17.03
Molecular Weight of Water		18.016
Diffusivity of NH_3 in air	80°F:	.200 cm^2/sec
	100°F:	.214 cm^2/sec
Diffusivity of H_2O in air	80°F:	.261 cm^2/sec
	100°F:	.279 cm^2/sec
Relative Humidity of Ambient Air		50%
Volume of Storage Tank		7000 gallons
Distance of Storage Tank from Intake Vent		182 m

TABLE 4-3. PROPERTIES AND STORAGE OF LIQUID CHLORINE

Molecular Weight		70.914
Normal Boiling Point		-34.05°C
Heat of Vaporization		68.79 cal/gm
Density of Saturated Liquid		1.557 gm/cm^3
Heat Capacity of Saturated Liquid		.222 cal/gm°C
Relative Vapor Density		2.45
Vapor Pressure	80°F:	116.49 psia
	100°F:	157.09 psia
Mass of Chlorine in One Tank		2000 lb
Distance of River Water Chlorinator from Intake Vent		100 m
Distance of Unit 1 Chlorinator from Intake Vent		354 m

TABLE 4-4. VALUES USED IN AUXFLOW MODEL

V_1 = 799316 ft^3
V_2 = 584370 ft^3
V_3 = 275450 ft^3
u_o = 120761 ft^3/min
u_1 = 59748 ft^3/min
u_2 = 16048 ft^3/min
u_3 = 2539 ft^3/min
u_4 = 1000 ft^3/min

TABLE 4-5. CONTROL ROOM ISOLATION ZONE FLOW RATES FOR VARIOUS CONDITIONS, cfm

Flow Conditions	U_o (a)	U_B	U_{I1}	U_{I2}	U_{I3}	U_{O1}	U_{O2}	U_{O3}
Economizer Mode	69667 (b)	25383	13660	15810	8074	0 (b)	0 (b)	0 (b)
Normal Mode, 20% Outside Air	32880	25383	13660	15810	8074	10880	12648	6459
Emergency Mode	3000	-	11755	13666	6979	10667	12401	6332
Emergency Mode	4000	-	11755	13666	6979	10304	11979	6117
Emergency Mode	5000	-	11755	13666	6979	9941	11557	5902
Emergency Mode	6000	-	11755	13666	6979	9578	11135	5687
Emergency Mode	7000	-	11755	13666	6979	9215	10713	5471
Emergency Mode	8000	-	11755	13666	6979	8853	10292	5256
Emergency Mode	9000	-	11755	13666	6979	8490	9870	5040
Emergency Mode	10000	-	11755	13666	6979	8127	9448	4825
Emergency Mode	11000	-	11755	13666	6979	7764	9026	4610
Emergency Mode	12000	-	11755	13666	6979	7401	8605	4394
Emergency Mode	13000	-	11755	13666	6979	7038	8183	4179
Emergency Mode	14000	-	11755	13666	6979	6676	7761	3963
Emergency Mode	15000	-	11755	13666	6979	6313	7339	3748
Emergency Mode	16000	-	11755	13666	6979	5950	6917	3533
Emergency Mode	17000	-	11755	13666	6979	5587	6496	3317
Emergency Mode	18000	-	11755	13666	6979	5224	6074	3102
Emergency Mode	19000	-	11755	13666	6979	4862	5652	2886
Emergency Mode	20000	-	11755	13666	6979	4499	5230	2671
Emergency Mode	21000	-	11755	13666	6979	4136	4808	2456

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TABLE 4-6. JOINT FREQUENCY TABLE - NUMBER OF OCCURRENCES OF WIND SPEED AND DIRECTION FOR EACH STABILITY CLASS

JULY 1976-JUNE 1977

STABILITY A

SPEED	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
CALM	1	0	1	0	0	0	1	0	0	1	0	0	0	0	0	2
1.5 MPH	3	2	0	0	0	0	3	1	0	1	3	7	3	2	5	8
2.5 MPH	10	6	4	0	0	1	3	0	2	2	3	5	7	8	11	10
3.5 MPH	7	7	2	2	5	2	1	4	1	2	4	6	4	6	5	14
4.5 MPH	18	12	1	2	4	4	3	2	3	2	11	17	14	5	7	17
5.5 MPH	24	7	3	1	0	2	4	5	4	2	10	8	9	9	13	13
6.5 MPH	15	14	5	5	3	2	1	6	2	3	6	13	12	5	14	15
7.5 MPH	13	6	3	1	1	0	0	4	2	3	6	9	9	7	19	18
12.5 MPH	57	17	7	6	4	3	7	7	7	29	38	26	49	65	86	79
18.5 MPH	24	4	1	0	0	1	2	5	1	7	13	7	32	40	56	38
24.5 MPH	4	1	0	0	0	0	0	0	0	0	0	0	0	6	17	7
24.6+MPH	6	1	0	0	0	0	0	0	0	0	0	0	0	1	3	5

STABILITY B

SPEED	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
CALM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.5 MPH	1	2	0	0	0	0	0	0	0	0	0	0	1	1	0	0
2.5 MPH	1	0	1	1	0	0	0	0	0	0	1	2	2	0	0	2
3.5 MPH	1	1	0	0	0	0	1	1	2	0	1	1	0	1	4	1
4.5 MPH	1	0	0	0	0	0	2	0	1	1	1	3	2	0	0	3
5.5 MPH	0	2	0	0	0	1	3	1	2	2	0	2	1	2	1	0
6.5 MPH	2	0	2	2	0	0	1	1	2	1	0	0	0	3	2	5
7.5 MPH	1	0	0	0	0	0	1	0	0	0	1	1	0	1	1	1
12.5 MPH	2	0	0	3	1	0	2	1	1	7	7	4	10	8	10	12
18.5 MPH	3	2	0	0	0	0	1	0	0	0	1	2	5	6	9	9
24.5 MPH	1	0	0	0	0	0	1	0	0	0	0	0	0	2	4	5
24.6+MPH	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1

STABILITY C

SPEED	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
CALM	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
1.5 MPH	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	0
2.5 MPH	0	1	0	0	0	1	1	0	0	0	2	0	1	0	1	0
3.5 MPH	0	1	1	0	1	1	0	0	1	1	1	0	0	1	0	1
4.5 MPH	1	0	0	0	0	0	0	1	1	1	3	1	2	0	1	0
5.5 MPH	0	0	1	1	0	1	0	1	0	2	2	2	1	1	0	0
6.5 MPH	0	0	0	1	0	2	0	0	2	1	3	3	0	1	0	1
7.5 MPH	0	0	0	0	1	1	0	1	1	3	2	1	1	1	1	2
12.5 MPH	4	3	1	1	1	1	1	0	2	6	3	0	4	6	8	4
18.5 MPH	4	0	0	0	0	0	0	0	0	3	2	0	3	4	4	4
24.5 MPH	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	2
24.6+MPH	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0

STABILITY D

SPEED	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
CALM	0	0	3	0	1	0	0	0	0	1	0	1	0	0	1	0
1.5 MPH	5	6	7	5	5	3	3	4	4	5	3	3	5	5	4	5
2.5 MPH	5	8	11	14	8	7	3	7	2	4	6	4	9	6	8	9
3.5 MPH	18	11	7	5	14	13	10	11	8	10	10	13	8	6	12	10
4.5 MPH	13	9	8	10	12	15	13	9	16	16	14	11	10	10	8	17
5.5 MPH	7	12	4	9	14	18	11	16	16	15	14	14	5	9	12	11
6.5 MPH	11	9	8	8	13	16	18	14	19	17	13	13	11	12	7	5
7.5 MPH	11	6	5	4	11	14	14	8	14	9	7	10	14	15	14	10
12.5 MPH	16	9	9	8	18	45	21	18	34	40	27	27	63	95	125	55
18.5 MPH	12	3	0	0	1	2	5	0	2	12	19	9	27	87	93	46
24.5 MPH	2	1	0	0	0	0	0	1	0	1	1	0	6	36	48	12
24.6+MPH	0	0	0	0	0	0	0	0	0	0	0	0	2	13	15	2

TABLE 4-6 (continued)

STABILITY E

SPEED	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
CALM	0	1	2	1	3	0	1	1	0	1	0	1	2	2	3	1
1.5 MPH	16	8	9	9	10	5	11	5	4	5	10	10	17	4	8	9
2.5 MPH	12	11	15	8	11	15	9	11	7	5	10	12	10	13	10	14
3.5 MPH	17	19	15	12	19	18	20	16	18	19	22	21	24	12	18	21
4.5 MPH	24	15	22	14	23	12	13	25	23	15	19	22	26	22	19	27
5.5 MPH	19	12	8	8	17	14	21	27	19	19	23	28	46	25	23	30
6.5 MPH	17	11	14	4	12	13	15	10	15	22	21	23	45	21	23	27
7.5 MPH	14	16	7	6	11	13	14	6	24	26	15	20	35	36	18	23
12.5 MPH	27	22	10	6	10	12	19	11	28	60	43	32	73	119	103	73
18.5 MPH	15	3	0	0	1	0	0	1	2	9	5	3	18	54	52	20
24.5 MPH	1	2	0	0	0	0	0	1	0	0	0	0	3	14	9	3
24.6+MPH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0

