SARGENT & LUNDY
ENGINEERS
CHICAGO

ACCIDENT RADIOLOGICAL DOSE ASSESSMENT - MANUAL METHOD FOR THE ENRICO FERMI ATOMIC POWER PLANT - UNIT 2

THE DETROIT EDISON COMPANY
ENRICO FERMI ATOMIC POWER PLANT - UNIT 2

Prepared by: R. S. Hubner
Sargent & Lundy
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TABLE OF CONTENTS

TABLES

APPENDIX A

TABLE OF CONTENTS

TABLES

FIGURES

ACCIDENT RADIOLOGICAL DOSE ASSESSMENT - MANUAL METHOD FOR THE ENRICO FERMI ATOMIC POWER PLANT - UNIT 2

1. Introduction

This report documents the assumptions and technical basis for the manual back-up method for Fermi-2 off-site, accident dose assessments and radiological emergency declarations. The method uses the accident classifications of the Environmental Protection Agency Protective Action Guides (PAG), Reference 1, as well as NUREG-0654, Reference 2. Total dose projections offsite are compared to the criteria of Reference 1. Reference 2 site and general emergencies based on radiological considerations at the site boundary are projected.

Accident classifications based on both projected dose rate at the site boundary and projected dose to the general population require a considerable amount of information to be known about the plant performance. In-plant monitor readings may provide an estimation of the amounts of radionuclides released in plant but do not predict the amounts that may be released to the environment without many assumptions. Additional parameters that are required but are not well known are:

(a) the nuclidic composition of the source
(b) the time dependent leakage rate from the primary containment to the secondary containment (reactor building)
(c) the amount of mixing in and the exhaust rate from the reactor building
(d) other releases; e.g. Standby Gas Treatment System (SGTS) bypass leakage, Main Steamline Isolation Valve (MSIV) leakage, and drywell purge
(e) the actual SGTS filter efficiency for iodines

(f) the effective height of the release to the environment

(g) the wind speed and direction

(h) the meteorological stability class

The actual values for these items may be unknown; however, their limiting values may be known. In order to make a manual method for determining accident classifications tractable, these items must be limited in a conservative manner; that is, the values chosen must give the highest doses and dose rates.

2. Model

The model for the manual method uses conservative assumptions similar to those of Reference 3. The accident scenario starts with instantaneous release of noble gases and iodines to the primary containment at reactor shutdown or at discrete times after shutdown. 100% of the core inventory of noble gases and 25% of the core inventory of iodines (both reduced by radiodecay for the time between shutdown and the accident) are airborne and are instantaneously mixed in the primary containment volume. These activities leak to the reactor building at the design basis leak rate where they are exhausted immediately by the SGTS through an iodine filter to the environment at ground level.

The calculated released activities are not necessarily the actual released activities. An estimation of the actual released activities may be made by normalizing the calculated released activities (based on conservative plant parameter assumptions) by the ratio of actual monitor readings to calculated monitor readings.

The estimated actual released activities are then transported instantaneously downwind to the dose point. Dose and dose rate equations used are those for a semi-infinite cloud whose concentration is that for the center of a Gaussian plume. The dispersion parameters are those for the current Pasquill stability class (Reference 4) at the distance downwind from the release point to the dose point; however, in certain applications, the "worst" class (class G) is used.

No iodine depletion by plating, washout, or ground deposition occurs. Thyroid inhalation doses and dose rates are based on the product of breathing rate times dose conversion factor for an awake (active) adult; for a child this product is taken to be two times larger. Parent-daughter relationships are not

considered after the accident; however, during the time between reactor shutdown and the accident, the parent-daughter relationships between I-135 and both Xe-135m and Xe-135 are included.

Noble gas and iodine nuclides with half-lives less than 3 minutes are omitted.

A more general model for off-site dose and dose rate projections including mathematical descriptions and solutions of equations can be found in Appendix A. The manual method is a specific application of this general model. Equations used for the production of tables, graphs, and worksheets for the manual method are developed from the equations of Appendix A using certain specific assumptions and using Fermi-2 data.

Among the potentially useful monitors, two have been chosen - an in-containment and a standby gas treatment system (SGTS) monitor. These monitors provide the idealized readings of Rad (air)/Hr and μci/cc of Xe-133 equivalent respectively. The in-containment monitor is located on the outer wall of the drywell at the 605 ft. elevation. It views a portion of a cylindrical annulus cloud of gamma emitters and is not affected by beta radiation. The SGTS monitor is located in the standby gas treatment effluent stream after the iodine filter. It provides the effective Xe-133 activity concentration, based on γ energy emitted, at that point.

Each of these monitors has its faults for accident classification. Although the SGTS monitor reflects what is being instantaneously released to the environment, it may not be conservative under certain conditions for projections of dose rate and dose as we will see later. The drywell monitor reflects what potentially might be released and may thus be overly conservative.

3. Assumptions

3.1 Nuclidic Composition of the Source

For noble gases the nuclide mix in the reactor core at the time of the accident would be the same as the mix in the core at reactor shutdown reduced by radiodecay for the time between shutdown and the accident. The maximum noble gas activity released to the primary containment would then be 100% of the core inventory at the time of the accident. To be conservative these activities are assumed to be immediately airborne. The ratio of the actual to the calculated monitor readings would be a measure of the fraction of the 100% core activity that was actually released. The exclusion of iodine activity from the monitor readings would result in a conservative estimate of that fraction since the actual monitor reading could be higher due to iodines.

For iodine, the amount of release relative to the noble gas release is unknown. Furthermore, the amounts airborne and available for leakage are unknown. We will rely on Reference 3 to obtain a conservative estimate of the relative amounts of iodine released. This Reference states that 100% of the noble gases and 25% of the iodines in the core inventory are airborne and available for leakage to the environment. We will assume that, for the purpose of determining thyroid inhalation doses, the amounts of iodine released are always in this proportion; that is, the amount of iodine airborne in the primary containment will always be 25% of the iodine core inventory times the fraction of the Reference 3 mixture that is actually airborne. This fraction is the ratio of the actual monitor reading to the calculated reading including both 100% noble gases and 25% iodines. For example, if the ratio of the monitor readings is ½, then we assume that 12-½% of the iodines are airborne.

We must note that in this example, the fraction of the 100% core inventory of noble gases that is airborne would be ½, but this fraction would not be conservative because the actual amounts of iodine present are unknown. So we exclude the iodine contribution to the calculated monitor reading when we determine the fraction of noble gases airborne. Thus, in the example, the fraction of the 100% noble gas core inventory that is airborne would be significantly larger than ½.

In any case the activities are assumed to be completely mixed in the entire primary containment volume.

3.2 <u>Primary Containment Leakage Rate</u>

The primary containment leakage rate is not only unknown but also is probably a complicated function of time. To be conservative the design basis leak rate given in Reference 5 (p. 15B.6-37) is used. This value of 0.5 %/day (2.083×10^{-4} hr^{-1}) is assumed to be constant for the duration of the accident (Reference 3).

3.3 <u>Mixing in and Exhaust Rate from the Reactor Building</u>

Reference 5 (pp. 15B.6-34 and 15B.6-37) states that no credit is taken for mixing and holdup in the reactor building. This is conservative for immediate dose considerations but leads to difficulties for projected dose rates and doses based on Standby Gas Treatment System monitor readings. One would expect that some mixing does occur. Thus an SGTS monitor would give increasing readings with time until a maximum is reached, and then the readings would fall with radiodecay. However, calculated monitor readings based on no mixing would start at a high value and fall monotonically with time. The result is that at early times the fraction of core inventory released would be underestimated. The estimation would improve with time and eventually become conservative. But the

drywell monitor would project overly conservative results at early times because holdup due to mixing was ignored.

Because we lack mixing data, we must assume no mixing, but we must recognize that the dose projections at early times must be closely watched.

The no mixing assumption is equivalent to direct leakage from the primary containment through the SGTS filter to the environment. In other words, the SGTS exhaust rate is infinite.

3.4 Other leakages

Bypass leakage is assumed to be zero. Reference 5 (p. 6.2-10f) states that a conservative estimate of the SGTS bypass leakage is zero for wind speeds less than 20 miles per hour.

MSIV leakage is assumed to be zero. Reference 5 (Section 9A.3.1, p. 9A-1) states that the MSIV leakage control system is designed to operate at a higher pressure than the primary containment. Thus, leakage is inhibited.

A drywell purge is not assumed to occur.

3.5 SGTS Filter Efficiency

Reference 5 (p. 15B.6-37) states that the SGTS filter efficiency for iodine is 99%. This is a conservative value. The actual value may be higher. Since the actual value is unknown, we must use the conservative value which will result in an overestimation of the thyroid inhalation dose consequences.

3.6 Release Height

The Fermi-2 SGTS vent is not at sufficient height to take credit for elevated release. Although some height effects are present, we must be conservative by selecting a ground level release. Although a methodology for partial elevated releases could be formulated (Reference 6), finite cloud considerations would have to be used for whole body dose determinations. In addition, terrain effects would have to be considered. These complications were rejected in favor of the more simple conservative ground release with no plume rise and no terrain effects; however, building wake is included.

3.7 Wind Speed and Direction

Dose rates and doses are inversely proportional to wind speed. To project such quantities over time, the wind speed must be known. It is assumed that the wind speed at the time of the projection is constant over the time period of the projection. Dose projections over large time periods should be avoided because of changes in wind speed and direction. Of course, instantaneous dose rates downwind are independent of wind direction but integrated doses apply only to directions in which the wind was blowing.

3.8 Meteorological Stability Class

The Pasquill stability class (Reference 4) is required to fix the amount of dispersion in the Gaussian plume model (References 7 and 3). The stability class is assumed to be constant over the time period of the projection.

3.9 Monitors

All calculated monitor readings use the following assumptions.

1. for the purpose of determining the actual amount of noble gas released to the primary containment, 100% of the core inventory of noble gases are instantaneously released to the entire primary containment with perfect mixing. Radiodecay from time of reactor shutdown to time of accident is included.
2. for the purpose of determining the actual amount of iodines airborne in the primary containment, 100% of the core inventory of noble gases plus 25% of the core inventory of iodines are instantaneously released to the entire primary containment with perfect mixing. Radiodecay from time of reactor shutdown to time of accident is included.

4. Data

Tables 1 and 2 present the specific Fermi-2 data used in preparing the material for the manual method.

TABLE 1

FERMI-2 PLANT DESIGN BASIS PARAMETERS

Appendix A Variable	Value	Description	Ref.	Location in Ref.
V	2.946×10^5 ft^3	Primary Containment Volume	5	p. 6.2-4
			5	Table 6.2-1
L	2.083×10^{-4} hr^{-1}	Primary Containment Leak Rate	5	p. 15B.6-37
P	0.0	Purge Rate (Primary Containment)	-	-
B	0.0	SGTS Bypass Fraction	5	p. 6.2-10f
V	1.836×10^6 ft^3	Secondary Containment Volume	8	p. 3
M	0.0*	Secondary Containment Mixing Fraction	5	p. 15B.6-34
			5	p. 15B.6-37
E	(1.0 hr^{-1})	SGTS Exhaust Rate (any non-zero value since $M = 0.0$)	-	-
ε_j	0.99	SGTS Filter Fractional Efficiency for Iodines; $1 \leq j \leq 5$; ($\varepsilon_j \equiv 0.0$ for $6 \leq j \leq 18$)	5	p. 15B.6-37

*Since $M \neq 0.0$ (See Appendix A), $M = 1.0 \times 10^{-10}$ was used.

TABLE 2

NUCLIDE DATA FOR FERMI-2

Nuclide Index, j	Nuclide	$A_j(0)$, Primary Containment Initial Airborne Activity, Ci	D_{cj}, Thyroid Dose Conv. Factor, Rem/Inhaled Ci	λ_j, Radiodecay Constant, hr^{-1}	$\overline{E}_{\gamma j}$, Average Energy per Disintegration, Mev	H_j, Infinite/Finite Gamma Cloud Dose Ratio
1	I-131	2.20+7	1.49+6	.003593	.381	28.74
2	I-132	3.32+7	5.48+4	.3035	2.26	31.33
3	I-133	4.80+7	3.66+5	.03334	.608	30.20
4	I-134	5.67+7	2.87+4	.792	2.601	32.12
5	I-135	4.41+7	1.17+5	.1051	1.557	34.71
6	Kr-83m	1.41+7	-	.374	.00245	1.173
7	Kr-85m	4.41+7	-	.1548	.158	26.08
8	Kr-85	1.40+6	-	7.38-6	.00221	29.55
9	Kr-87	7.97+7	-	.5472	.7825	36.10
10	Kr-88	1.10+8	-	.2477	1.934	37.92
11	Kr-89	1.37+8	-	13.18	1.713	36.22
12	Xe-131m	8.90+5	-	.002408	.01975	7.245
13	Xe-133m	4.80+6	-	.01296	.04123	11.60
14	Xe-133	1.90+8	-	.00547	.04501	13.73
15	Xe-135m	5.34+7	-	2.718	.4317	28.61
16	Xe-135	1.80+8	-	.0756	.2471	28.39
17	Xe-137	1.80+8	-	10.84	.1968	30.68
18	Xe-138	1.68+8	-	2.93	1.096	35.68

The data in Table 2 were obtained from the following sources:

$A_j(0)$	from Reference 5, Table 15B.6.5-2 but with the 1 minute values in the Table multiplied by $\exp(.01667\lambda_j)$ to obtain values at time = 0.0; λ_j is given in Table 2, and its units are hr^{-1}.
D_{tj}	from Reference 9
λ_j	from Reference 10
$\overline{E}_{\gamma j}$	from Reference 11 by summing the products of the frequencies times their discrete energies.
H_j	from Appendix A.4

5. Manual Method Theory

5.1 Projected Effective Activity Release

Projected effective Xe-133 and effective I-131 activity releases are given by Eqns. A17, A18, A21, and A22 in Appendix A.3.3. In each case an effective activity released during a time period is given by an actual monitor reading times the ratio of the design basis effective activity released to the design basis calculated monitor reading; e.g., from Eqn. A17 of Appendix A.3.3,

$$_{AD}Q_{eff\,Xe\text{-}133}(t_A, t_B) = R_{AD}(t) \left\{ \frac{Q_{eff\,Xe\text{-}133}(t_A, t_B)}{R_{CD}(t)} \right\}$$

This ratio (that in the curly brackets) will be called Q/R and may be tabulated for various combinations of release time period (t_A to t_B) and time (t) of the monitor reading. Such Q/R tabulations can be made for both effective Xe-133 and effective I-131 as well as for both drywell monitor and SGTS monitor. To obtain the actual effective activity released during a time period, the actual monitor reading at time t is multiplied by the appropriate Q/R. Since the actual drywell monitor reading units are mrad/hr, that reading must be multiplied by 1.0×10^{-3} to convert the units to rad/hr.

Such Q/R tables were prepared for the accident occurring 0, 2, 4, 6, and 8 hours after the reactor shutdown. Consecutive 8 hour release time periods were used.

Worksheets were prepared which provided a record of

(a) time after shutdown of release to primary containment

(b) time of monitor reading

(c) 8 hr period desired for activity release

(d) Q/R as obtained from the appropriate table

(e) the monitor reading

(f) the calculation of the activity, Q, released.

For the drywell monitor:

$$Q = [Q/R]\ [\text{monitor reading (mrad/hr)}]\ [1.0 \times 10^{-3}]$$

For the SGTS monitor:

$$Q = [Q/R]\ [\text{monitor reading } (\mu\text{ci/cc})]$$

5.2 PAG Emergency Classification - Worst EAB Conditions

Projected downwind doses for the time period t_A to t_B are given by Eqns. A67 through A70 in Appendix A.3.8.2. These equations may be solved for actual released activity required to obtain the PAG dose limit, $D_{k\gamma}$ or $D_{k\,Thyroid}$ (See Appendix A, Section A.3.8.3). The subscripts D and S may be dropped because the actual release activity found in this manner is independent of plant parameters. Thus, from either Eqn. A67 or Eqn. A68,

$$_{kA}Q_{eff\,Xe\text{-}133}(t_A, t_B) = \frac{D_{k\gamma}\,\bar{u}}{K\,\bar{E}_{\gamma Xe\text{-}133}\left[\bar{u}\left(\chi/Q'\right)_{id}\right]} \qquad \text{Eqn. 1}$$

where $\left[\bar{u}\left(\chi/Q'\right)_{id}\right]$ equations are found in Appendix A.3.7.2.

And, from either Eqn. A69 or Eqn. A70,

$$_{kA}Q_{eff\,I\text{-}131}(t_A, t_B) = \frac{D_{k\,Thyroid}\,\bar{u}}{D_{c\,I\text{-}131}\,B_R\left[\bar{u}\left(\chi/Q'\right)_{id}\right]} \qquad \text{Eqn. 2}$$

Eqns. 1 and 2, may be evaluated for the worst conditions (conditions giving the smallest activity release). These conditions are:

(a) Pasquill class G, $i = 7$

and (b) shortest downwind distance of importance, d = 915m (EAB distance Ref. 5, P. 15B.6-37, Table 15B.6.5-1).

Any time period t_A to t_B may be assumed. When this is done the effective activity released to obtain the k^{th} PAG dose limit becomes a linear function of the wind speed $\bar{u}$.

A graph of Eqn. 1 and a graph of Eqn. 2 with wind speed in units of miles per hour and with worst conditions were prepared. Each graph consisted of 3 curves, one for each value of k . Any known or projected (Section 5.1) effective activity release and the current wind speed are coordinates of a point that may be plotted on each of the graphs. If the point lies above the $k = 1$ curve, there is a red emergency; if the point lies between the $k = 1$ and $k = 2$ curves, there is a yellow emergency; if the point lies between the $k = 2$ and $k = 3$ curves, there is a white emergency; and, if the point lies below the $k = 3$ curve, there is no emergency.

A worksheet was prepared which provides a record of

(a) wind speed
(b) effective Xe-133 activity released
(c) whole body dose emergency classification from graph
(d) effective I-131 activity released
(e) thyroid inhalation dose emergency classification from graph

5.3 PAG Emergency Classification

5.3.1 Whole Body Dose Emergency

Equation 1 may be rewritten

$$Q_{k\,eff\,Xe-133} = \frac{0.447\, D_{kr}\, \bar{u}'}{K\, \bar{E}_{rXe-133}\left[\bar{u}\left(\chi/Q'\right)_{id}\right]} \qquad \text{Eqn. 3}$$

where $Q_{k\,eff\,Xe\text{-}133}$ is the effective Xe-133 activity released over any time period to obtain the k^{th} PAG whole body dose limit, and the wind speed $\bar{u}'$ in the numerator is expressed in units of miles per hour.

The activity $Q_{k\,eff\,Xe\text{-}133}$ may be normalized such that the normalized value ${}_NQ_{k\,eff\,Xe\text{-}133}$ equals 1 for $k = 3$ and $\bar{u}' = 1$ mph; since $D_{3\gamma} = 0.05$ Rem (Appendix A.3.8.3 and Table A4) and $\bar{E}_{\gamma\,Xe\text{-}133}$ = 0.04501 Mev (Table 2),

$${}_NQ_{3\,eff\,Xe\text{-}133} = K_{id\gamma} \frac{0.447 \times 0.05 \times 1}{0.253 \times 0.04501 \left[\bar{u}(\chi/Q')_{id}\right]}$$

where $K_{id\gamma}$ is the normalization constant.
Since ${}_NQ_{3\,eff\,Xe\text{-}133} = 1$,

$$K_{id\gamma} = 0.5095 \left[\bar{u}(\chi/Q')_{id}\right] \qquad \text{Eqn. 4}$$

where $\left[\bar{u}(\chi/Q')_{id}\right]$ is found in Appendix A.3.7.2. Applying the normalization factor $K_{id\gamma}$ to Eqn. 3 gives

$${}_NQ_{3\,eff\,Xe\text{-}133} = \left(1 \frac{ci}{mph}\right)\bar{u}' \qquad \text{Eqn. 5}$$

for $k = 3$. For $k = 2$, since $D_{2\gamma} = 1.0$ Rem (Appendix A.3.8.3 and Table A4) and, thus, $D_{2\gamma}/D_{3\gamma} = 20$,

$${}_NQ_{2\,eff\,Xe\text{-}133} = \left(20 \frac{ci}{mph}\right)\bar{u}' \qquad \text{Eqn. 6}$$

For $k = 1$, since $D_{1\gamma} = 5$ Rem (Appendix A.3.8.3 and Table A4) and, thus, $D_{1\gamma}/D_{3\gamma} = 100$,

$${}_NQ_{1\,eff\,Xe\text{-}133} = \left(100 \frac{ci}{mph}\right)\bar{u}' \qquad \text{Eqn. 7}$$

A graph of Eqns. 5 through 7 (3 curves) was prepared. On this graph, titled PAG Emergency Classification - Normalized Curves Including Stability Class and Distance, the ordinate is the normalized effective Xe-133 activity released. Any known or projected (Section 5.1) effective Xe-133 activity release can be multiplied by the normalization factor $K_{id\gamma}$ evaluated by Eqn. 4 for a particular downwind distance and Pasquill stability class to produce the normalized effective Xe-133 activity release. Any normalized effective Xe-133 activity release and the current wind speed $\bar{u}'$ are coordinates of a point that may be plotted on the graph. If the point lies above the k = 1 (Eqn. 7) curve, there is a red whole body dose emergency; if the point lies between the k = 1 and k = 2 (Eqn. 6) curves, there is a yellow whole body dose emergency; if the point lies between the k = 2 and k = 3 (Eqn. 5) curves, there is a white whole body dose emergency; and, if the point lies below the k = 3 curve, there is no whole body dose emergency.

A table of normalization factors titled Multiplying Factors For Xe-133 Activity (Ci) Released was prepared. The entries in this table resulted from the evaluation of Eqn. 4 for all seven Pasquill stability classes at the distances 915m and the integral miles from 1 through 10.

5.3.2 Thyroid Inhalation Dose Emergency

Equation 2 may be rewritten

$$Q_{k\,eff\,I-131} = \frac{0.447\, D_{k\,Thyroid}\, \bar{u}'}{D_{c\,I-131}\, B_R \left[\bar{u}(\chi/Q')_{id}\right]} \qquad \text{Eqn. 8}$$

where $Q_{k\,eff\,I\text{-}131}$ is the effective I-131 activity released over any time period to obtain the k^{th} PAG thyroid inhalation dose limit, and the wind speed $\bar{u}'$ in the numerator is expressed in units of miles per hour.

The activity $Q_{k\,eff\,I\text{-}131}$ may be normalized such that the normalized value $\tilde{Q}_{k\,eff\,I\text{-}131}$ equals 1 for $k = 3$ and $\bar{u}' = 1$ mph; since

$D_{3\,Thyroid}$ = 0.3 Rem (Appendix A.3.8.3 and Table A4)

$D_{c\,I\text{-}131}$ = 1.49×10^{6} Rem/(inhaled ci) (Table 2)

and B_R = 3.47×10^{-4} m^3/sec (Ref. 3),

$$\tilde{Q}_{3\,eff\,I\text{-}131} = K_{id\,Thyroid} \frac{0.447 \times 0.3 \times 1}{1.49 \times 10^{6} \times 3.47 \times 10^{-4} \left[\bar{u}(\chi/Q')_{id}\right]}$$

where $K_{id\,Thyroid}$ is the normalization constant. Since $\tilde{Q}_{3\,eff\,I\text{-}131}$ = 1,

$$K_{id\,Thyroid} = 3.856 \times 10^{3} \left[\bar{u}(\chi/Q')_{id}\right] \qquad \text{Eqn. 9}$$

where $\left[\bar{u}(\chi/Q')_{id}\right]$ is found in Appendix A.3.7.2. Applying the normalization factor $K_{id\,Thyroid}$ to Eqn. 8 gives

$$\tilde{Q}_{3\,eff\,I\text{-}131} = \left(1 \frac{ci}{mph}\right)\bar{u}' \qquad \text{Eqn. 10}$$

for $k = 3$. For $k = 2$, since $D_{2\,Thyroid}$ = 5 Rem (Appendix A.3.8.3 and Table A4) and, thus

$D_{2\,Thyroid} / D_{3\,Thyroid}$ = 16.667,

$$\tilde{Q}_{2\,eff\,I\text{-}131} = \left(16.667 \frac{ci}{mph}\right)\bar{u}' \qquad \text{Eqn. 11}$$

For $k = 1$, since $D_{1\,Thyroid}$ = 25 Rem (Appendix A.3.8.3 and Table A4) and, thus, $D_{1\,Thyroid}/D_{3\,Thyroid}$ = 83.33,

$$Q_{1\,eff\,I\text{-}131} = \left(83.33\ \frac{ci}{mph}\right)\bar{u}' \qquad \text{Eqn. 12}$$

A graph of Eqns. 10 through 12 (3 curves) was prepared. On this graph, titled PAG Emergency Classification - Normalized Curves Including Stability Class and Distance, the ordinate is the normalized effective I-131 activity released. Any known or projected (Section 5.1) effective I-131 activity release can be multiplied by the normalization factor $K_{id\,Thyroid}$ evaluted by Eqn. 9 for a particular downwind distance and Pasquill stability class to produce the normalized effective I-131 activity release. Any normalized effective I-131 activity release and the current wind speed $\bar{u}'$ are coordinates of a point that may be plotted on the graph. If the point lies above the $k = 1$ (Eqn. 12) curve, there is a red thyroid inhalation dose emergency; if the point lies between the $k = 1$ and $k = 2$ (Eqn. 11) curves, there is a yellow thyroid inhalation dose emergency; if the point lies between the $k = 2$ and $k = 3$ (Eqn. 10) curves, there is a white thyroid inhalation dose emergency; and, if the point lies below the $k = 3$ curve, there is no thyroid inhalation dose emergency.

A table of normalization factors titled Multiplying Factors For I-131 Activity (ci) Released was prepared. The entries in this table resulted from the evaluation of Eqn. 9 for all seven Pasquill stability classes at the distances 915m and the integral miles from 1 to 10.