STABILITY F

SPEED	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
CALM	0	1	4	0	2	2	2	1	1	2	1	1	1	2	2	0
1.5 MPH	5	13	8	9	11	10	8	4	11	10	11	6	15	10	11	4
2.5 MPH	11	1	5	10	12	9	10	9	5	11	11	12	12	13	17	10
3.5 MPH	7	9	5	7	6	14	11	4	11	9	11	13	17	8	9	16
4.5 MPH	16	8	7	5	5	9	8	9	11	10	22	14	27	8	17	13
5.5 MPH	10	4	8	5	3	2	2	7	1	8	10	7	10	12	8	9
6.5 MPH	3	7	1	1	4	0	3	4	3	7	10	8	12	4	3	11
7.5 MPH	4	1	0	1	3	0	0	1	3	2	2	3	9	8	6	5
12.5 MPH	12	3	0	0	2	3	2	0	2	3	4	8	8	3	4	7
18.5 MPH	1	0	0	0	0	0	0	0	0	1	0	0	0	2	0	1
24.5 MPH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24.6+MPH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

STABILITY G

SPEED	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
CALM	0	3	5	0	0	2	1	1	2	0	1	1	0	2	0	0
1.5 MPH	5	2	8	4	6	4	2	5	9	9	11	6	11	2	6	3
2.5 MPH	5	3	4	3	13	12	8	7	3	5	12	4	7	3	10	4
3.5 MPH	3	6	8	10	13	11	3	7	9	5	9	12	14	11	7	8
4.5 MPH	4	7	5	1	2	3	2	5	11	6	8	7	9	4	10	6
5.5 MPH	4	1	1	0	5	3	2	1	1	5	4	2	4	1	3	9
6.5 MPH	4	0	0	2	0	2	0	2	3	5	1	2	1	1	1	3
7.5 MPH	7	0	0	0	1	1	0	0	0	0	0	1	2	1	0	2
12.5 MPH	3	0	0	0	1	0	0	1	0	0	0	2	0	2	0	3
18.5 MPH	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
24.5 MPH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24.6+MPH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 4-7. DATA FOR AND RESULTS FROM MURPHY-CAMPE METHOD FOR THE DESIGN BASIS LOCA

Source Type: Diffuse

Receptor Type: Point

Containment Diameter, d: 41.76 m

Source-Receptor Distance, s: 20.9 m

Containment Projected Area: 1985 m^2

Wind Direction Sectors that result in exposure: N, NNE, NE, ENE, E
WSW, W, WNW, NW, NNW

K factor: 7.917

σ_y for 5% stability: negligible

σ_z for 5% stability: negligible

5% windspeed: 0.67 m/s

10% windspeed: 1.12 m/s

20% windspeed: 1.56 m/s

40% windspeed: 2.46 m/s

F factor: 0.7090

χ/Q, 0-8 hrs: 7.45E-3 sec/m^3

χ/Q, 8-24 hrs: 4.15E-3 sec/m^3

χ/Q, 1-4 days: 2.73E-3 sec/m^3

χ/Q, 4-30 days: 1.44E-3 sec/m^3

TABLE 4-8. VALUES OF Xu/Q FOR CHEMICAL RELEASES

Unit 1 Chlorinator to Exhaust Vent
Wind Directions NNE and NE

Stability Class	Xu/Q (m^{-2})
A	5.70E-5
B	1.10E-4
C	1.99E-4
D	3.40E-4
E	5.30E-4
F	6.40E-4
G	7.00E-4

Unit 1 Ammonium Hydroxide Storage Tank to Exhaust Vent
All Stability Classes

Wind Direction	Xu/Q (m^{-2})
NE	1.38E-4
ENE	1.10E-4
E	4.14E-4

5. ANALYSIS PROCEDURE

In this section, the calculational procedures used in each part of the analysis are detailed. The flow rate assumptions and the codes used are given.

5.1 ANALYSIS OF THE LARGE BREAK LOCA VIA THE EXHAUST DAMPER

In this case, it is assumed that the dampers close upon the ES actuation signal, but that the emergency fans do not go on until the radiation detectors in the control room detect abnormal radiation levels. This is assumed to occur one minute into the accident. The flow rate is the same in either flow condition; only the filter efficiency changes (0.0 before emergency mode activation, 0.90 afterwards). The intake flow rate was varied between 3000 to 21000 cfm in increments of 1000 cfm, with either 200 cfm or 2000 cfm assumed to leak through the exhaust damper, and the remainder flowing through the control building intake system. Since the dose is a linear function of the leakage rate through the damper for a given total intake flow rate, the limiting leakage rate may be determined as a function of total intake flow rate.

For this part of the analysis, the HYDROS code is coupled directly with the CRDOSE code, with one HYDROS run providing input for all of the CRDOE runs.

5.2 ANALYSIS OF THE DESIGN BASIS LOCA VIA THE AUXILIARY AND FUEL HANDLING BUILDINGS

As in the case above, it is assumed that the dampers close upon the ES actuation signal. However, due to the small dose rates expected, the radiation detectors are not assumed to detect abnormal radiation levels, thus no filtration is assumed. Emergency flow rates were used. The intake flow rate was varied between 3000 cfm and 2100C cfm total with 1000 cfm assumed to flow via the auxiliary building - fuel handling building flow path, and with the entire release directed into the auxiliary building. The results were extrapolated to determine the maximum allowable flow rate through the Auxiliary Building - Fuel Handling Building flow path as a function of total intake flow rate.

For this part of the analysis, the HYDROS code is coupled to the CRDOSE code via the AUXFLOW code in order to model the Auxiliary Building - Fuel Handling Building flow path.

5.3 ANALYSIS OF THE UNIT 1 AMMONIUM HYDROXIDE TANK RUPTURE VIA THE EXHAUST VENT

The rupture of the Unit 1 ammonium hydroxide storage tank was analyzed using the NH3VAP code in conjunction with the CRCONI code to find the ammonium concentration in the control room as a function of time. Two cases were run: one with the control room ventilation system in the economizer mode, the other with the outside air reduced to 20% of the total flow. In both cases, the 5% worst meteorological case and the actual dike area of 453 square feet were used.

5.4 ANALYSIS OF THE CHLORINE TANK RUPTURE AT THE UNIT 1 CHLORINATOR VIA THE EXHAUST VENT

The rupture of a one tone chlorine tank at the Unit 1 chlorinator was analyzed using the CL2VAP code in conjunction with the CRCONI code to find the chlorine concentration in the control room as a function of time. Two cases were run: one with the control room ventilation system in the economizer mode, the other with the outside air reduced to 20% of the total flow. In both cases, the 5% worst meteorological case was used.

6. RESULTS OF THE ANALYSIS

The results of the analysis performed for each accident type are given in separate sections below.

6.1 DOSES TO CONTROL ROOM PERSONNEL FROM THE DESIGN BASIS LOCA VIA THE EXHAUST VENT

The beta skin dose and gamma whole body dose are given as a function of total intake flow rate for leakage rates through the exhaust damper of 200 cfm and 2000 cfm in Tables 6-1 and 6-2. Doses are computed using Murphy-Campe occupancy factors for thirty days starting with accident initiation. In Table 6-3, and Figure 6-1, the limiting leakage rates for beta skin dose not to exceed 30 rem are given. The leakage rates required for the gamma whole body dose to exceed 5 rem are larger than those for the beta skin dose to exceed 30 rem for all flow rates, and thus are not given.

6.2 DOSES TO CONTROL ROOM PERSONNEL FROM THE DESIGN BASIS LOCA VIA THE AUXILIARY AND FUEL HANDLING BUILDINGS

The thirty-day beta skin dose and gamma whole body dose are given in Table 6-4 as a function of total intake flow rate for a constant leakage rate of 1000 cfm into the control building envelope for this flow path. Release of all containment leakage into the auxiliary building is assumed. In Table 6-5 and Figure 6-2, the limiting leakage rates for beta skin dose not to exceed 30 rem are given. The leakage rates required for the gamma whole body dose to exceed 5 rem are larger than the total flow rate for all flow rates, and thus are not given.

6.3 RESULTS OF THE UNIT 1 AMMONIUM HYDROXIDE TANK RUPTURE VIA THE EXHAUST VENT

The maximum concentrations of ammonia in the control room for these scenarios are 3.44 ppm with the system in the economizer mode and 17.75 ppm with 20% outside air. In both cases, a leakage rate of 3500 cfm through the exhaust damper is assumed. These values are well below the 100 ppm limit.

6.4 RESULTS OF THE RUPTURE OF A CHLORINE TANK AT THE UNIT 1 CHLORINATOR HOUSE VIA THE EXHAUST VENT

The maximum concentrations of chlorine in the control room for these scenarios are 2.62 ppm with the system in the economizer mode and 7.31 ppm with 20% outside air. In both cases, a leakage rate of 3500 cfm through the exhaust damper is assumed. In order to reduce the peak level in the latter case to the 3 ppm limit, the leakage rate must be reduced to below 1436 cfm.

TABLE 6-1. DOSE TO CONTROL ROOM PERSONNEL VS. TOTAL INTAKE FLOW RATE WITH 200 cfm LEAKAGE THROUGH EXHAUST DAMPER

U_o	Beta Skin Dose	Gamma Dose
3000	4.985	0.196
4000	4.340	0.172
5000	3.936	0.156
6000	3.665	0.145
7000	3.466	0.137
8000	3.316	0.131
9000	3.196	0.126
10000	3.099	0.122
11000	3.019	0.119
12000	2.954	0.116
13000	2.895	0.113
14000	2.842	0.111
15000	2.802	0.109
16000	2.766	0.108
17000	2.731	0.106
18000	2.699	0.105
19000	2.673	0.103
20000	2.653	0.102
21000	2.627	0.101

TABLE 6-2. DOSE TO CONTROL ROOM PERSONNEL VS. TOTAL INTAKE FLOW RATE INCLUDING 2000 cfm THROUGH EXHAUST DAMPER

U_o	Beta Skin Dose	Gamma Dose
3000	31.230	1.342
4000	24.664	1.091
5000	20.585	0.931
6000	17.777	0.818
7000	15.750	0.734
8000	14.198	0.669
9000	12.999	0.618
10000	11.983	0.573
11000	11.148	0.536
12000	10.465	0.505
13000	9.898	0.479
14000	9.361	0.454
15000	8.926	0.434
16000	8.533	0.415
17000	8.189	0.399
18000	7.882	0.384
19000	7.599	0.371
20000	7.347	0.358
21000	7.118	0.347

TABLE 6-3. LIMITING FLOW RATES THROUGH EXHAUST DAMPER TO AVOID EXCEEDENCES OF LIMITING BETA SKIN DOSE

Total Flow Rate (cfm)	Limiting Flow Rate (cfm) Beta Skin Dose
3000	1915
4000	2472
5000	3017
6000	3559
7000	4088
8000	4613
9000	5121
10000	5650
11000	6174
12000	6681
13000	7166
14000	7684
15000	8194
16000	8700
17000	9193
18000	9681
19000	10185
20000	10686
21000	11171

TABLE 6-4. DOSE TO CONTROL ROOM PERSONNEL VS. TOTAL INTAKE FLOW RATE FOR RELEASE INTO AUXILIARY BUILDING

Total Flow Rate (cfm)	Beta Skin Dose (rem)	Gamma Whole Body Dose (rem)
3000	9.814	0.381
4000	7.421	0.294
5000	6.034	0.239
6000	5.059	0.202
7000	4.366	0.176
8000	3.835	0.155
9000	3.413	0.139
10000	3.008	0.126
11000	2.819	0.116
12000	2.591	0.107
13000	2.391	0.099
14000	2.219	0.092
15000	2.075	0.086
16000	1.945	0.081
17000	1.844	0.077
18000	1.743	0.073
19000	1.656	0.069
20000	1.569	0.066
21000	1.496	0.063

TABLE 6-5. LIMITING FLOW RATES INTO CONTROL BUILDING ENVELOPE FOR AUXILIARY BUILDING RELEASE TO AVOID EXCEEDANCES OF LIMITING BETA SKIN DOSES

Total Flow Rate (cfm)	Limiting Flow Rate (cfm) Beta Skin Dose
3000	3000*
4000	4000*
5000	4971
6000	5930
7000	6871
8000	7822
9000	8789
10000	9715
11000	10642
12000	11578
13000	12547
14000	13519
15000	14457
16000	15424
17000	16268
18000	17211
19000	18115
20000	19120
21000	20053