5.3.3 Worksheet

A worksheet titled Emergency Classification Calculation was prepared which provides a record of

(a) Pasquill stability class
(b) downwind distance
(c) type of dose (whole body or thyroid inhalation)
(d) multiplying factor from appropriate table
(e) effective activity release (effective Xe-133 or effective I-131)
(f) normalized effective activity released (the product of item (d) and item (e))
(g) wind speed

The coordinates of the point as itemized in (f) and (g) are then plotted on the appropriate graph; the location of the point on the graph determines the emergency classification.

5.4 Dose Calculation at 10 Miles or Less

5.4.1 Whole Body Dose

From Appendix A.3.8.2 Eqn. A67, the whole body dose $D_{id\gamma}$ due to an effective Xe-133 activity release $Q_{eff\,Xe\text{-}133}$ over any time period at a distance d downwind and for Pasquill class i is

$$D_{id\gamma} = 0.253\, Q_{eff\,Xe\text{-}133}\, \overline{E}_{\gamma\,Xe\text{-}133} \left[\bar{u}\left(\chi/Q'\right)_{id}\right] / \bar{u}$$

Rewriting this equation, using the data of Section 5.3.1 for $\overline{E}_{\gamma Xe\text{-}133}$, and expressing the wind speed as $\bar{u}'$ in units of miles per hour,

$$D_{id\gamma} = 0.025475\, Q_{eff\,Xe\text{-}133} \left[\bar{u}\left(\chi/Q'\right)_{id}\right] / \bar{u}' \qquad \text{Eqn. 13}$$

Rearranging Eqn. 13,

$$\frac{D_{idr}\bar{u}'}{Q_{eff\,Xe\text{-}133}} = 0.025475\left[\bar{u}\left(\chi/Q'\right)_{id}\right]$$ Eqn. 14

Eqn. 14 says that for a particular distance downwind and Pasquill stability class the quantity $D_{idr}\bar{u}'/Q_{eff\,Xe\text{-}133}$ is a constant; let C_{idr} be that constant.

Thus,

$$C_{idr} = 0.025475\left[\bar{u}\left(\chi/Q'\right)_{id}\right]$$ Eqn. 15

From Eqn. 14, the units of C_{idr} are Rem·mph/ci. Using Eqn. 15, Eqn. 13 can be rewritten

$$D_{idr} = C_{idr}\,Q_{eff\,Xe\text{-}133}\,/\bar{u}'$$ Eqn. 16

A table of the C_{idr} factors titled Dose Calculation Table, Xe-133 Whole Body Gamma Dose, Rem·mph/ci was prepared. The entries in this table resulted from the evaluation of Eqn. 15 for all seven Pasquill stability classes at the distances 915m and the integral miles from 1 to 10. These data were also prepared in graphical form. The graph title was Whole Body Dose · MPH Per Curie Released vs. Distance For Indicated Pasquill Stability Classes.

Given the effective Xe-133 activity released over any time period and given the wind speed $\bar{u}'$, the downwind whole body dose may be calculated using Eqn. 16 with a value of C_{idr} from the table or graph.

5.4.2 Thyroid Inhalation Dose

From Appendix A.3.8.2 Eqn. A69, the thyroid inhalation dose $D_{id\,Thyroid}$ due to an effective I-131 activity release $Q_{eff\,I\text{-}131}$ over any time period at a distance d downwind and for Pasquill class i is

$$D_{id\,Thyroid} = D_{C\,I\text{-}131}\, B_R\, Q_{eff\,I\text{-}131} \left[\bar{u}\left(\chi/Q'\right)_{id}\right] / \bar{u}$$

Rewriting this equation, using the data of Section 5.3.2 for $D_{C\,I\text{-}131}$ and B_R, and expressing the wind speed as $\bar{u}'$ in units of miles per hour,

$$D_{id\,Thyroid} = 1156.67\, Q_{eff\,I\text{-}131} \left[\bar{u}\left(\chi/Q'\right)_{id}\right] / \bar{u}' \qquad \text{Eqn. 17}$$

Rearranging Eqn. 17,

$$\frac{D_{id\,Thyroid}\, \bar{u}'}{Q_{eff\,I\text{-}131}} = 1156.67 \left[\bar{u}\left(\chi/Q'\right)_{id}\right] \qquad \text{Eqn. 18}$$

Eqn. 18 says that for a particular distance downwind and Pasquill stability class the quantity $D_{id\,Thyroid}\,\bar{u}'/Q_{eff\,I\text{-}131}$ is a constant; let $C_{id\,Thyroid}$ be that constant. Thus,

$$C_{id\,Thyroid} = 1156.67 \left[\bar{u}\left(\chi/Q'\right)_{id}\right] \qquad \text{Eqn. 19}$$

From Eqn. 18, the units of $C_{id\,Thyroid}$ are Rem·mph/ci. Using Eqn. 19, Eqn. 17 can be rewritten

$$D_{id\,Thyroid} = C_{id\,Thyroid}\, Q_{eff\,I\text{-}131} / \bar{u}' \qquad \text{Eqn. 20}$$

A table of the $C_{id\,Thyroid}$ factors titled Dose Calculation Table, I-131 Thyroid Inhalation Dose, Rem·mph/ci was prepared. The entries in this table resulted from the evaluation of Eqn. 19 for all seven Pasquill stability classes at the distances 915m and the intergral miles from 1 to 10. These data were also prepared in graphical form. The graph title was Thyroid Inhalation Dose·MPH Per Curie Released vs. Distance For Indicated Pasquill Stability Classes.

Given the effective I-131 activity released over any time period and given the wind speed $\overline{u}'$, the downwind thyroid inhalation dose may be calculated using Eqn. 20 with a value of $C_{id\,Thyroid}$ from the table or graph.

5.4.3 Worksheet

A worksheet titled Dose Calculation was prepared which provides a record of

(a) Pasquill stability class
(b) downwind distance
(c) type of dose (whole body or thyroid inhalation)
(d) value from $C_{id\gamma}$ or $C_{id\,Thyroid}$ table or graph
(e) effective activity released (effective Xe-133 or effective I-131)
(f) wind speed
(g) calculation of item (e) divided by item (f)
(h) calculation of dose: item (d) times item (g)

5.5 Area Affected Calculation for PAG Classification

5.5.1 $\left[\bar{u}(\chi/Q')_{id}\right]$ Curves

A graph of $\left[\bar{u}(\chi/Q')_{id}\right]$ vs. distance was prepared. The graph contained a curve for each of the seven Pasquill stability classes. The plotted values were obtained from the evaluation of equations given in Appendix A.3.7.2. Note that this is for a ground level release with building wake included.

5.5.2 Outer Boundary of PAG Whole Body Dose Emergency Condition

Rearranging Eqn. 3,

$$\left[\bar{u}(\chi/Q')_{id}\right]_k = \left(\frac{0.447\, D_{k\gamma}}{K\, \bar{E}_{\gamma Xe\text{-}133}}\right)\left(\frac{\bar{u}'}{Q_{eff\, Xe\text{-}133}}\right) \qquad \text{Eqn. 21}$$

where the subscript k was removed from the $Q_{eff\, Xe\text{-}133}$ in order to denote any effective Xe-133 activity released over any time period and the subscript k was added to the $\left[\bar{u}(\chi/Q')_{id}\right]_k$ to denote that this quantity is that required to obtain the dose $D_{k\gamma}$. Using the values of K and $\bar{E}_{\gamma Xe\text{-}133}$ from Section 5.3.1, Eqn. 21 becomes

$$\left[\bar{u}(\chi/Q')_{id}\right]_k = \left(39.25346\, D_{k\gamma}\right)\left(\frac{\bar{u}'}{Q_{eff\, Xe\text{-}133}}\right) \qquad \text{Eqn. 22}$$

For $k = 1$, $D_{1\gamma} = 5.0$ Rem and Eqn. 22 becomes

$$\left[\bar{u}(\chi/Q')_{id}\right]_1 = 196.27\, \bar{u}'/Q_{eff\, Xe\text{-}133} \qquad \text{Eqn. 23}$$

For $k = 2$, $D_{2\gamma} = 1.0$ Rem and Eqn. 22 becomes

$$\left[\bar{u}(\chi/Q')_{id}\right]_2 = 39.25\, \bar{u}'/Q_{eff\, Xe\text{-}133} \qquad \text{Eqn. 24}$$

For $k = 3$, $D_{3\gamma} = 0.05$ Rem and Eqn. 22 becomes

$$\left[\bar{u}\left(\chi/Q'\right)_{id}\right] = 1.9627\,\bar{u}'/Q_{eff\ Xe\text{-}133} \qquad \text{Eqn. 25}$$

Eqns. 23 through 25 provide the means of calculating the wind speed times the atmospheric relative concentration at the outer boundary of the PAG whole body dose emergency condition k for any effective Xe-133 activity release over any time period. The value obtained along with the current Pasquill stability class can be used to obtain the outer boundary distance from the curves developed in Section 5.5.1; let this distance be $d_{k\gamma}$. Then, for any distance, d

$0.57 \text{ miles} \leq d \leq d_{1\gamma}$	, Red Emergency
$d_{1\gamma} < d \leq d_{2\gamma}$	, Yellow Emergency
$d_{2\gamma} < d \leq d_{3\gamma}$	, White Emergency
$d_{3\gamma} < d$	, No Emergency

The curves of Section 5.5.1 are not defined for distances less than 0.57 miles (915m). If any of the upper boundaries $d_{k\gamma}$ are apparently less than 0.57 miles because the associated $\left[\bar{u}\left(\chi/Q'\right)_{id}\right]_k$ is greater than any value on the appropriate curve, then the corresponding emergency condition is not required. The curves of Section 5.5.1 are also not defined for distances greater than 50 miles because emergency condition evaluations are not required beyond that distance.

A worksheet titled Area Affected Calculation - Xe-133 was prepared which provides a record of

(a) effective Xe-133 activity released

(b) wind speed

(c) Eqn. 25 evaluation

(d) Eqn. 24 evaluation

(e) Eqn. 23 evaluation

(f) Pasquill stability class

(g) white emergency outer boundary

(h) Yellow emergency outer boundary

(i) red emergency outer boundary

5.5.3 Outer Boundary of PAG Thyroid Inhalation Dose Emergency Condition

Rearranging Eqn. 8,

$$\left[\bar{u}\left(\chi/Q'\right)_{id}\right]_k = \left(\frac{0.447\, D_{k\,Thyroid}}{D_{c\,I\text{-}131}\, B_R}\right)\left(\frac{\bar{u}'}{Q_{eff\,I\text{-}131}}\right) \qquad \text{Eqn. 26}$$

where the subscript k was removed from the $Q_{eff\,I\text{-}131}$ in order to denote any effective I-131 activity released over any time period and the subscript k was added to the $\left[\bar{u}\left(\chi/Q'\right)_{id}\right]_k$ to denote that this quantity is that required to obtain the dose $D_{k\,Thyroid}$. Using the values of $D_{c\,I\text{-}131}$ and B_R from Section 5.3.2, Eqn. 26 becomes

$$\left[\bar{u}\left(\chi/Q'\right)_{id}\right]_k = \left(8.64553\times10^{-4}\, D_{k\,Thyroid}\right)\left(\frac{\bar{u}'}{Q_{eff\,I\text{-}131}}\right) \qquad \text{Eqn. 27}$$

For $k = 1$, $D_{1\,Thyroid} = 25.0$ Rem and Eqn. 27 becomes

$$\left[\bar{u}\left(\chi/Q'\right)_{id}\right]_1 = 2.1614\times10^{-2}\, \bar{u}'/Q_{eff\,I\text{-}131} \qquad \text{Eqn. 28}$$

For $k = 2$, $D_{2\,Thyroid} = 5.0$ Rem and Eqn. 27 becomes

$$\left[\bar{u}\left(\chi/Q'\right)_{id}\right]_2 = 4.3228\times10^{-3}\, \bar{u}'/Q_{eff\,I\text{-}131} \qquad \text{Eqn. 29}$$

For $k = 3$, $D_{3\,Thyroid} = 0.5$ Rem and Eqn. 27 becomes

$$\left[\bar{u}(\chi/Q')_{id}\right]_3 = 2.5937\times 10^{-4}\ \bar{u}'/Q_{eff\,I\text{-}131} \qquad \underline{\text{Eqn. 30}}$$

Eqns. 28 through 30 provide the means of calculating the wind speed times the atmospheric relative concentration at the outer boundary of the PAG thyroid inhalation dose emergency condition k for any effective I-131 activity release over any time period. The value obtained along with the current Pasquill stability class can be used to obtain the outer boundary distance from the curves developed in Section 5.5.1; let this distance be $d_{k\,Thyroid}$. Then, for any distance d ,

$0.57 \text{ miles} \leq d \leq d_{1\,Thyroid}$, Red Emergency

$d_{1\,Thyroid} < d \leq d_{2\,Thyroid}$, Yellow Emergency

$d_{2\,Thyroid} < d \leq d_{3\,Thyroid}$, White Emergency

$d_{3\,Thyroid} < d$, No Emergency

The curves of 5.5.1 are not defined for distances less than 0.57 miles (915m). If any of the upper boundaries $d_{k\,Thyroid}$ are apparently less than 0.57 miles because the associated $\left[\bar{u}(\chi/Q')_{id}\right]_k$ is greater than any value on the appropriate curve, then the corresponding emergency condition is not required. The curves of Section 5.5.1 are also not defined for distances greater than 50 miles because emergency condition evaluations are not required beyond that distance.

A worksheet titled Area Affected Calculation - I-131 was prepared which provides a record of

(a) effective I-131 activity released
(b) wind speed
(c) Eqn. 30 evaluation

(d) Eqn. 29 evaluation

(e) Eqn. 28 evaluation

(f) Pasquill stability class

(g) white emergency outer boundary

(h) yellow emergency outer boundary

(i) red emergency outer boundary

5.6 Doses at Distances Between 0.57 and 50 Miles

5.6.1 Whole Body Dose

Eqn. 13 enables the calculation of the downwind whole body dose for any effective Xe-133 activity release over any time period. The value of $\left[\bar{u}(\chi/Q')_{id}\right]$ for a given distance and Pasquill stability class may be found from the appropriate curve developed in Section 5.5.1.

A worksheet titled Calculation of Dose at Distances Between 0.57 and 50 Miles - Xe-133 was prepared which provides a record of

(a) downwind distance

(b) Pasquill stability class

(c) wind speed times atmospheric relative concentration from the appropriate curve developed in Section 5.5.1

(d) wind speed

(e) effective Xe-133 activity released

(f) Eqn. 13 evaluation for whole body dose

5.6.2 Thyroid Inhalation Dose

Eqn. 17 enables the calculation of the downwind thyroid inhalation dose for any effective I-131 activity release over any time period. The value of $\left[\bar{u}(\chi/Q')_{id}\right]$ for a given distance and Pasquill stability class may be found from the appropriate curve developed in Section 5.5.1.

A worksheet titled Calculation of Dose at Distances Between 0.57 and 50 Miles - I-131 was prepared which provides a record of

(a) down wind distance
(b) Pasquill stability class
(c) wind speed times atmospheric relative concentration from the appropriate curve developed in Section 5.5.1
(d) wind speed
(e) effective I-131 activity released
(f) Eqn. 17 evaluation for thyroid inhalation dose

5.7 NUREG-0654 Emergency Classification

In the following development, the theory of Appendix A.3.9.2 leading to Eqns. A82 and A83 will be used. These two equations are now rewritten.

$$\frac{F_\ell}{\bar{u}} = \frac{\dot{D}_\ell}{K_1 \bar{u} (\chi/Q)_i \dot{Q}_{eff}} \qquad \text{Eqn. 31}$$

and

$$R_\ell = \frac{F_\ell}{\bar{u}} R_c \bar{u} \qquad \text{Eqn. 32}$$

See Appendix A.2 for definitions of the variables.

These equations are now made more explicit by elaborations for monitor type, downwind dose rate type, time dependence, and Pasquill stability class. Thus, Eqn. 31 becomes

$$\frac{F_{i\ell\gamma}}{\bar{u}} = \frac{\dot{D}_{\ell\gamma}}{0.253\, E_{\gamma Xe-133} \left[\bar{u}(\chi/Q)_i\right] \dot{Q}_{eff\, Xe-133}(T_{Max\, Xe-133})} \qquad \text{Eqn. 33}$$

and

$$\frac{F_{i\ell\, Thyroid}}{\bar{u}} = \frac{\dot{D}_{\ell\, Thyroid}}{D_{C\, I-131}\, B_R \left[\bar{u}(\chi/Q)_i\right] \dot{Q}_{eff\, I-131}(T_{Max\, I-131})} \qquad \text{Eqn. 34}$$

Also, after dividing Eqn. 32 by $\bar{u}$, that equation becomes

$$\frac{R_{ADil\gamma}(t)}{\bar{u}} = \left(\frac{F_{il\gamma}}{\bar{u}}\right) R_{CD}(t)$$ Eqn. 35

$$\frac{R_{ASil\gamma}(t)}{\bar{u}} = \left(\frac{F_{il\gamma}}{\bar{u}}\right) R_{CS}(t)$$ Eqn. 36

$$\frac{R_{ADil\,Thyroid}}{\bar{u}} = \left(\frac{F_{il\,Thyroid}}{\bar{u}}\right) R_{CD}(t)$$ Eqn. 37

$$\frac{R_{ASil\,Thyroid}}{\bar{u}} = \left(\frac{F_{il\,Thyroid}}{\bar{u}}\right) R_{CS}(t)$$ Eqn. 38

The following definitions apply.

$F_{il\gamma}$ = fraction of the design basis accident release with iodines excluded that is actually released to the primary containment and will result in the NUREG-0654 whole body dose rate limit l at the site boundary for Pasquill stability class i .

$F_{il\,Thyroid}$ = fraction of the design basis accident release including 25% of the core inventory of iodines that is actually released to the primary containment and will result in the NUREG-0654 thyroid inhalation dose rate limit l at the site boundary for Pasquill stability class i .

$R_{ADi\ell\gamma}(t)$ = actual drywell monitor reading at time t for the NUREG-0654 whole body dose rate limit ℓ at the site boundary for Pasquill stability class i .

$R_{ASi\ell\gamma}(t)$ = same as $R_{ADi\ell\gamma}(t)$ except for SGTS monitor.

$R_{ADi\ell Thyroid}(t)$ = same as $R_{ADi\ell\gamma}(t)$ except for resulting in the NUREG-0654 thyroid inhalation dose rate limit ℓ .

$R_{ASi\ell Thyroid}(t)$ = same as $R_{ADi\ell Thyroid}(t)$ except for SGTS monitor.

5.7.1 Calculated Monitor Readings

Calculated monitor readings, $R_{cD}(t)$ and $R_{cS}(t)$, were tabulated at several times, t , after the accident from 0.167 hr through 24.0 hr. Tabulations were made for both 0% and 25% iodine core inventory airborne in the primary containment; in both cases, 100% of the noble gas core inventory was airborne. Drywell monitor readings, $R_{cD}(t)$, were evaluated from Eqn. A13 in Appendix A.3.2.1. SGTS monitor readings, $R_{cS}(t)$, were evaluated from Eqn. A14 in Appendix A.3.2.2.

These tabulations were done for the accident occurring 0, 2, 4, 6, and 8 hrs after reactor shutdown.

5.7.2 General Emergency

Eqns. 33 and 34 were evaluated with ℓ = 1 for each of the seven Pasquill stability classes, $1 \leq i \leq 7$. Results of Eqn. 33 were tabulated. There was a table for each time interval between reactor shut-down and the accident. The title of each table was

Fractions of 100% Noble Gases Plus N% Iodines
Released And Wind Speed Ranges to Give Gamma
Whole Body Emergency Condition (NUREG-0654)
For Release to Primary Containment at X. Hours
After Shutdown Without I-135 As Parent

where X was the appropriate time 0, 2, 4, 6, or 8.

Four tables containing minimum monitor readings divided by wind speed, at times t and for all Pasquill stability classes, at which general emergencies exist were prepared. There was a table for evaluations of each of Eqns. 35 through 38 with $\ell = 1$. The titles of the tables were

(a) for Eqn. 35 evaluation
Drywell Monitor Readings - General Emergency
For Release at X. Hr After Shutdown
Whole Body Gamma Dose Rate Emergency

(b) for Eqn. 36 evaluation
SGTS Monitor Readings - General Emergency
For Release at X. Hr After Shutdown
Whole Body Gamma Dose Rate Emergency

(c) for Eqn. 37 evaluation
Drywell Monitor Readings - General Emergency
For Release at X. Hr After Shutdown
Thyroid Inhalation Dose Rate Emergency

(d) for Eqn. 38 evaluation
SGTS Monitor Readings - General Emergency
For Release at X. Hr After Shutdown
Thyroid Inhalation Dose Rate Emergency

where X was the appropriate time 0, 2, 4, 6, or 8.

Worksheets titled
General Energency Determination For Drywell Monitor
and
General Emergency Determination For SGTS Monitor
were prepared which provide a record of

(a) Pasquill stability class

(b) type of dose rate - whole body or thyroid inhalation

(c) time of monitor reading

(d) value of monitor reading divided by wind speed from the general emergency table

(e) wind speed (mph)

(f) calculation of monitor reading for general emergency

Drywell monitor: 447.0 x item (d) x item (e), mrad/hr

SGTS monitor: 0.447 x item (d) x item (e), μci/cc

(g) actual monitor reading

(h) comparison of item (g) with item (f) for emergency determination

If item (g) $\geq$ item (f) then general emergency.

If item (g) $<$ item (f) then no emergency.

5.7.3 Site Emergency

Table A5 in Appendix A.3.9.1 lists two criteria for determining a site emergency. One states that a given dose rate limit (ℓ = 3) at the site boundary for Pasquill stability class G (i = 7) and for a 1.0 m/sec wind speed must be equalled or exceeded for a period of ½ hour. The other is similar except the dose rate limit (ℓ = 2) is ten times larger and the duration is 2 minutes. For the types of accidents considered, a large dose rate for a period of 2 minutes is not possible without a similar large dose rate for a period of ½ hr. The largest possible time rate of change of dose rate is that for the whole body during the first 30 minutes of the accident

assuming the accident occurs at reactor shutdown; however, this decrease in dose rate is considerably less than a factor of 10. Thus, all ℓ = 2 site emergencies are a subset of the ℓ = 3 site emergencies. In site emergency determination only the ℓ = 3 criterion will be used.

Since both $T_{max\ Xe-133}$ and $T_{max\ I-131}$ are always zero because there is no reactor building mixing and since the activity release rates are monotonically decreasing, the times $T_{max\ Xe-133}$ and $T_{max\ I-131}$ should both be set to ½ hour for ℓ = 3 calculations.

Eqns. 33 and 34 were evaluated with ℓ = 3 for Pasquill class G (i = 7). The results were included in the tables described in the first paragraph of Section 5.7.2.

Two tables containing minimum monitor readings, at times t and Pasquill stability class G (i = 7), at which site emergencies exist were prepared. One table was for the drywell monitor and contained the evaluations of Eqns. 37 and 35. The other table was for the SGTS monitor and contained the evaluations of Eqns. 38 and 36. The titles of the bles were

(a) for Eqns. 37 and 35 evalua

Drywell Monitor Readings - Site Emergency
Release at X. Hr After Shutdown
Pasquill Stability Class G
Wind Speed = 1.0 M/Sec

(b) for Eqns. 38 and 36 evalautions

SGTS Monitor Readings - Site Emergency
Release at X. Hrs After Shutdown
Pasquill Stability Class G
Wind Speed = 1.0 M/Sec

where X was the appropriate time 0, 2, 4, 6, or 8.

Worksheets titled
Site Emergency Determination For Drywell Monitor
and
Site Emergency Determination For SGTS Monitor
were prepared which provide a record of

(a) type of dose rate - whole body or thyroid inhalation

(b) time of monitor reading

(c) value of monitor reading from the site emergency table. For the drywell monitor multiply this value by 1000 to convert to mrad/hr

(d) actual monitor reading

(e) comparison of item (d) with item (c) for emergency determination

If item (d) $\geq$ item (c) then site emergency

If item (d) $<$ item (c) then no emergency.

5.8 Adjustment for Infant Thyroid Inhalation Dose Assessment

In Section 5.2 through 5.7 thyroid inhalation dose assessment methods were based on the response of an awake, active adult. From Reference 1, the response of an infant is conservatively twice that for an adult. This factor of 2 will now be used to extend the manual method to include infant dose assessments.

The thyroid inhalation dose response is the breathing rate times the thyroid inhalation dose conversion factor, $D_{cI-131} B_R$. In Section 5.2 through 5.7, $D_{cI-131} B_R$ is evaluated for an awake, active adult. For an infant response the factor should be multiplied by two. However, this is equivalent to recording on the worksheets of Section 5.2 through 5.6 two times the projected effective I-131 activity release found in Section 5.1. If two times the projected effective I-131 activity release is used, no other change is required to effect an infant thyroid inhalation dose assessment for Section 5.2 through 5.6.

For Section 5.7, an increase in $D_{cI-131} B_R$ would cause a decrease in the quantity calculated in Eqn. 34; a corresponding decrease in the tables generated by Eqns. 37 and 38 would occur. Thus, when using the worksheet in Section 5.7.2, item (d) (the value from the general emergency table) should be divided by 2 when doing thyroid inhalation dose rate evaluations. Similarly, when using the worksheet in Section 5.7.3, item (c) (the value from the site emergency table) should be divided by 2 when doing thyroid inhalation dose rate evaluations. No other change is required to effect an infant thyroid inhalation dose emergency assessment for Section 5.7.

6. References

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14. R. S. Hubner, "User's Manual for POSTDBA - Supplement for Modification No. 1", S&L Program No. 09.8.085-1.1, August 25, 1980.

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*Thyroid inhalation dose conversion factors were selected from this draft because they were more conservative than the values which were used in U.S.N.R.C. Regulatory Guide 1.109, Rev. 1, Oct. 1977, and they agreed better with values from TID-14844 and values in a letter from J. C. Golden, "AEC Standard Assumptions", Jan. 10, 1973.