*Dose never exceeds limit

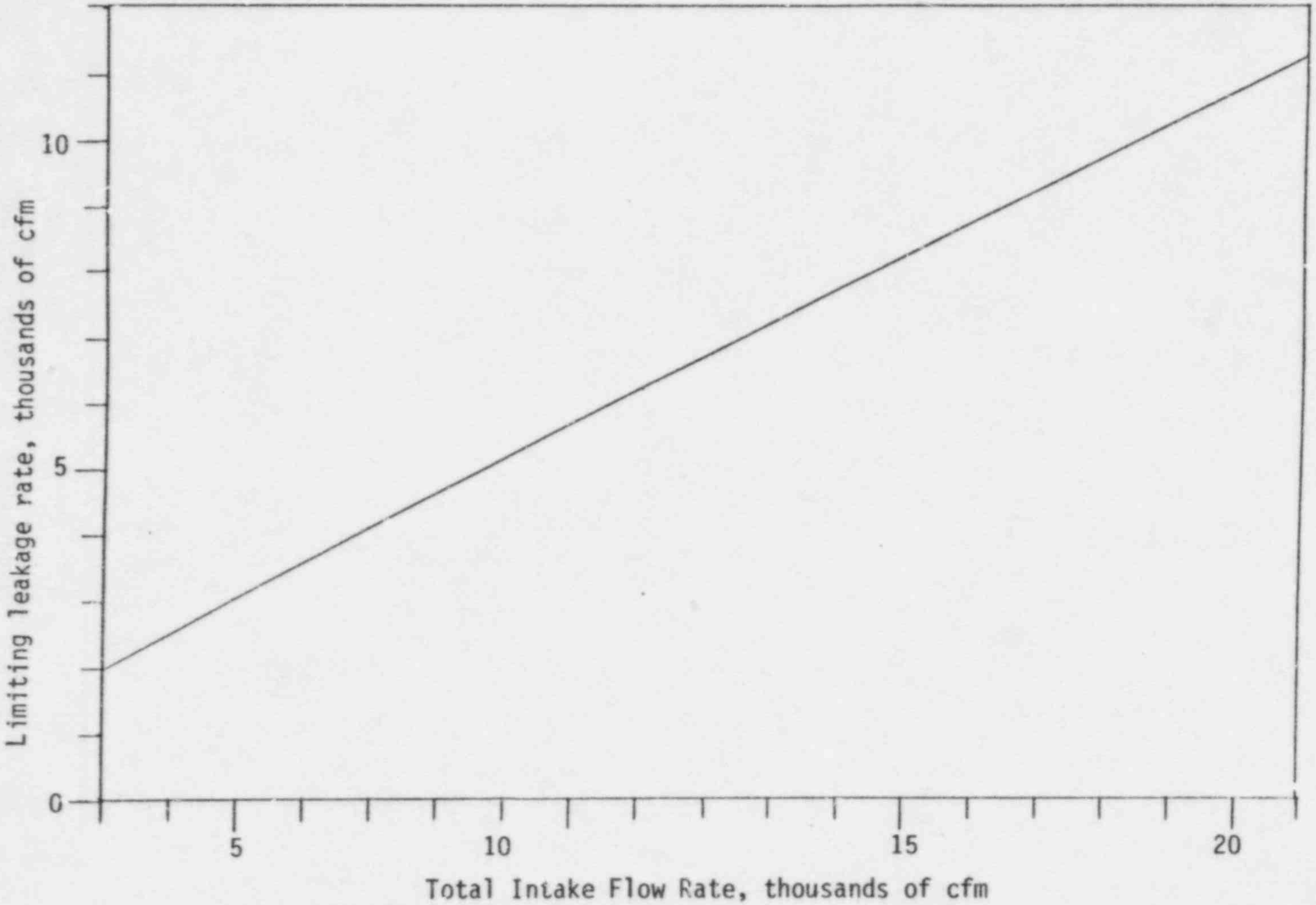

FIGURE 6-1. MAXIMUM LEAKAGE THROUGH EXHAUST DAMPER WHICH WILL NOT RESULT IN EXCEEDING 30 REM BETA SKIN DOSE

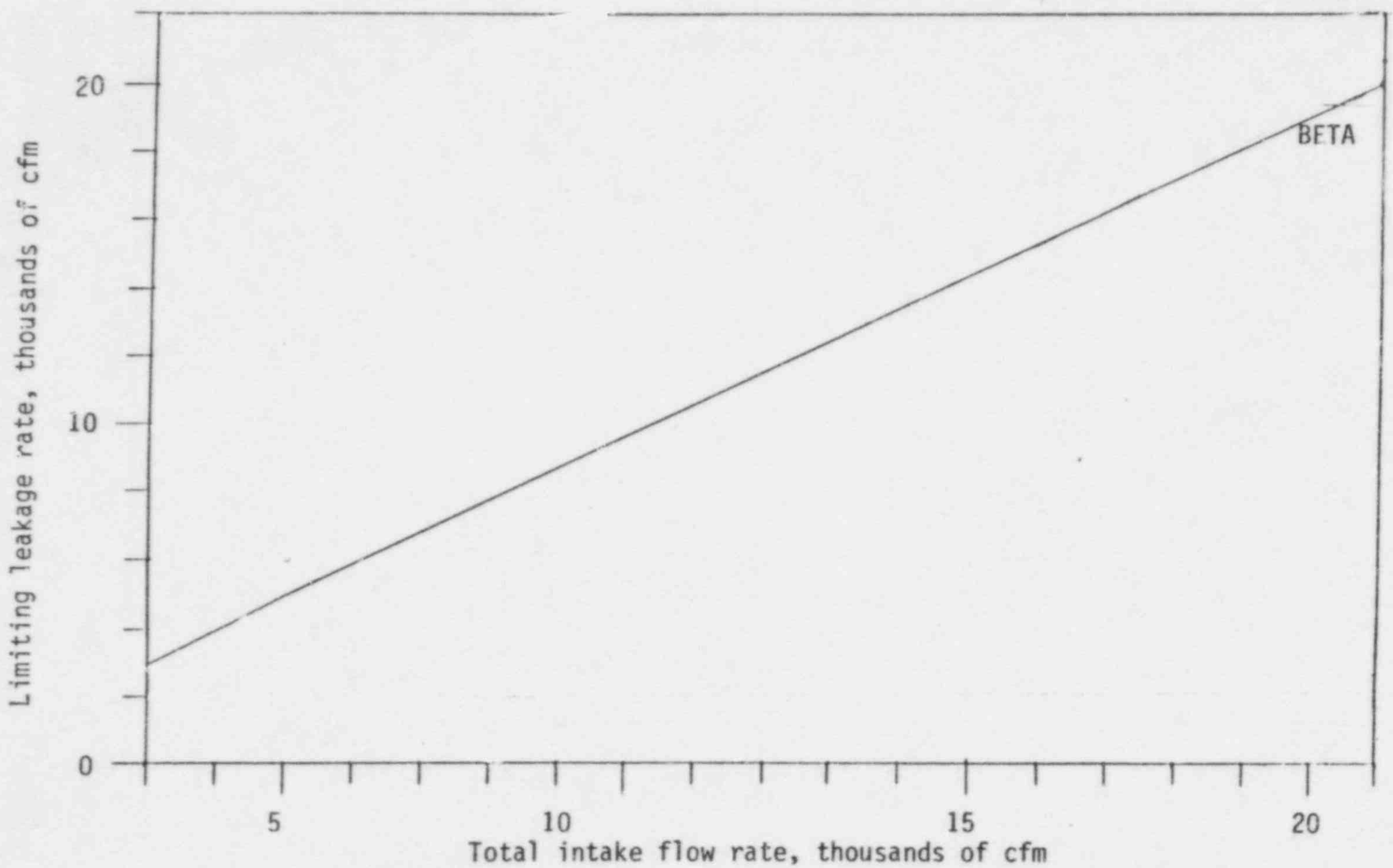

FIGURE 6-2. MAXIMUM ALLOWABLE LEAKAGE INTO CONTROL ROOM ISOLATION ZONE VIA AUXILIARY AND FUEL HANDLING BUILDINGS

7. CONCLUSIONS

From the above analysis, it may be concluded that the beta skin dose will never exceed 30 rem for either of the LOCA cases as long as the flow through the exhaust damper is limited to no more than about 53% of the total intake flow rate for the first case and as long as the leakage via the auxiliary building and fuel handling building is held below 95% of the total flow in the second case.

The rupture of the ammonium hydroxide storage tank results in ammonium concentrations well below the 100 ppm threshold, and thus pose no problem. The chlorine concentration resulting from a rupture at the Unit 1 chlorinator is below the 3.0 ppm limit if the ventilation system is in the economizer mode, but could rise as high as 7.3 ppm if only 20% outside air is used. A reduction of the leakage rate through the damper in this case below about 1430 cfm would remove the possibility of exceedance.

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Calculation of $\chi u/Q$

at

TMI Unit 1 Control Room Exhaust-to-Atmosphere Duct

for

Chlorine and Ammonium Hydroxide Tank Releases

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June 19, 1985

Table of Contents

A 1 Introduction

This Appendix describes the analysis techniques employed to predict $\chi u/Q$ at the Unit 1 control room exhaust-to-atmosphere duct opening, assuming continuous releases at the Unit 1 chlorine tank located between cooling towers A and B, and at the Unit 1 ammonium hydroxide tank located at the base of the east wall of the Unit 1 turbine building.

The duct opening to the atmosphere is in the north wall of the Unit 1 fuel handling building, 89 ft above grade and 10.5 ft below the roof parapet coping. The opening faces the south wall of the containment structure, about 5 ft away. The constricted air space between the containment and fuel handling buildings is closed at its east end. In the event of flow reversal in the duct (duct supplies outside air to control room), replacement air for the constricted air space will be drawn from above and from the west.

The analysis is similar to that in Ref. 1, with adjustment for changed receptor location. For convenience in this analysis, the release and receptor locations will be referred to as "tank" and "vent", respectively.

A 2 General Arrangement

Fig. A-1 shows a plan view of Units 1 and 2, cooling towers A and B, and the locations of the chlorine and ammonium hydroxide tanks and the vent. A chlorine release has a potential for contaminating the vent most strongly in an 033° wind. An ammonium hydroxide release has a potential for contaminating the vent in 045°, 067.5° and 090° winds.

A 3 Chlorine Release

The method of analysis follows that of Ref. 1, Sec. B 2.22. Fig. A-2 is the equivalent of Ref. 1, Fig. B-3. The plume originates at C and is drawn upwind to the fictitious cooling tower plate A, from which it disperses downwind as a volume source. At P, a portion of the A plume is mixed in the pumphouse wake, and the A plume is replaced by a P plume and an A' (depleted A) plume. The R plume of Ref. 1 is omitted because the vent is in the middle of the building complex.

The equation for $\chi u/Q$ is the same as Ref. 1, Eq. 14 :

$$\chi u/Q = \sum_{j=1}^{n} F_j(\pi\sigma_y\sigma_z)^{-1} \exp\left[-0.5(y/\sigma_y)^2\right] \qquad \text{(A-1)}$$

where F_j = fraction of Q assigned to plume j. In this case, n = 2,

$j = 1 = P,\ j = 2 = A'$,

and σ_y and σ_z are the plume sigmas calculated by Ref. 1, Eqs. 10 to 12 at the plate-to-vent distances shown in Fig. A-2.

The values of F_j were calculated by

$$F_1 = F_P = (2\pi\sigma_y\sigma_z)^{-1} \int_{-31}^{29} \exp\left[-0.5(y/\sigma_y)^2\right]dy \int_{0}^{6} \exp\left[-0.5(z/\sigma_z)^2\right]dz \qquad \text{(A-2)}$$

$$F_2 = F_{A'} = 1 - F_1, \qquad \text{(A-3)}$$

using σ_y and σ_z calculated at x = 115 m by Ref. 1, Eqs. 10 to 14.

Numerical values of the plume parameters and calculated values of F_j and $\chi u/Q$ are given in Table A-1.

A 4 Ammonium Hydroxide Release

Figs. A-3, A-4 and A-5 show plan views and elevation sections of the major plant buildings in the three critical wind directions. In each Figure, elevation section B-B is taken longitudinally through the tank in the direction of the wind, and elevation section A-A is taken transversely through the vent, normal to the wind. The dot-dash lines in the sections are outlines of the building contours in the respective viewing directions.

Following the method of analysis in Ref. 1, Sec. B 3.11, $\chi u/Q$ at the vent is given by

$$\chi u/Q = K_c/A \ . \tag{A-4}$$

The estimation of A and vent K_c in the three wind directions was done with the aid of Figs. A-6, A-7 and A-8 which show the equivalent prismatic building (dashed lines) that controls plume formation in the region between tank and vent, and the wind flow and dispersion patterns. The prism dimensions are 98 m square in plan and 37 m high. The reference area in Eq. A-4 is the prism frontal area $A = 98 \times 37 = 3{,}626 \ m^2$.

In an 045° wind (Fig. A-6), the wind sweeping around the northwest side of cooling tower B approaches the prism in a diagonal orientation and flows smoothly over the roof of the turbine building. The wind on the southeast side approaches the building in normal orientation and creates a roof cavity. The tank is located between the two flows. The effluent from the tank will be directed southward along the turbine building wall and up into the roof cavity, but it will be prevented from spreading northward in the cavity by the smooth flow over the roof. Therefore, it is unlikely that the air space will be contaminated from above, and contamination from the west should be small since it will be carried in by side wall cavity return flow from the plume edge. The closest matching configuration is Ref. 2, Fig. 5.27k. A conservative estimate of K_c at the vent is $K_c = 0.5$.

In an 067.5° wind (Fig. A-7), the tank is in the region of normal flow impaction on the east wall of the turbine building, and substantially all of the roof and lee side of the prism will be contaminated. The matching configuration is Ref. 2, Fig. 5.27i. $K_c = 4$ seems appropriate for a location on the downwind side of the roof, near the centerline of the building.

In an 090° wind (Fig. A-8) the flow is substantially normal to the wall of the turbine building, but it has a small component toward the north due to the presence of the cavity of cooling tower B. Higher concentrations are to be expected on the north side of the prism. The vent, being on the opposite side, will experience lower concentrations. The effect of the asymmetry may be estimated using Ref. 3, Fig. 1.20. A value of $K_c = 1.5$ seems appropriate.

Using $A = 3{,}626\ m^2$ and K_c values specified above, we obtain

Wind direction	045°	067.5°	090°
K_c	0.5	4.0	1.5
$\chi u/Q\ (m^{-2}) = K_c/A$	1.38-04	1.10-03	4.14-04

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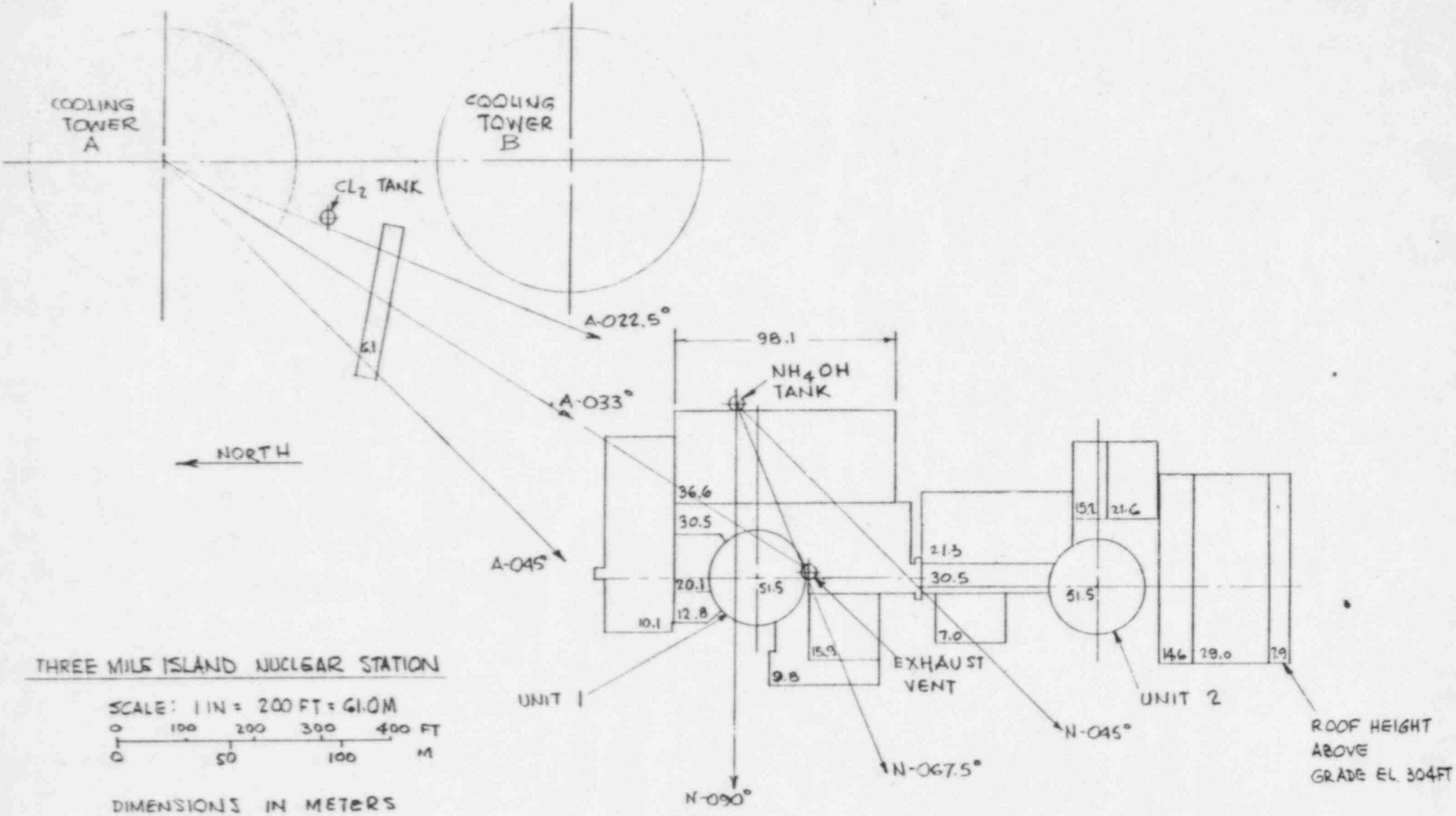
Table A-1 Values of $\chi u/Q$ for Chlorine Release

Plume parameters

Designation	A'	P
σ_{yo} (m)	24.8	12.0
σ_{zo} (m)	6.4	2.4
x (m)	344	299
y (m)	0	1

Plume fractions and dispersion factors

Stability class	$F_{A'}$	F_P	Total $\chi u/Q$ (m^{-2}) at vent
A	0.93	0.07	5.70-05
B	0.88	0.12	1.10-04
C	0.83	0.17	1.99-04
D	0.77	0.23	3.40-04
E	0.70	C.30	5.30-04
F	0.67	0.33	6.40-04
G	0.65	0.35	7.00-04