APPENDIX A

A.1 Method of Solution

A.1.1 Solution Models

Figure A1 shows a simple model of a Boiling Water Reactor (BWR) power plant building structure and shows nuclide activity transport paths. In this model the accident occurs at time t equal to zero. The activity $A_j(0)$ for nuclide j is instantaneously mixed in the drywell plus wetwell (primary containment) volume. The airborne activity $A_j(t)$ is assumed to leak at a constant rate L to the reactor building (secondary containment) volume; a fraction B of this leakage is immediately released, unfiltered, to the environment (bypass leakage), and a fraction $1-B$ of this leakage is instantaneously mixed in the reactor building volume. Airborne activity $C_j(t)$ in the reactor building is exhausted to the environment by the standby Gas Treatment System (SGTS); the iodine portion of this effluent may be filtered. Mixing in the reactor building volume can include any percentage of that volume; e.g. 0% would be no mixing and 100% would be complete mixing. In addition, a filtered purge of the primary containment volume is possible. These three modes of release - SGTS, purge, and bypass leakage - then contribute to the total activity release rate $\dot{Q}_j(t)$ for nuclide j.

The activities $A_j(t)$ and $C_j(t)$ and the activity release rates $\dot{Q}_j(t)$ are calculated using design basis accident plant parameters or, if possible, known parameters at the time of the accident. Such activities and activity release rates are referred to as design basis accident or just design basis values. By suitable input the design basis accident may be changed; however, the actual activities and activity release rates are not necessarily the design basis values. To calculate the actual values, the design basis values are normalized to actual radiation monitor readings

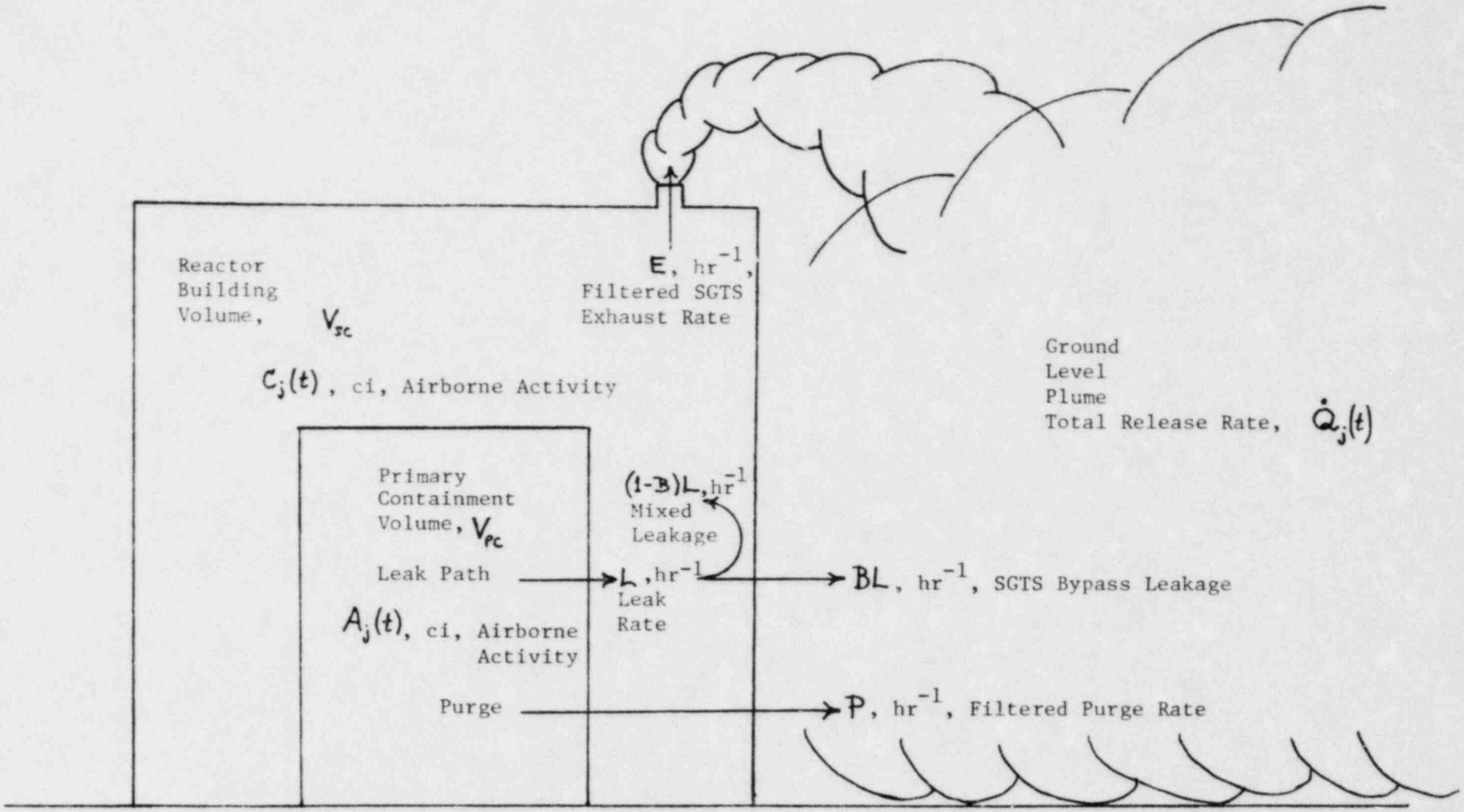

Figure A1. Activity Transport Model

in the drywell or in the SGTS effluent. The normalization requires a calculation of the monitor readings using the design basis activities.

The drywell (in-containment) monitor calculated reading is the actual air dose rate due to gamma radiation at a specific point in the drywell.* The calculational model is that for a semi-infinite cloud (Ref. 3) of activities $A_j(t)$ but with a finite cloud correction (see Section A.4). The SGTS monitor calculated reading is the actual effective Xe-133 activity concentration in the SGTS effluent; a definition of effective Xe-133 activity is given at the beginning of Section A.3.2.2 of this report. The SGTS monitor is placed downstream from the SGTS iodine filter.

In order to be conservative and in view of the fact that the iodine releases to the primary containment may be considerably smaller then the design basis values, the calculated monitor readings should not include contributions from iodines when normalizing the activity releases for the purpose of determining downwind whole body doses and dose rates. However, if the amount of iodine present is known, suitable input will effect the inclusion of iodine in the monitor calculations. For the purpose of determining downwind thyroid inhalation doses and dose rates, the contribution from the design basis iodine or the actual iodine, if known, is always included in the calculation of the monitor readings.

Both the SGTS and purge effluents are assumed to be released near the top of the highest structure and, thus, will be completely mixed in the building wake resulting in a ground level release (Ref. 3). Although the exhaust velocities may be sufficient to

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*For the Enrico Fermi Atomic Power Plant - Unit 2, this monitor is located on the outer wall of the drywell at the 605 ft. elevation. It views a portion of a cylindrical annulus cloud of gamma emmitters. See Section A.4 for a discussion of the finite cloud correction.

claim partial elevated release (Ref. 6), this effect is conservatively ignored. A partial elevated release would require the consideration of finite plume models as well as terrain effects which would greatly increase the complexity of the problem.

Any bypass leakage effluent would probably be of a diffuse nature over the reactor building structure. Such effluent must then be a ground level release.

The transport of the effluent is modelled by a straight line Gaussian plume with a building wake correction using current site meteorological data. Such data include the average wind speed and the Pasquill stability class (Ref. 4); wind direction is not required. The centerline concentrations of nuclide activities as predicted by this model at a given downwind distance is assumed to exist at all points in space - the semi-infinite cloud model. The transport of activities from the release point to the dose point is instantaneous; there is no radiodecay in transit. This conservative modelling is used to reduce the complexity of the problem.

Downwind whole body doses and dose rates use the semi-infinite cloud immersion tissue dose model of Reference 3; body depth shielding is conservatively ignored. Downwind thyroid inhalation doses and dose rates are for an awake adult, but this may be modified by suitable input.

Emergency classifications based on radiological dose and dose rate considerations are obtained from the criteria given in both the Environmental Protection Agency Portective Action Guides, Appendix D, (Ref. 1) and NUREG-0654, Appendix 1, (Ref. 2).

A.1.2 Assumptions

The assumptions are:

1. The accidental release of radioactive nuclides is to the primary containment
2. For the two types of releases -
   (a) If the release is at or after reactor shutdown, the release is instantaneous at time equal zero hours.
   (b) If the release is during reactor operation, the release is continuous and the reactor is not shutdown during the time period of interest; that time period should start at zero hours.
3. The release consists of noble gases and iodines - the noble gases in proportion to their core inventory and the iodines in proportion to 25% of their core inventory (Ref. 3). Optionally, the iodines may be in proportion to any amount of their core inventory. Optionally, the core inventory may be changed to any desired values.
4. The release is instantaneously mixed in the entire primary containment volume.
5. The primary containment leaks to the reactor building at a constant rate.
6. The leakage into the reactor building is instantaneously mixed into any desired fraction of the reactor building volume.
7. The reactor building is exhausted to the environment at a constant rate through an iodine filter of constant efficiency.
8. The primary containment may be purged to the environment with a constant purge rate through an iodine filter of constant efficiency.
9. Bypass leakage is direct and instantaneous from the primary containment to the environment and is unfiltered.
10. All exhausts are released as a ground level Gaussian plume with no plume rise and no terrain effects; however, building wake is included.

11. Whole body doses and dose rates can be conservatively calculated with a semi-infinite gamma cloud model.
12. No iodine depletion by plating, washout, or ground deposition occurs.
13. Radioactive decay in transit may be conservatively excluded.
14. Parent-daughter relationships need not be considered in the release calculations (Reference 3 stipulates only 100% noble gases and 25% iodines in the reactor core are released). However, optionally, the contribution of I-135 to Xe-135m and Xe-135 may be included; this relationship is the only one of importance.
15. The drywell monitor views a portion of an easily modelled (simple geometry) finite cloud of thoroughly mixed gamma emitters and is not affected by beta radiation; also, this monitor is not affected by plated out activities.
16. The SGTS monitor is placed in the SGTS exhaust after the iodine filter. It measures the effective Xe-133 activity concentration in the SGTS exhaust.
17. All monitors respond to gamma radiation only.
18. The ratio of the actual monitor reading to the calculated reading for that monitor is the fraction of the design basis accident release that has actually occurred.
19. For the purpose of determining downwind whole body doses and dose rates, no iodine is present when calculating the monitor readings. However, iodine may optionally be included.
20. For the purpose of determining downwind thyroid inhalation doses and dose rates, contributions of both noble gases and iodines (design basis accident amounts) are included in the calculated monitor readings.
21. Thyroid inhalation dose and dose rate criteria for determination of emergency classifications are for an awake adult. Optional input can adjust this for any person.

22. The wind direction is assumed to be constant over the dose accumulation time period.
23. The average wind speed for the dose accumulation time period is appropriate for use during the entire time period.
24. The Pasquill stability class is constant over the dose accumulation time period.
25. Nuclides with half-lives less than 3 minutes may be excluded.

A.2 Definitions of Variables

A_{iy}	Parameter in the algorithm for $\sigma_{iy}(d)$
A_{iz}	Parameter in the algorithm for $\sigma_{iz}(d)$
$A_j(t)$	Time dependent airborne activity, ci, in the primary containment. For $1 \leq j \leq 5$, $A_j(o)$ is the desired fraction of the core inventory of iodines at reactor shutdown. For $j > 5$, $A_j(o)$ is all of the core inventory of noble gases.
$A_p(t)$	Same as $A_j(t)$ but for a parent nuclide (I-135).
A_R	Smallest vertical plane cross-sectional area, m^2, of the reactor building.
B	Standby Gas Treatment System bypass fraction; fraction of primary containment leakage that goes directly to the environment (unfiltered).
B_{iy}	Parameter in the algorithm for $\sigma_{iy}(d)$
B_{iz}	Parameter in the algorithm for $\sigma_{iz}(d)$
B_R	Awake, adult breathing rate, m^3/sec.
b_j	Branching ratio from parent nuclide (I-135) to daughter nuclide j; $j = 15$ for Xe-135m and $j = 16$ for Xe-135.
C_{iz}	Parameter in the algorithm for $\sigma_{iz}(d)$
$C_j(t)$	Time dependent airborne activity, ci, in the secondary containment (Reactor Building). $C_j(o) \equiv 0.0$ ci. $C_j(t)$ is a meaningful quantity only if M does not equal its equivalent of zero, i.e., 1.0×10^{-10}.
$C_p(t)$	Same as $C_j(t)$ but for a parent nuclide (I-135).
D_{cj}	Thyroid inhalation dose conversion factor, Rem/(inhaled ci), for iodine nuclide j, $1 \leq j \leq 5$.
$D_{c\,I\text{-}131}$	Same as D_{cj} but for I-131, $j = 1$.
D_{kr}	Whole body dose, rem, for PAG (Reference 1) lower dose limit k. (See definition of k).

$D_{k\,Thyroid}$ — Thyroid inhalation dose, rem, for PAG (Reference 1) lower dose limit k. (See definition of k).

${}_{D}D_{id\gamma}(t_A, t_B)$ — Drywell monitor projected downwind whole body dose, Rem, at distance d for Pasquill class i for the time period t_A to t_B . This quantity is also dependent on windspeed $\bar{u}$.

${}_{D}D_{id\,Thyroid}(t_A, t_B)$ — Drywell monitor projected downwind thyroid inhalation dose, Rem, at distance d for Pasquill class i for the time period t_A to t_B . This quantity is also dependent on windspeed $\bar{u}$.

${}_{S}D_{id\gamma}(t_A, t_B)$ — Same as ${}_{D}D_{id\gamma}(t_A, t_B)$ except SGTS monitor projected.

${}_{S}D_{id\,Thyroid}(t_A, t_B)$ — Same as ${}_{D}D_{id\,Thyroid}(t_A, t_B)$ except SGTS monitor projected.

${}_{D}\dot{D}_{id\gamma}(T_{Max\,Xe\text{-}133})$ — Drywell monitor projected downwind maximum whole body dose rate, Rem/hr, at distance d for Pasquill class i . This quantity is also dependent on windspeed $\bar{u}$.

${}_{D}\dot{D}_{id\,Thyroid}(T_{Max\,I\text{-}131})$ — Drywell monitor projected downwind maximum thyroid inhalation dose rate, Rem/hr, at distance d for Pasquill class i . This quantity is also dependent on windspeed $\bar{u}$.

${}_{S}\dot{D}_{id\gamma}(T_{Max\,Xe\text{-}133})$ — Same as ${}_{D}\dot{D}_{id\gamma}(T_{Max\,Xe\text{-}133})$ except SGTS monitor projected.

${}_{S}\dot{D}_{id\,Thyroid}(T_{Max\,I\text{-}131})$ — Same as ${}_{D}\dot{D}_{id\,Thyroid}(T_{Max\,I\text{-}131})$ except SGTS monitor projected.

$\dot{D}_{\ell}$ — A NUREG-0654 (Ref. 2) dose rate, Rem/hr, limit at the site boundary for emergency classification ℓ (see definition of ℓ).

$\dot{D}_{\ell\gamma}$ — The NUREG-0654 (Ref. 2) whole body dose rate, Rem/hr, limit at the site boundary for emergency classification ℓ . (See definition of ℓ).

$\dot{D}_{\ell\,Thyroid}$ Same as $\dot{D}_{\ell\gamma}$ except for thyroid inhalation dose rate.

d Downwind distance, m, between activity release point and dose point.

${}_{D}d_{k\gamma}$ Maximum distance, m, to which the PAG (Ref. 1) whole body dose emergency condition k extends (See definition of k) as projected by the drywell monitor. This quantity is also dependent on windspeed $\bar{u}$.

${}_{D}d_{k\,Thyroid}$ Maximum distance, m, to which the PAG (Ref. 1) thyroid inhalation dose emergency condition k extends (See definition of k) as projected by the drywell monitor. This quantity is also dependent on windspeed $\bar{u}$.

${}_{S}d_{k\gamma}$ Same as ${}_{D}d_{k\gamma}$ except as projected by the SGTS monitor.

${}_{S}d_{k\,Thyroid}$ Same as ${}_{D}d_{k\,Thyroid}$ except as projected by the SGTS monitor.

${}_{D}d_{\ell\gamma}$ Distance, m, at which NUREC 0654 (Ref. 2) whole body dose rate limit for emergency classification ℓ (see definition of ℓ) occurs as projected by the drywell monitor. This quantity is also dependent on windspeed $\bar{u}$.

${}_{D}d_{\ell\,Thyroid}$ Distance, m, at which NUREG-0654 (Ref. 2) thyroid inhalation dose rate limit for emergency classification ℓ (see definition of ℓ) occurs as projected by the drywell monitor. This quantity is also dependent on windspeed $\bar{u}$.

${}_{S}d_{\ell\gamma}$ Same as ${}_{D}d_{\ell\gamma}$ except as projected by the SGTS monitor.

${}_{S}d_{\ell\,Thyroid}$ Same as ${}_{D}d_{\ell\,Thyroid}$ except as projected by the SGTS monitor.

E SGTS exhaust rate, hr^{-1}. This is defined as the SGTS actual exhaust rate, cfm, times 60 $\frac{min.}{hr}$ divided by the entire volume, ft^3, being exhausted without regard to mixing fraction.

$\overline{E}_{\gamma j}$	Average energy, Mev, per disintegration for nuclide j; see, also, the definition of j.
$\overline{E}_{\gamma Xe-133}$	Same as $\overline{E}_{\gamma j}$ but for j corresponding to Xe-133.
ε_j	Fractional efficiency of SGTS filter for nuclide j. $1 \leq j \leq 5$ are iodine nuclides. For $j > 5$, $\varepsilon_j \equiv 0.0$.
F_{id}	The building wake correction factor as defined by Eqn. A62 for a point at a distance d downwind and for Pasquill class i.
F_ℓ	The fraction of the design basis accident activity release that is actually released to the primary containment and that will result in the NUREG-0654 (Ref. 2) dose rate limit at the site boundary for emergency classification ℓ (see definition of ℓ).
f_j	Fraction of nuclide j that contributes to a monitor reading for the purpose of projecting downwind whole body dose and dose rate. $1 \leq j \leq 5$ are iodine nuclides. For $j > 5$, $f_j \equiv 1.0$.
H_j	Ratio of a semi-infinite gamma cloud dose rate to that for a finite cloud for nuclide j. See Section A.4 for theory.
i	Pasquill Stability Class index for atmospheric dispersion (Ref. 4).

Index i	Class
1	A (least stable)
2	B
3	C
4	D
5	E
6	F
7	G (most stable)

j Nuclide index

index j	nuclide	index j	nuclide
1	I-131	10	Kr-88
2	I-132	11	Kr-89
3	I-133	12	Xe-131m
4	I-134	13	Xe-133m
5	I-135	14	Xe-133
6	Kr-83m	15	Xe-135m
7	Kr-85m	16	Xe-135
8	Kr-85	17	Xe-137
9	Kr-87	18	Xe-138

K Dose conversion factor for semi-infinite cloud whole body immersion dose rate (Ref. 3); $K = 0.253$ Rem·m^3/(ci·Mev·sec).

K' Same as K except for air dose rate; $K' = K/1.11$ (Ref. 7).

K_c Defined in Eqn. A61; $K_c = A_R/(2\pi)$; see definition of A_R .

K_1 Constant of proportionality between activity release rate and dose rate.

k An index denoting the PAG (Ref. 1) emergency condition dose limit.

k = 1, Red emergency; whole body and thyroid dose limits are 5.0 and 25.0 Rem respectively.

k = 2, Yellow emergency; whole body and thyroid dose limits are 1.0 and 5.0 Rem respectively.

k = 3, White emergency; whole body and thyroid dose limits are 0.05 and 0.3 Rem respectively.

L Primary containment leak rate, hr^{-1}.

ℓ — An index denoting the NUREG-0654 (Ref. 2) dose rate limit for the emergency classifications in Table A5: thus,

- ℓ = 1 for General Emergency
- ℓ = 2 for Site Emergency with duration 2 minutes.
- ℓ = 3 for Site Emergency with duration ½ hour.

$\mathcal{M}$ — That fraction of the secondary containment volume in which the primary containment leaked activity is instantaneously and completely mixed before being exhausted by the SGTS. $\mathcal{M}$ cannot be zero. The flag $\mathcal{M} = 1.0 \times 10^{-10}$ effects no mixing; i.e., direct leakage from the primary containment through the SGTS.

P — Primary containment purge rate, hr^{-1}. A purge is assumed to be filtered by a filter whose iodine efficiency is the same as that for the SGTS filter.

p — A subscript which denotes a parent nuclide.

$Q_{eff\,Xe\text{-}133}(t_A, t_B)$ — Effective Xe-133 activity, ci, (as defined by Eqn. A11) released to the environment during the time period t_A to t_B for a design basis accident; note that this quantity is not the actual effective Xe-133 activity released because it has not been normalized by the monitor readings. Note, also, that this quantity contains the gamma energy importance of all nuclides including iodines.

$Q_{eff\,I\text{-}131}(t_A, t_B)$ — Effective I-131 activity, ci, (as defined by Eqn. A12) released to the environment during the time period t_A to t_B for a design basis accident; note that this quantity is not the actual effective I-131 activity released because it has not been normalized by the monitor readings. Note, also, that this quantity contains the thyroid inhalation dose conversion importance of all the iodines.

$Q_j(t_A, t_B)$ The activity, ci, for nuclide j released to the environment during the time period t_A to t_B for a design basis accident; note that this quantity is not the actual activity released because it has not been normalized by the monitor readings.

$Q_{T\,Nobles}(t_A, t_B)$ The total noble gas activity, ci, (as defined by Eqn. A9) released to the environment during the time period t_A to t_B for a design basis accident; note that this quantity is not the actual total noble gas activity released because it has not been normalized by the monitor readings.

$Q_{T\,Iodines}(t_A, t_B)$ The total Iodine activity, ci, (as defined by Eqn. A10) released to the environment during the time period t_A to t_B for a design basis accident; note that this quantity is not the actual total iodine activity released because it has not been normalized by the monitor readings.

${}_{AD}Q_{eff\,Xe\text{-}133}(t_A, t_B)$ Same as $Q_{eff\,Xe\text{-}133}(t_A, t_B)$ except this quantity has been normalized by the drywell monitor and is the projected actual effective Xe-133 activity released to the environment.

${}_{AD}Q_{eff\,I\text{-}131}(t_A, t_B)$ Same as $Q_{eff\,I\text{-}131}(t_A, t_B)$ except this quantity has been normalized by the drywell monitor and is the projected actual effective I-131 activity released to the environment.

${}_{AD}Q_{T\,Nobles}(t_A, t_B)$ Same as $Q_{T\,Nobles}(t_A, t_B)$ except this quantity has been normalized by the drywell monitor and is the projected total noble gas activity released to the environment.

${}_{AD}Q_{T\,Iodines}(t_A, t_B)$	Same as $Q_{T\,Iodines}(t_A, t_B)$ except this quantity has been normalized by the drywell monitor and is the projected total iodine activity released to the environment.
${}_{AS}Q_{eff\,Xe\text{-}133}(t_A, t_B)$	Same as ${}_{AD}Q_{eff\,Xe\text{-}133}(t_A, t_B)$ but normalized by the SGTS monitor.
${}_{AS}Q_{eff\,I\text{-}131}(t_A, t_B)$	Same as ${}_{AD}Q_{eff\,I\text{-}131}(t_A, t_B)$ but normalized by the SGTS monitor.
${}_{AS}Q_{T\,Nobles}(t_A, t_B)$	Same as ${}_{AD}Q_{T\,Nobles}(t_A, t_B)$ but normalized by the SGTS monitor.
${}_{AS}Q_{T\,Iodines}(t_A, t_B)$	Same as ${}_{AD}Q_{T\,Iodines}(t_A, t_B)$ but normalized by the SGTS monitor.
$\dot{Q}_j(t)$	Nuclide j activity release rate, ci/hr, to the environment at time t for a design basis accident; note that this quantity is not the actual activity release rate because it has not been normalized by the monitor readings.
$\dot{Q}_{eff\,\ell}(t)$	The actual effective Xe-133 or I-131 activity release rate, ci/hr, to the environment at time t to obtain the NUREG-0654 (Ref. 2) dose rate limit at the site boundary for emergency classification ℓ ; see definition of ℓ .
$\dot{Q}_{eff\,Xe\text{-}133}(t)$	Effective Xe-133 activity release rate, ci/hr, (as defined by Eqn. A23) to the environment at time t for a design basis accident; note that this quantity is not the actual effective Xe-133 activity release rate because it has not been normalized by the monitor readings. Note, also, that this quantity contains the gamma energy importance of all nuclides including iodines.

$\dot{Q}_{eff\ I\text{-}131}(t)$ Effective I-131 activity release rate, ci/hr, (as defined by Eqn. A24) to the environment at time t for a design basis accident; note that this quantity is not the actual effective I-131 activity release rate because it has not been normalized by the monitor readings. Note, also, that this quantity contains the thyroid inhalation dose conversion importance of all the iodines.

$\dot{Q}_{eff}(t)$ Same as $\dot{Q}_{eff\ Xe\text{-}133}(t)$ or $\dot{Q}_{eff\ I\text{-}131}(t)$.

${}_{AD}\dot{Q}_{eff\ Xe\text{-}133}(t)$ Same as $\dot{Q}_{eff\ Xe\text{-}133}(t)$ except this quantity has been normalized by the drywell monitor and is the projected actual effective Xe-133 activity release rate to the environment.

${}_{AD}\dot{Q}_{eff\ I\text{-}131}(t)$ Same as $\dot{Q}_{eff\ I\text{-}131}(t)$ except this quantity has been normalized by the drywell monitor and is the projected actual effective I-131 activity release rate to the environment.

${}_{AS}\dot{Q}_{eff\ Xe\text{-}133}(t)$ Same as ${}_{AD}\dot{Q}_{eff\ Xe\text{-}133}(t)$ but normalized by the SGTS monitor.

${}_{AS}\dot{Q}_{eff\ I\text{-}131}(t)$ Same as ${}_{AD}\dot{Q}_{eff\ I\text{-}131}(t)$ but normalized by the SGTS monitor.

${}_{AS}\hat{\dot{Q}}_{eff\ Xe\text{-}133}(T_A, T_B)$ Same as ${}_{AS}\dot{Q}_{eff\ Xe\text{-}133}(t)$ except this is an average value over the time interval T_A to T_B .

${}_{AS}\hat{\dot{Q}}_{eff\ I\text{-}131}(T_A, T_B)$ Same as ${}_{AS}\dot{Q}_{eff\ I\text{-}131}(t)$ except this is an average value over the time interval T_A to T_B .