THREE MILE ISLAND NUCLEAR STATION

SCALE: 1 IN = 200 FT = 61.0M

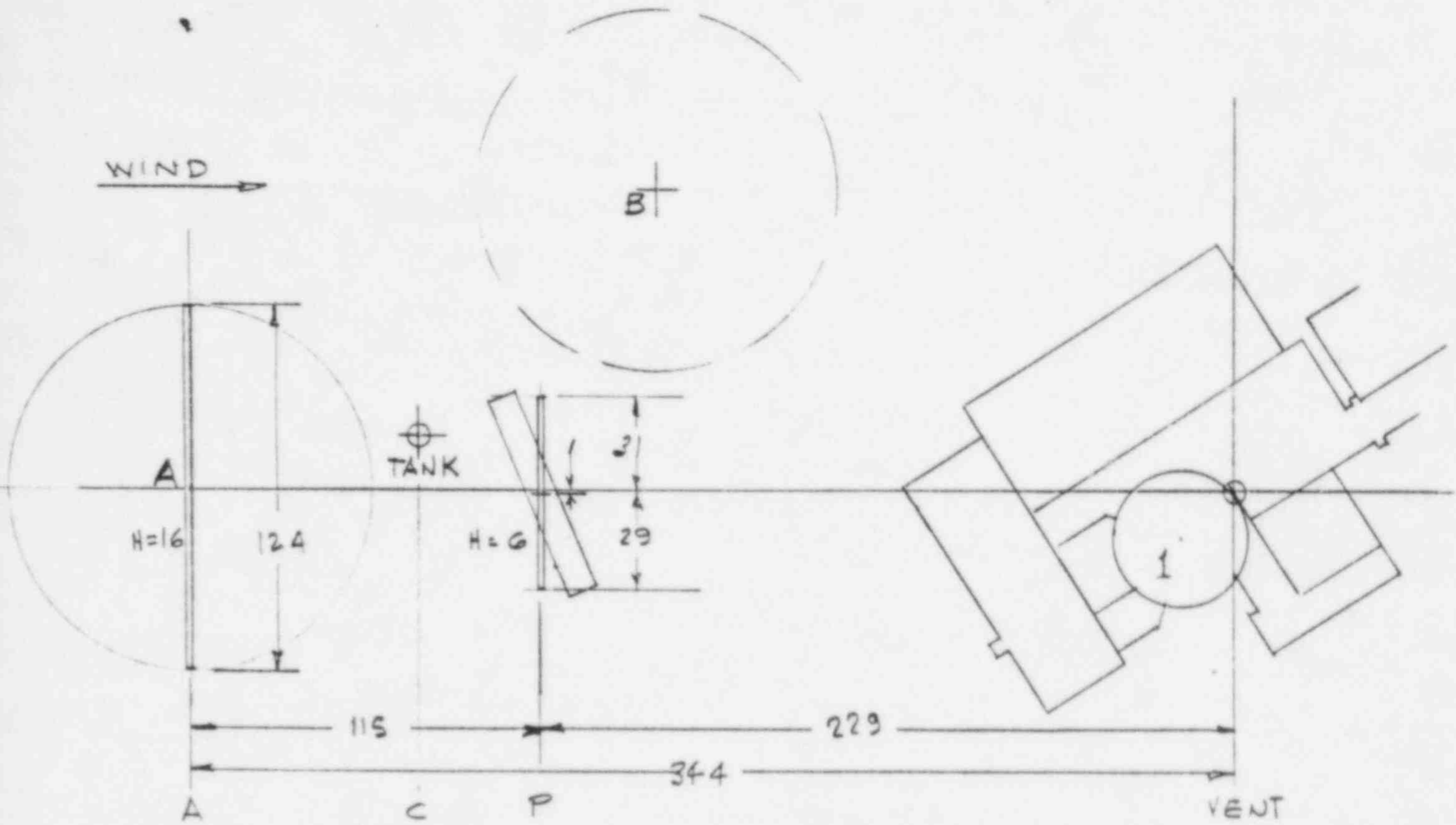
0 100 200 300 400 FT

0 50 100 M

DIMENSIONS IN METERS

J. HALITSKY
6/17/85

FIG. A-1 GENERAL ARRANGEMENT



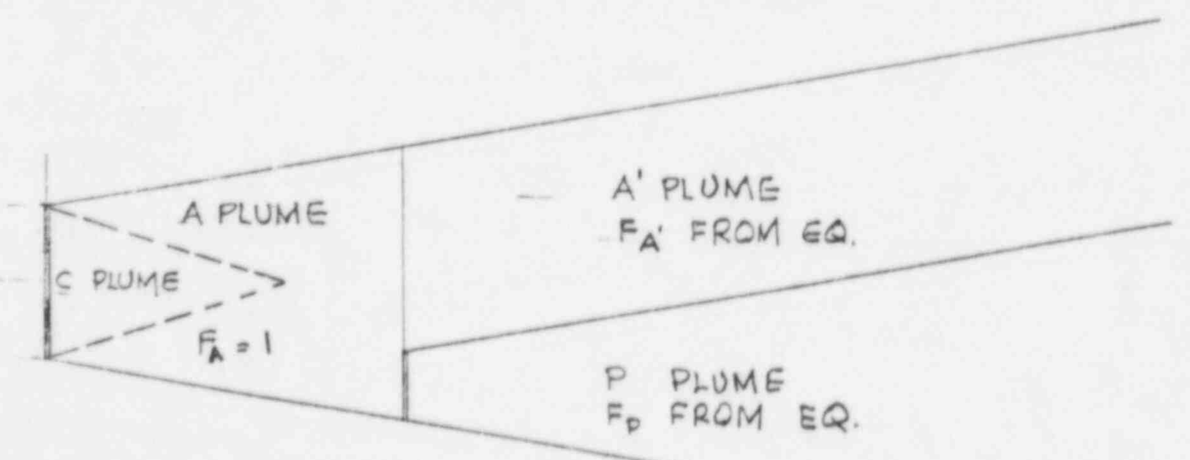