$\ddot{Q}_{eff\ Xe\text{-}133}(t)$ Time derivative of $\dot{Q}_{eff\ Xe\text{-}133}(t)$.

$\ddot{Q}_{eff\ I\text{-}131}(t)$ Time derivative of $\dot{Q}_{eff\ I\text{-}131}(t)$.

$\ddot{Q}_j(t)$ Time derivative of $\dot{Q}_j(t)$.

$R_{AD}(t)$ Actual time dependent drywell monitor reading, Rad/hr.

$R_{CD}(t)$ Calculated time dependent drywell monitor reading, Rad/hr, for the design basis accident.

$R_{AS}(t)$ Actual time dependent SGTS monitor reading, μci/cc.

$R_{cs}(t)$	Calculated time dependent SGTS monitor reading, μci/cc, for the design basis accident.
R_c	Calculated monitor reading for the design basis accident at the time of the maximum release rate (either the drywell or the SGTS monitor).
R_ℓ	The monitor reading (either drywell or SGTS) which would result in the NUREG-0654 (Ref. 2) dose rate limit at the site boundary for emergency classification ℓ; see definition of ℓ.
T_A	The lower time, hr, limit of the time period T_A to T_B .
T_B	The upper time, hr, limit of the time period T_A to T_B .
$T_{Max\ Xe\text{-}133}$	The time, hr, of the maximum release rate for effective Xe-133 activity; thus, the time of the maximum whole body dose rate downwind.
$T_{Max\ I\text{-}131}$	The time, hr, of the maximum release rate for effective I-131 activity; thus, the time of the maximum thyroid inhalation dose rate downwind.
t	Time, hr, after the accident.
t_A	The lower time, hr, of the time period t_A to t_B .
t_B	The upper time, hr, of the time period t_A to t_B .
t_1	The lower time, hr, of the time period t_1 to t_2 .
t_2	The upper time, hr, of the time period t_1 to t_2 .
$\overline{u}$	The average wind speed, m/sec, over a time period for a given direction at ground level.
V_{PC}	The volume, ft^3, of the primary containment, both wetwell and drywell.
V	The volume, ft^3. of the secondary containment - reactor building - serviced by the SGTS.
α	A collection of constants defined by Eqn. A41.
β	A collection of constants defined by Eqn. A42.

γ	A collection of constants defined by Eqn. A43.
δ	A collection of constants defined by Eqn. A47
λ_j	Radiodecay constant, hr^{-1}, for nuclide j.
λ_p	Radiodecay constant, hr^{-1}, for a parent nuclide.
μ	A collection of constants defined by Eqn. A45.
ν	A collection of constants defined by Eqn. A46.
ν_{2j}, ν_{1j}, ν_{3j}	Collections of constants defined in Section A.3.4 preceding Eqn. A23.
ξ_p	The ratio of the fraction of the core inventory of the parent nuclide contributing to the airborne daughter in the primary containment to the fraction of the core inventory of the parent nuclide that is airborne in the primary containment.
$\sigma_{iy}(d)$	The lateral (crosswind) standard deviation, m, of a Gaussian plume a distance d downwind from the release point for Pasquill class i.
$\sigma_{iz}(d)$	The vertical standard deviation, m, of a Gaussian plume a distance d downwind from the release point for Pasquill class i.
$(\chi/Q')_{id}$	The atmospheric relative concentration, sec/m^3, for Pasquill class i at a distance d downwind from the release point. It is the ratio of the activity concentration, ci/m^3, at the downwind location to the activity release rate, ci/sec, at the release point. As used in this report, the value is on the centerline of a ground released Gaussian plume with a possible building wake correction.

A.3 Development of Equations

A.3.1 Activities and Activity Releases Based on Design Basis Assumptions

The differential equations describing the time dependent activities in the primary and secondary containments without parent contributions are:

$$\dot{A}_j(t) = -(\lambda_j + L + P)\, A_j(t) \qquad \text{Eqn. A1}$$

$$\dot{C}_j(t) = -(\lambda_j + \frac{E}{M})C_j(t) + (1-B)L\,A_j(t) \qquad \text{Eqn. A2}$$

The quantity $\frac{E}{M}$ is the effective SGTS exhaust rate. A value of M equal to zero is not allowed in the above differential equations. Such a value would imply direct leakage from the primary containment through the SGTS; thus, $C_j(t)$ would be identically zero. However, the use of a very small value for M, e.g. 1.0×10^{-10}, gives the same results as direct leakage. The above differential equations can then be used for both no mixing and mixing.

The solutions to the above differential equations are:

$$A_j(t) = A_j(t_A)\, e^{-(\lambda_j + L + P)(t - t_A)} \qquad \text{Eqn. A3}$$

$$C_j(t) = \left[C_j(t_A) - \frac{(1-B)L\,A_j(t_A)}{(\frac{E}{M} - L - P)}\right] e^{-(\lambda_j + \frac{E}{M})(t - t_A)} + \frac{(1-B)L\,A_j(t_A)}{(\frac{E}{M} - L - P)}\, e^{-(\lambda_j + L + P)(t - t_A)} \qquad \text{Eqn. A4}$$

The initial conditions are, when $t_A = 0.0$, $A_j(0)$ is the initial airborne activity in the primary containment and $C_j(0) = 0.0$.

The release rate to the environment for nuclide j is then

$$\dot{Q}_j(t) = \left[BL + (1-\varepsilon_j)P\right] A_j(t) + (1-\varepsilon_j)\frac{E}{M}\, C_j(t) \qquad \text{Eqn. A5}$$

Substituting Eqns. A3 and A4 into Eqn. A5,

$$\dot{Q}_j(t) = \left[BL + (1-\varepsilon_j)P + \frac{(1-\varepsilon_j)(1-B)L\frac{E}{M}}{\left(\frac{E}{M} - L - P\right)}\right] A_j(t_A)\, e^{-(\lambda_j + L + P)(t - t_A)}$$

$$+ \left[C_j(t_A) - \frac{(1-B)L A_j(t_A)}{\left(\frac{E}{M} - L - P\right)}\right](1-\varepsilon_j)\frac{E}{M}\, e^{-(\lambda_j + \frac{E}{M})(t - t_A)} \qquad \text{Eqn. A6}$$

The total release to the environment during the time period t_A to t_B is then

$$Q_j(t_A, t_B) = \int_{t_A}^{t_B} \dot{Q}_j(t)\, dt \qquad \text{Eqn. A7}$$

$$Q_j(t_A, t_B) = \left[BL + (1-\varepsilon_j)P + \frac{(1-\varepsilon_j)(1-B)L\frac{E}{M}}{\left(\frac{E}{M} - L - P\right)}\right] \frac{A_j(t_A)}{(\lambda_j + L + P)}\left[1 - e^{-(\lambda_j + L + P)(t_B - t_A)}\right]$$

$$+ \left[C_j(t_A) - \frac{(1-B)L A_j(t_A)}{\left(\frac{E}{M} - L - P\right)}\right] \frac{(1-\varepsilon_j)\frac{E}{M}}{\left(\lambda_j + \frac{E}{M}\right)}\left[1 - e^{-(\lambda_j + \frac{E}{M})(t_B - t_A)}\right] \qquad \text{Eqn. A8}$$

The total and the effective activities released to the environment for the time period are

$$Q_{T\,Nobles}(t_A, t_B) = \sum_{j=6}^{18} Q_j(t_A, t_B) \quad \text{with exclusions*} \qquad \text{Eqn. A9}$$

$$Q_{T\,Iodines}(t_A, t_B) = \sum_{j=1}^{5} Q_j(t_A, t_B) \qquad \text{Eqn. A10}$$

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*The sum over all noble gas nuclides must exclude Kr-83m, Kr-89, Xe-131m, Xe-137, and Xe-138 for subsequent use in the methods of Appendix D in Reference 1.

$$Q_{eff\,Xe-133}(t_A, t_B) = \sum_{j=1}^{18} \frac{\overline{E}_{\gamma j}}{\overline{E}_{\gamma\,Xe-133}} Q_j(t_A, t_B)$$ Eqn. A11

(includes all nuclides, even iodines)

$$Q_{eff\,I-131}(t_A, t_B) = \sum_{j=1}^{5} \frac{D_{cj}}{D_{c\,I-131}} Q_j(t_A, t_B)$$ Eqn. A12

Note that the above total and effective activities released are not the actual activities released. They are the result of a design basis accident and have not been modified by actual monitor readings.

$$Q_{eff\,Xe-133}(t_A, t_B) = \sum_{j=1}^{18} \frac{\bar{E}_{\gamma j}}{\bar{E}_{\gamma\,Xe-133}} Q_j(t_A, t_B)$$ Eqn. A11

(includes all nuclides, even iodines)

$$Q_{eff\,I-131}(t_A, t_B) = \sum_{j=1}^{5} \frac{D_{t\,j}}{D_{t\,I-131}} Q_j(t_A, t_B)$$ Eqn. A12

Note that the above total and effective activities released are not the actual activities released. They are the result of a design basis accident and have not been modified by actual monitor readings.

A.3.2 Calculated Monitor Readings

A.3.2.1 Calculated Drywell Monitor Readings

The drywell monitor is assumed to be unshielded and to read the air dose rate due to a finite cloud of gamma emitting nuclides. The finite cloud is approximated by a cylindrical annulus. Cloud geometry, monitor location, and calculated ratio, H_j , of semi-infinite to finite gamma cloud dose rates for each nuclide as well as the theory for the ratios are given in Section A.4. The calculation of these ratios is not a part of the Accident Radiological Dose Assessment Program.

The drywell monitor response is assumed to be independent of energy. However, a response function can be incorporated in the H_j's if needed.

The calculated drywell monitor reading as a function of time is for the design basis accident

$$R_{CD}(t) = \frac{K' \; 3600 \left(\frac{sec}{hr}\right)}{V_{PC} \left(0.3048 \frac{m}{ft}\right)^3} \sum_{j=1}^{18} \left[f_j \bar{E}_{\gamma j} A_j(t) / H_j \right]$$

where $A_j(t)$ is obtained from Eqn. A3.

Thus

$$R_{CD}(t) = \frac{2.8986 \times 10^4}{V_{PC}} \sum_{j=1}^{18} \left[\frac{f_j \bar{E}_{\gamma j}}{H_j} A_j(t_A) e^{-(\lambda_j + L + P)(t - t_A)} \right] \qquad \text{Eqn. A13}$$

A.3.2.2 Calculated SGTS Monitor Readings

The SGTS monitor is assumed to measure the effective Xe-133 activity concentration in the SGTS effluent at a point after the iodine filter. The effective Xe-133 activity concentration is the sum of all nuclide activity concentrations each weighted by the ratio of their gamma energy emitted per disintegration to that for Xe-133.

The calculated SGTS monitor reading as a function of time is for the design basis accident

$$R_{cs}(t) = \frac{1}{(0.3048\ \frac{m}{ft})^3 M V_{sc}} \sum_{j=1}^{18} \frac{f_j \overline{E}_{\gamma j}\ C_j(t)}{\overline{E}_{\gamma Xe-133}}$$

where $C_j(t)$ is obtained from Eqn. A4.

Thus

$$R_{cs}(t) = \frac{35.3147}{M V_{sc}} \sum_{j=1}^{18} \frac{f_j \overline{E}_{\gamma j}}{\overline{E}_{\gamma Xe-133}} \left\{ \left[C_j(t_A) - \frac{(1-B) L A_j(t_A)}{(\frac{E}{M} - L - P)} \right] e^{-(\lambda_j + \frac{E}{M})(t - t_A)} + \frac{(1-B) L A_j(t_A)}{(\frac{E}{M} - L - P)} e^{-(\lambda_j + L + P)(t - t_A)} \right\}$$

Eqn. A14

A.3.3 Activity Releases Normalized to Actual Monitor Readings

The ratio of an actual monitor reading $R_{AD}(t)$ or $R_{AS}(t)$ to the calculated monitor reading for the design basis accident is assumed to be a measure of the ratio of the actual activity released (or the actual activity release rate) to the calculated activity released (or the calculated activity release rate) based on the design basis accident. This is a good assumption if the accident is according to the design basis and departs from design basis only in the percentage of core inventory activities that are released to the primary containment. However, if $\frac{E}{M}$ is large the assumption is also good for other values of L that are not too large.