FIG. A-2 CHLORINE RELEASE IN AN 033° WIND

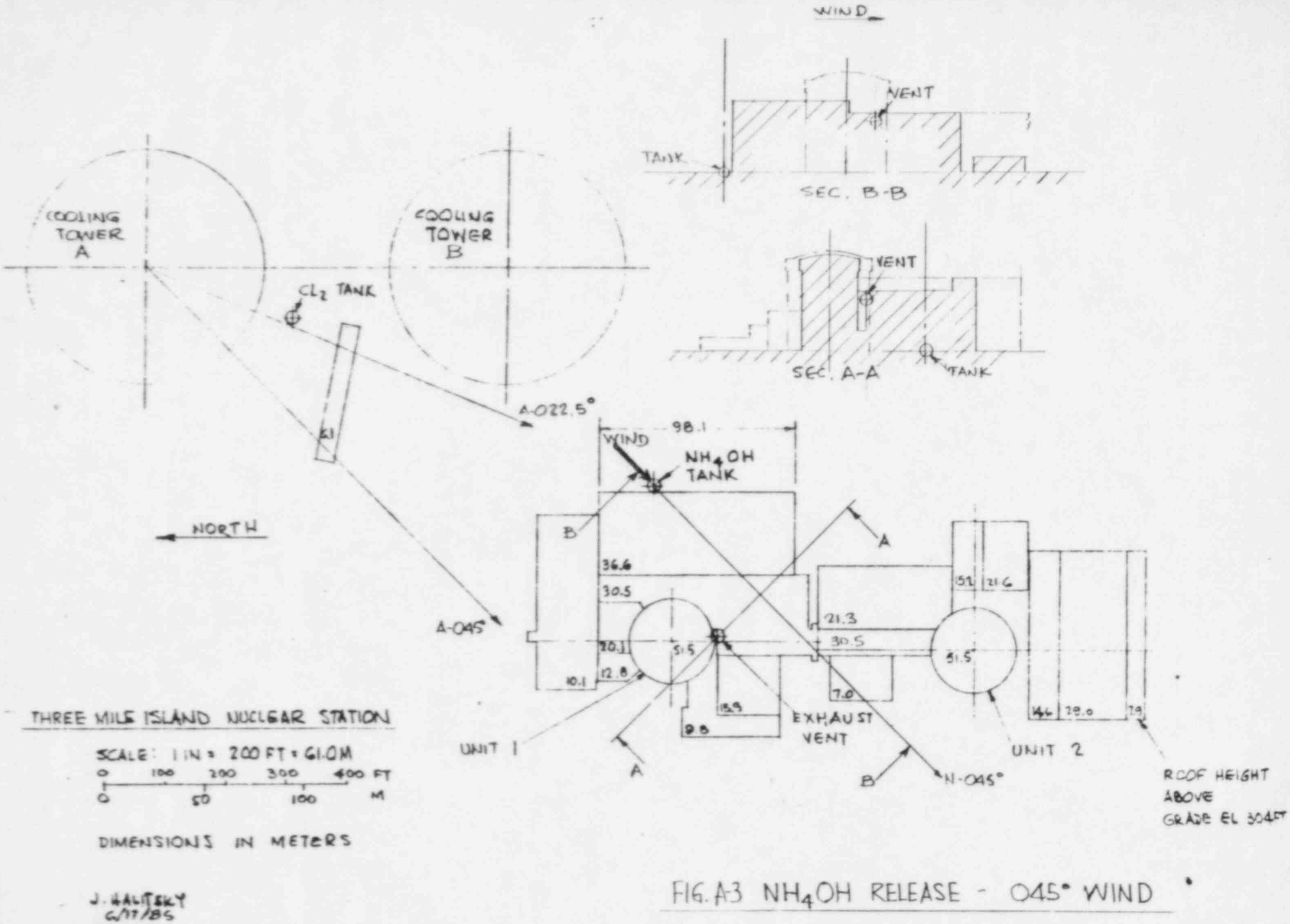


FIG. A-3 NH_4OH RELEASE - 045° WIND

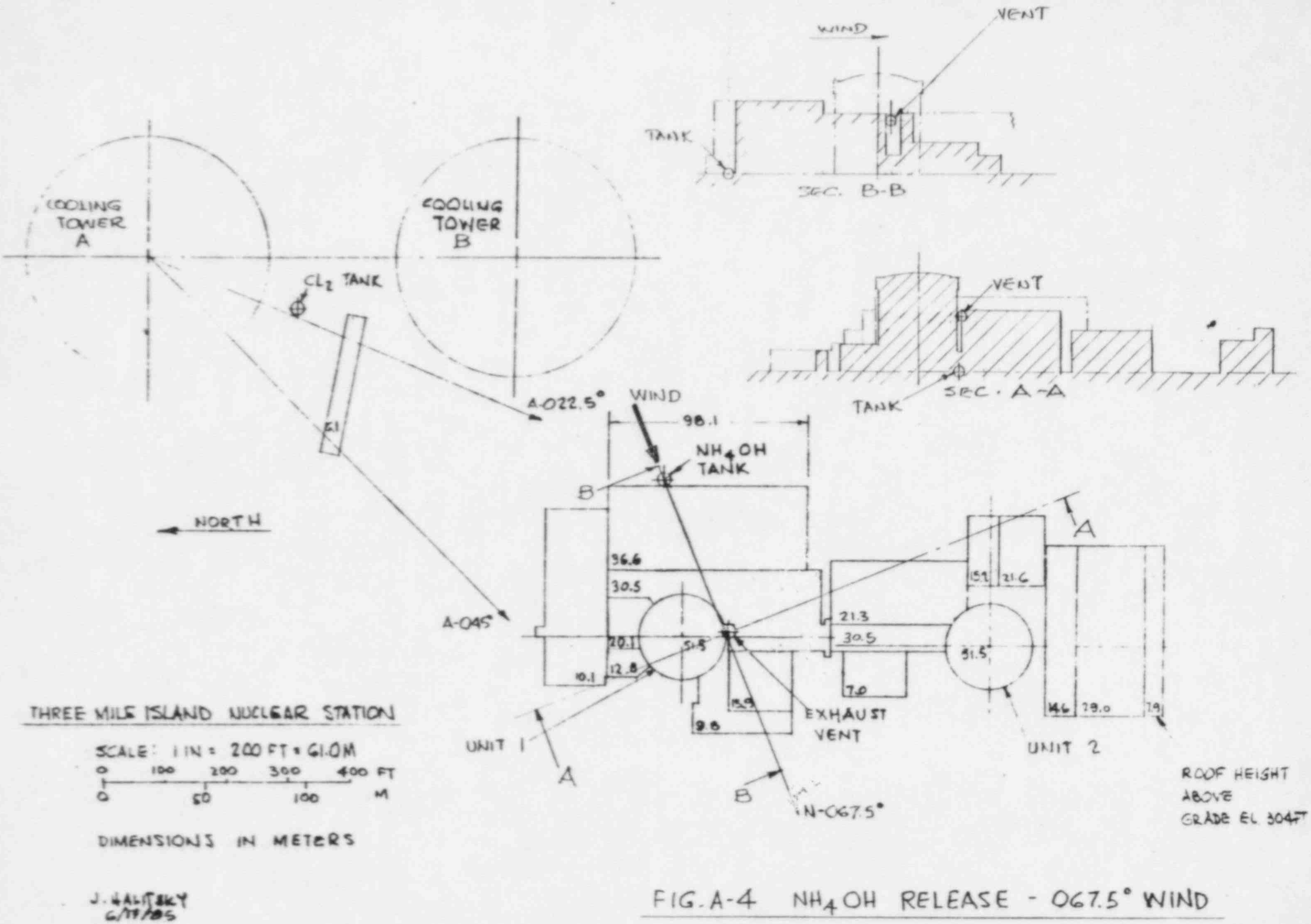


FIG. A-4 NH_4OH RELEASE - 067.5° WIND

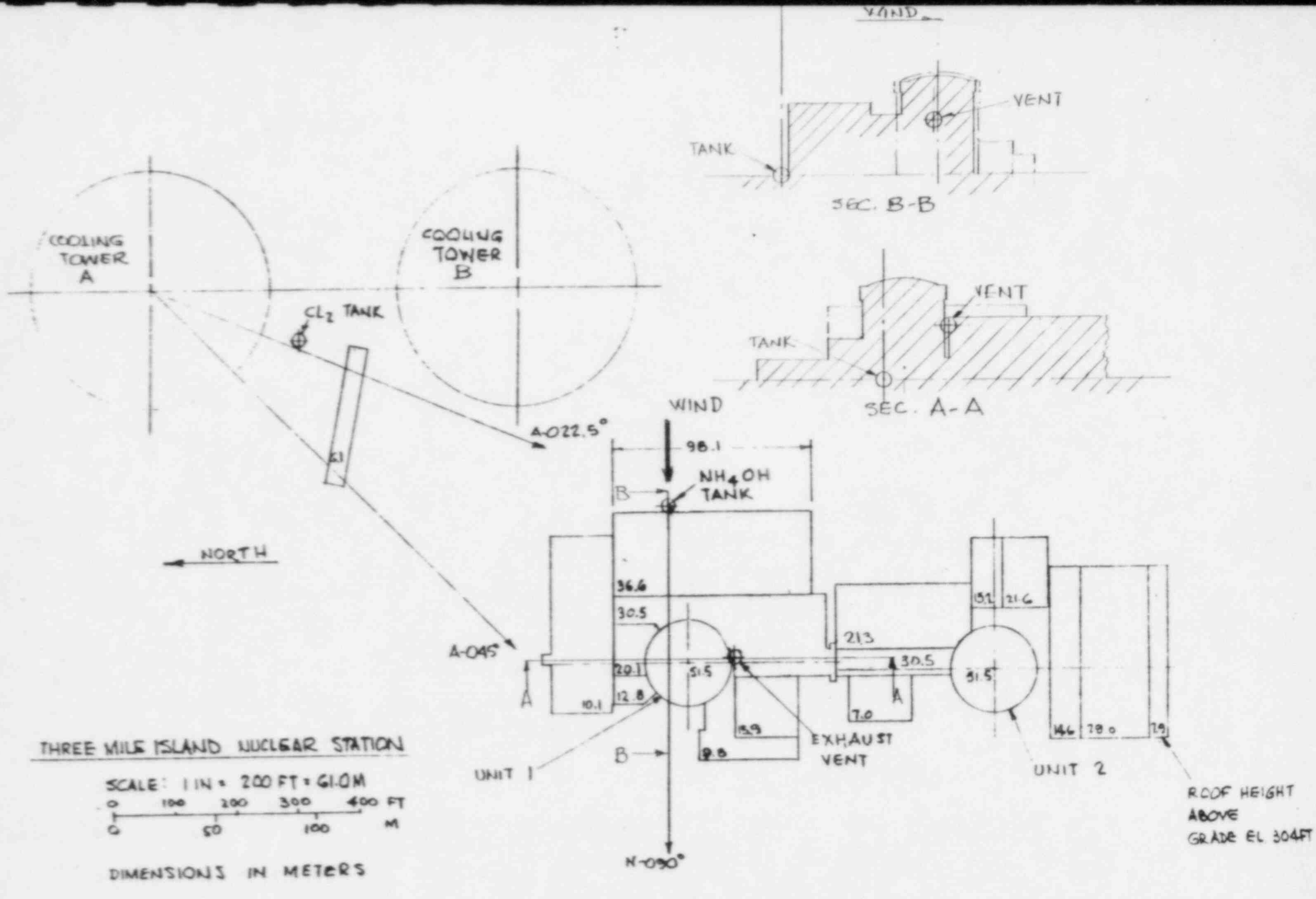
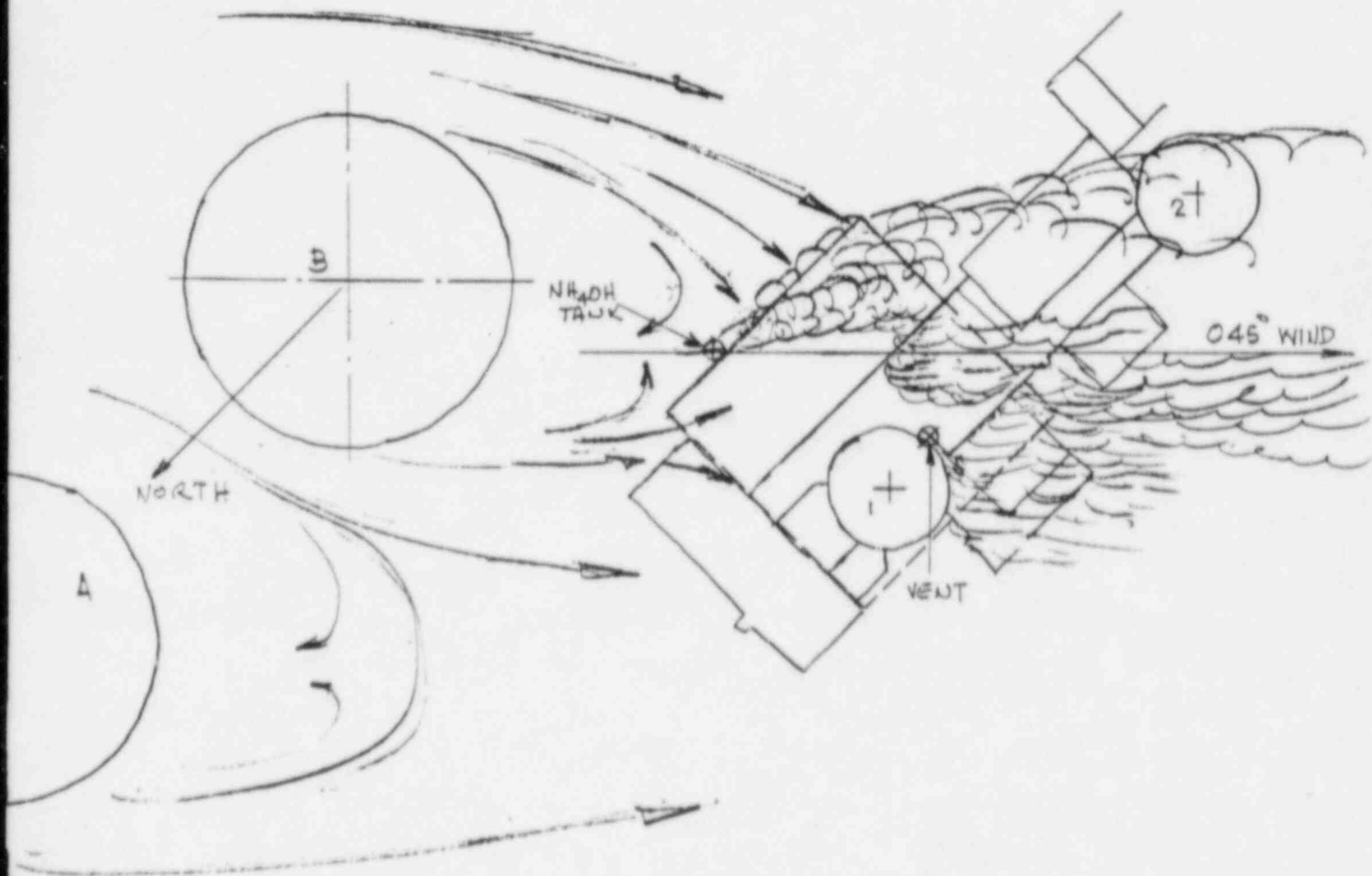


FIG. A-5 NH_4OH RELEASE · 090° WIND



SCALE: 1 IN = 200 FT

FIG. A-6 DISPERSION PATTERNS IN AN 045° WIND
NH_4OH RELEASE

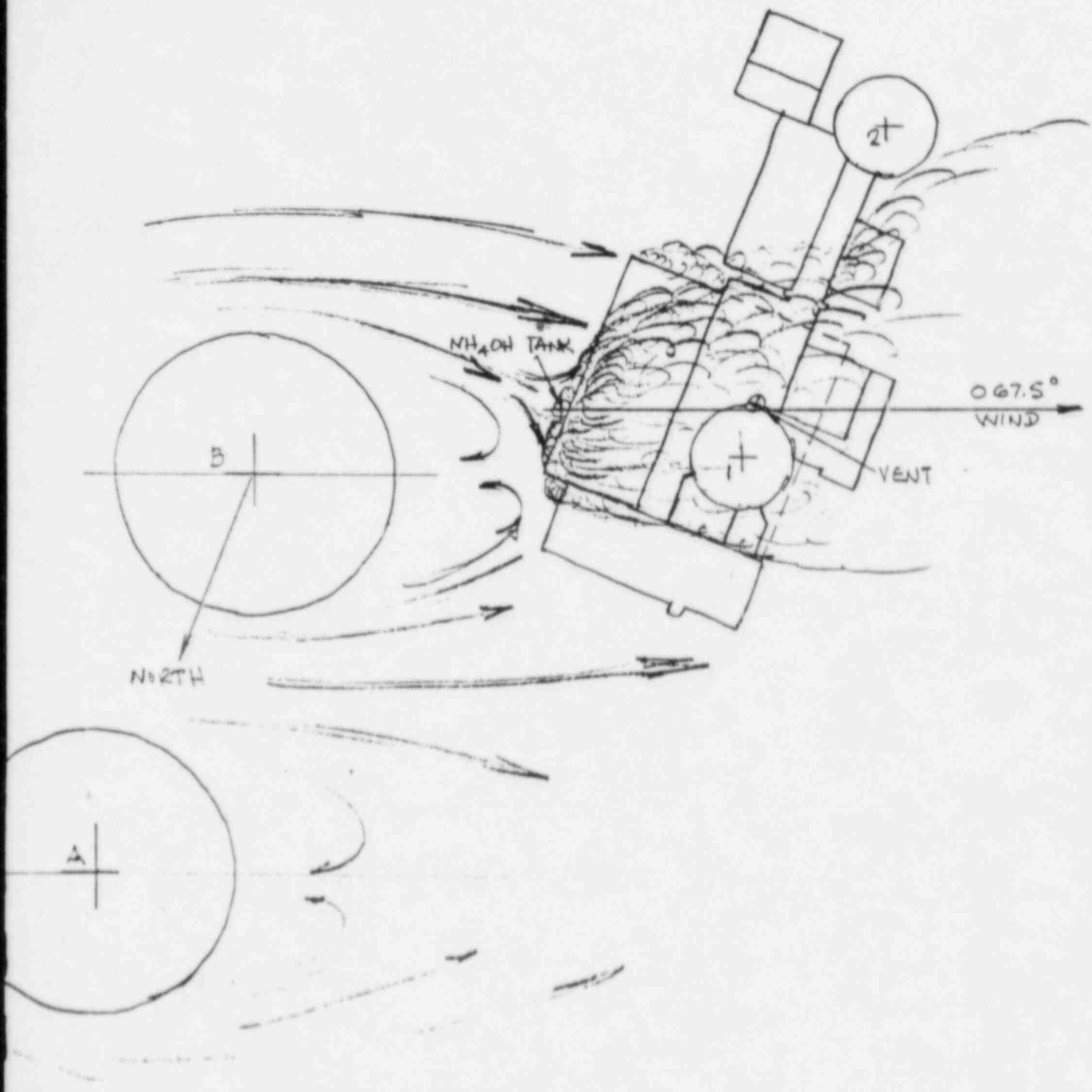


FIG A-7 DISPERSION PATTERNS IN AN 067.5° WIND
NH_4OH RELEASE

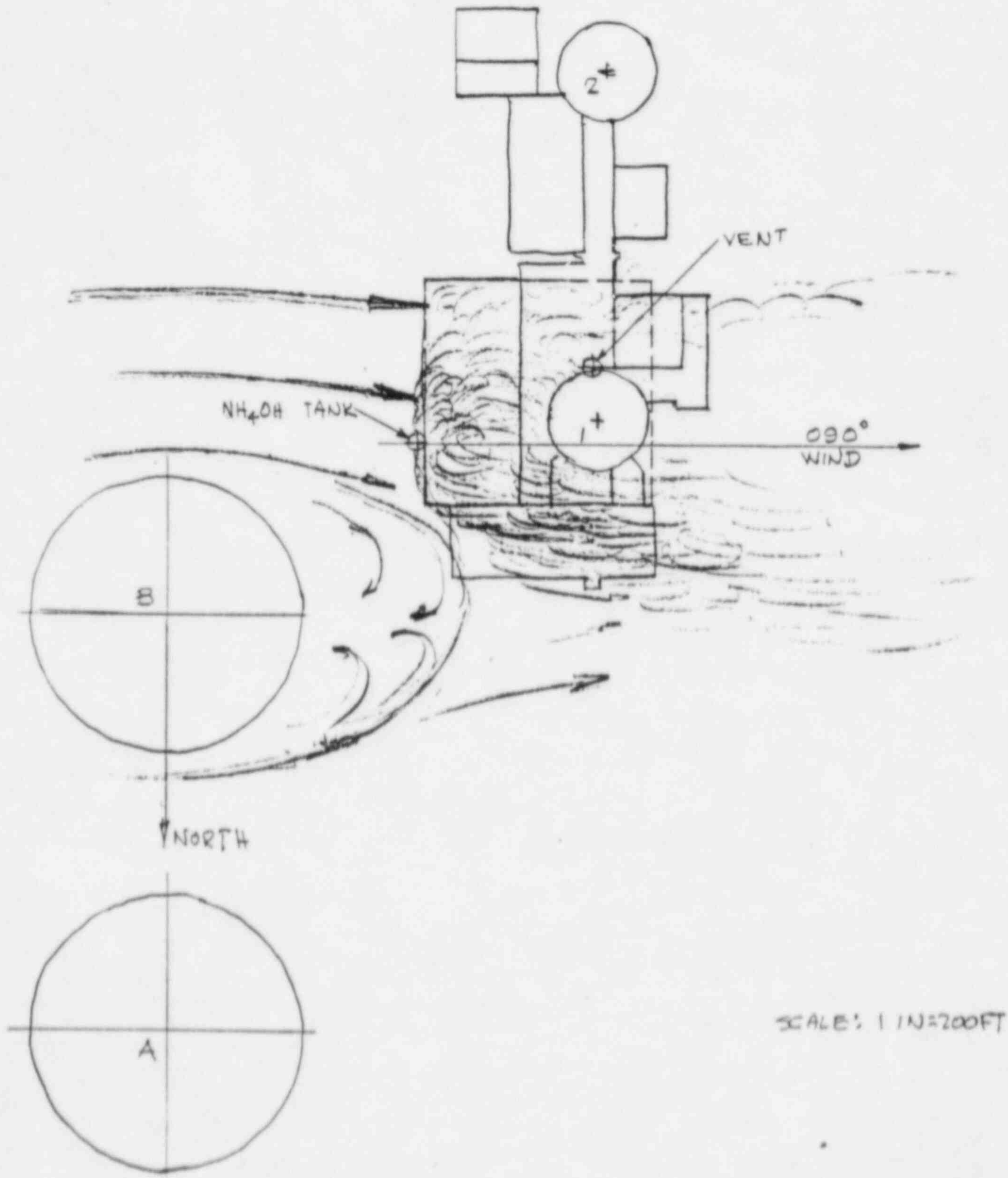


FIG. A-8 DISPERSION PATTERNS IN AN 090° WIND
NH_4OH RELEASE

ADDENDUM - A

ADDENDUM A. ANALYSIS OF RADIATION DOSES FROM MEASURED FLOW CONDITIONS

An analysis of the radiation doses in the TMI-1 Control Building Envelope has been performed for a variety of measured flow conditions, with the results given in Table A-1. There are five sets of flow data with 100% recirculation and the following damper positions:

1. Damper 39 closed
2. Dampers 37 and 39 open
3. Damper 39 open and damper 37 forced open
4. Damper 39 closed and damper 41 forced open
5. Damper 39 open and damper 28 forced open

Within each set there are five cases. The first three correspond to the assumption that inleakage occurs via the auxiliary and fuel handling buildings. Doses are given for each of three radionuclide pathways: damper 37, damper 39, and the auxiliary and fuel handling buildings. The last two cases correspond to the assumption that the inleakage occurs via damper 39. For this assumption, doses are given for the damper 37 and damper 39 pathway. Dose via the auxiliary and fuel handling buildings is zero for this assumption, since there is no flow by that pathway.

Thus, for all of the measured flow cases, the beta skin dose and gamma whole body dose remain within allowable limits.

TABLE A-1. SUMMARY OF DOSES TO THE CONTROL ROOM OPERATOR FROM LARGE BREAK LOCA RELEASES FOR MEASURED INFLOW THROUGH VARIOUS LEAK PATHS

Test Cases	Intake Flow Rates			Pathway	30 day Dose,rem	
	AHD-37[(a)]	AHD-39[(b)]	A&FHB[(c)]		Beta, Skin	Gamma, Whole Body
1	500	3658	2628	AHD-37	4.976	0.213
1	500	3658	2628	AHD-39	8.288	0.392
1	500	3658	2628	A&FHB	10.319	0.388
1	500	6286	0	AHD-37	5.608	0.241
1	500	6286	0	AHD-39	13.442	0.647
2a	0	9612	572	AHD-37	1.995	0.068
2a	0	9612	572	AHD-39	13.022	0.676
2a	0	9612	572	A&FHB	1.519	0.058
2a	0	10184	0	AHD-37	2.112	0.072
2a	0	10184	0	AHD-39	13.790	0.716
3b	0	3780	792	AHD-37	1.725	0.058
3b	0	3780	792	AHD-39	10.552	0.497
3b	0	3780	792	A&FHB	4.539	0.167
3b	0	4572	0	AHD-37	2.087	0.070
3b	0	4572	0	AHD-39	12.751	0.600
4a	775	1296	2848	AHD-37	8.141	0.367
4a	775	1296	2848	AHD-39	5.812	0.242
4a	775	1296	2848	A&FHB	15.245	0.564
4a	775	4144	0	AHD-37	9.347	0.407
4a	775	4144	0	AHD-39	13.248	0.596
5b	0	10440	572	AHD-37	2.004	0.068
5b	0	10440	572	AHD-39	13.153	0.688
5b	0	10440	572	A&FHB	1.406	0.054
5b	0	11012	0	AHD-37	2.114	0.072
5b	0	11012	0	AHD-39	13.885	0.727

a. Measured flow through damper AHD-37 included in total intake flow rate
b. Measured flow through damper AHD-39 included in total intake flow rate
c. Calculated inleakage from auxiliary and fuel handling buildings through sealed doors and penetrations included in total intake flow rate