Using this assumption with the drywell monitor read and calculated at the same time t, (see also Eqns. A9 through A12), the actual activity releases are

$$_{AD}Q_{T\,Nobles}(t_A, t_B) = \frac{R_{AD}(t)}{R_{CD}(t)} Q_{T\,Nobles}(t_A, t_B) \qquad \text{Eqn. A15}$$

$$_{AD}Q_{T\,Iodines}(t_A, t_B) = \frac{R_{AD}(t)}{R_{CD}(t)} Q_{T\,Iodines}(t_A, t_B) \qquad \text{Eqn. A16}$$

$$_{AD}Q_{eff\,Xe\text{-}133}(t_A, t_B) = \frac{R_{AD}(t)}{R_{CD}(t)} Q_{eff\,Xe\text{-}133}(t_A, t_B) \qquad \text{Eqn. A17}$$

$$_{AD}Q_{eff\,I\text{-}131}(t_A, t_B) = \frac{R_{AD}(t)}{R_{CD}(t)} Q_{eff\,I\text{-}131}(t_A, t_B) \qquad \text{Eqn. A18}$$

Similarly for the SGTS monitor,

$$_{AS}Q_{T\,Nobles}(t_A, t_B) = \frac{R_{AS}(t)}{R_{CS}(t)} Q_{T\,Nobles}(t_A, t_B) \qquad \text{Eqn. A19}$$

$$_{AS}Q_{T\,Iodine}(t_A, t_B) = \frac{R_{AS}(t)}{R_{CS}(t)} Q_{T\,Iodines}(t_A, t_B) \qquad \text{Eqn. A20}$$

$$ {}_{AS}Q_{eff\ Xe\text{-}133}(t_A, t_B) = \frac{R_{AS}(t)}{R_{CS}(t)} Q_{eff\ Xe\text{-}133}(t_A, t_B) $$ Eqn. A21

$$ {}_{AS}Q_{eff\ I\text{-}131}(t_A, t_B) = \frac{R_{AS}(t)}{R_{CS}(t)} Q_{eff\ I\text{-}131}(t_A, t_B) $$ Eqn. A22

A.3.4 Time of Maximum Effective Activity Release Rate

This section presents equations for the time of maximum effective activity release rate (for a design basis accident) on a specific time interval. This section does not apply if the value of $\mathcal{M}$ is 1.0×10^{-10} ($\mathcal{M} = 1.0 \times 10^{-10}$ is a flag for the desired value of $\mathcal{M}$ equal to zero).

If $\mathcal{M}$ does not equal zero, the effective activity release rate should increase with time until the activity buildup in the secondary containment reaches a level at which the removal through the SGTS equals the addition through the primary containment leakage. After this point the effective activity release rate should decrease because of radiodecay. If the specific time interval includes the time of maximum effective activity release rate, then this section presents equations for the time at which that release rate occurs. If that time interval does not include the time of maximum effective activity release then, for that time interval, the time of maximum effective activity release is that interval end point time which has the larger effective activity release rate.

Substituting

$$\nu_{2j} = \frac{(1-B)(1-\varepsilon_j)L\frac{E}{\mathcal{M}}}{\left(\frac{E}{\mathcal{M}} - L - P\right)}$$

$$\nu_{1j} = \nu_{2j} + (1-\varepsilon_j)P + BL$$

$$\nu_{3j} = (1-\varepsilon_j)\frac{E}{\mathcal{M}}$$

and $t_1 = t_A$

into Eqn. A6, employing the definitions of effective activity, and summing over appropriate nuclides, the effective activity release rates are

$$\dot{Q}_{eff\,Xe\text{-}133}(t) = \sum_{j=1}^{18} \frac{\bar{E}_{\gamma j}}{\bar{E}_{\gamma Xe\text{-}133}} \left\{ \nu_{1j} A_j(t_1)\, e^{-(\lambda_j + L + P)(t-t_1)} - \left[\nu_{2j} A_j(t_1) - \nu_{3j} C_j(t_1)\right] e^{-\left(\lambda_j + \frac{E}{\mathcal{M}}\right)(t-t_1)} \right\}$$

Eqn. A23

$$\dot{Q}_{eff\ I\text{-}131}(t) = \sum_{j=1}^{5} \frac{D_{cj}}{D_{c\ I\text{-}131}} \Big\{ \nu_{1j} A_j(t_1) e^{-(\lambda_j + L + P)(t - t_1)} - \left[\nu_{2j} A_j(t_1) - \nu_{3j} C_j(t_1)\right] e^{-(\lambda_j + \frac{E}{M})(t - t_1)} \Big\}$$ Eqn. A24

To find the time of maximum $\dot{Q}_{eff\ Xe\text{-}133}(t)$ and $\dot{Q}_{eff\ I\text{-}131}(t)$, the derivatives of Eqns. A23 and A24 must be set equal to zero and the result solved for the time. The derivatives of Eqns. A23 and A24 are

$$\ddot{Q}_{eff\ Xe\text{-}133}(t) = \sum_{j=1}^{18} \frac{\overline{E}_{\gamma j}}{\overline{E}_{\gamma Xe\text{-}133}} \Big\{ -(\lambda_j + L + P)\nu_{1j} A_j(t_1) e^{-(\lambda_j + L + P)(t - t_1)} + (\lambda_j + \frac{E}{M})\left[\nu_{2j} A_j(t_1) - \nu_{3j} C_j(t_1)\right] e^{-(\lambda_j + \frac{E}{M})(t - t_1)} \Big\}$$ Eqn. A25

$$\ddot{Q}_{eff\ I\text{-}131}(t) = \sum_{j=1}^{5} \frac{D_{cj}}{D_{c\ I\text{-}131}} \Big\{ -(\lambda_j + L + P)\nu_{1j} A_j(t_1) e^{-(\lambda_j + L + P)(t - t_1)} + (\lambda_j + \frac{E}{M})\left[\nu_{2j} A_j(t_1) - \nu_{3j} C_j(t_1)\right] e^{-(\lambda_j + \frac{E}{M})(t - t_1)} \Big\}$$ Eqn. A26

The desired times of maximum effective activity release rates $T_{max\ Xe\text{-}133}$ and $T_{max\ I\text{-}131}$ on the interval t_1 to t_2 are then given by

$$\ddot{Q}_{eff\ Xe\text{-}133}(T_{max\ Xe\text{-}133}) = 0.0$$ Eqn. A27

$$\ddot{Q}_{eff\ I\text{-}131}(T_{max\ I\text{-}131}) = 0.0$$ Eqn. A28

with the conditions $\ddot{Q}_{eff\ Xe\text{-}133}(t_1)$ and $\ddot{Q}_{eff\ I\text{-}131}(t_1)$ must be positive; if they are negative then the time of maximum effective activity release rate is t_1.

Thus if

$$\ddot{Q}_{eff\,Xe-133}(t_1) \leq 0.0 \quad \text{then} \quad T_{max\,Xe-133} = t_1$$ Eqn. A29

or if

$$\ddot{Q}_{eff\,I-131}(t_1) \leq 0.0 \quad \text{then} \quad T_{max\,I-131} = t_1$$ Eqn. A30

Eqns. A27 and A28 may be solved for $T_{max\,Xe-133}$ and $T_{max\,I-131}$ respectively by a method of interpolation (regula falsi). The first guess should be t_1 and Eqns. A29 and A30 tested. The second guess may be any value between t_1 and t_2. If the solution to either Eqns. A27 or A28 exceed t_2 then the solution is set equal to t_2.

In the following steps describing the method of interpolation, the subscripts Xe-133 and I-131 have been dropped because the method applies either quantities denoted by those subscripts.

Step 1: Let first guess for the maximum time be T_1 and calculate $\ddot{Q}_{eff}(T_1)$ using either Eqn. A25 or Eqn. A26 whichever is appropriate.

Step 2: Let the second guess for the maximum time be T_2.

Step 3: Increment the loop counter.

Step 4: Calculate $\ddot{Q}_{eff}(T_2)$ using either Eqn. A25 or Eqn. A26 whichever is appropriate.

Step 5: Calculate new maximum time T by linear interpolation; thus, $T = T_1 - (T_2 - T_1)\ddot{Q}_{eff}(T_1)/[\ddot{Q}_{eff}(T_2) - \ddot{Q}_{eff}(T_1)]$

Step 6: If $|T_2 - T_1|/T < 0.0001$ then $T_{max} = T$; finished

Step 7: If loop counter exceeds 30 then finished.

Step 8: If $|\ddot{Q}_{eff}(T_1)| > |\ddot{Q}_{eff}(T_2)|$ then go to Step 10.

Step 9: Set $T_2 = T$ and go to Step 3.

Step 10: Set $\ddot{Q}_{eff}(T_1) = \ddot{Q}_{eff}(T_2)$; set $T_1 = T_2$; set $T_2 = T$; then go to Step 3.

A.3.5 Effective Activity Release Rates Normalized to Actual Monitor Readings

With the assumptions of Section A.3.3, and Eqns. A23 and A24, the actual activity releases are for the drywell monitor

$$_{AD}\dot{Q}_{eff\,Xe\text{-}133}(t) = \frac{R_{AD}(t)}{R_{cD}(t)}\,\dot{Q}_{eff\,Xe\text{-}133}(t) \qquad \text{Eqn. A31}$$

$$_{AD}\dot{Q}_{eff\,I\text{-}131}(t) = \frac{R_{AD}(t)}{R_{cD}(t)}\,\dot{Q}_{eff\,I\text{-}131}(t) \qquad \text{Eqn. A32}$$

Similarly for the SGTS monitor,

$$_{AS}\dot{Q}_{eff\,Xe\text{-}133}(t) = \frac{R_{AS}(t)}{R_{cS}(t)}\,\dot{Q}_{eff\,Xe\text{-}133}(t) \qquad \text{Eqn. A33}$$

$$_{AS}\dot{Q}_{eff\,I\text{-}131}(t) = \frac{R_{AS}(t)}{R_{cS}(t)}\,\dot{Q}_{eff\,I\text{-}131}(t) \qquad \text{Eqn. A34}$$

A.3.6 Parent Contributions

Section A.3.1 developed equations excluding parent effects. For most of the required nuclides parent effects are negligible. Only the parent I-135 is of any consequence in its production of Xe-135. This section develops the equations which include the effects of one parent. Note that the subscript p denotes parent and the subscript j denotes daughter.

The differential equations describing the time dependent activities of the parent in the primary and secondary containments (without contributions from its parent) are the same as Eqns. A1 and A2 with subscript j replaced by subscript p . The solutions are then similar to Eqns. A3 and A4; thus

$$A_p(t) = A_p(t_4)\, e^{-(\lambda_p + L + P)(t - t_4)} \qquad \text{Eqn. A35}$$

$$C_p(t) = \left[C_p(t_4) - \frac{(1-B) L A_p(t_4)}{(\frac{E}{m} - L - P)} \right] e^{-(\lambda_p + \frac{E}{m})(t - t_4)} + \frac{(1-B) L A_p(t_4)}{(\frac{E}{m} - L - P)} e^{-(\lambda_p + L + P)(t - t_4)} \qquad \text{Eqn. A36}$$

Let ζ_p be the ratio of the fraction of the core inventory of the parent contributing to the airborne daughter in the primary containment to the fraction of the core inventory of the parent that is airborne on the primary containment. Then the differential equations describing the time dependent daughter activities in the primary and secondary containments are

$$\dot{A}_j(t) = -(\lambda_j + L + P) A_j(t) + b_j \lambda_j \zeta_p A_p(t) \qquad \text{Eqn. A37}$$

$$\dot{C}_j(t) = -(\lambda_j + \frac{E}{m}) C_j(t) + (1-B) L A_j(t) + b_j \lambda_j C_p(t) \qquad \text{Eqn. A38}$$

Note that the absence of λ_p in Eqns. A37 and A38 is correct.

After substituting Eqns. A35 and A36 into Eqns. A37 and A38, the solutions are

$$A_j(t) = A_j(t_A)\, e^{-(\lambda_j + L + P)(t - t_A)} + \frac{b_j \lambda_j \xi_p A_p(t_A)}{(\lambda_j - \lambda_p)} \left[e^{-(\lambda_p + L + P)(t - t_A)} - e^{-(\lambda_j + L + P)(t - t_A)} \right] \qquad \text{Eqn. A39}$$

$$C_j(t) = \left[C_j(t_A) + \alpha - \beta - \gamma \right] e^{-(\lambda_j + \frac{E}{M})(t - t_A)} + \left[\gamma - \alpha \right] e^{-(\lambda_p + \frac{E}{M})(t - t_A)} + \left[\beta - \alpha \right] e^{-(\lambda_j + L + P)(t - t_A)} + \alpha\, e^{-(\lambda_p + L + P)(t - t_A)} \qquad \text{Eqn. A40}$$

where

$$\alpha = b_j (1 - B) \lambda_j L \xi_p A_p(t) \Big/ \left[\left(\frac{E}{M} - L - P \right) (\lambda_j - \lambda_p) \right] \qquad \text{Eqn. A41}$$

$$\beta = (1 - B) L A_j(t_A) \Big/ \left(\frac{E}{M} - L - P \right) \qquad \text{Eqn. A42}$$

$$\gamma = b_j \lambda_j C_p(t_A) \Big/ (\lambda_j - \lambda_p) \qquad \text{Eqn. A43}$$

The initial conditions are, when $t_A = 0.0$, $A_j(0)$ is the initial airborne daughter activity in the primary containment, $A_p(0)$ is the initial airborne parent activity in the primary containment, and both $C_j(0)$ and $C_p(0)$ are zero.

The release rate to the environment for the daughter nuclide is then

$$\dot{Q}_j(t) = \left[(1 - \varepsilon_j) P + BL \right] A_j(t) + (1 - \varepsilon_j) \frac{E}{M} C_j(t) \qquad \text{Eqn. A44}$$

Let $\mu = \left[(1 - \varepsilon_j) P + BL \right]$ Eqn. A45

$\nu = (1 - \varepsilon_j) \frac{E}{M}$ Eqn. A46

and $\delta = b_j \lambda_j \zeta_p A_p(t_A)/(\lambda_j - \lambda_p)$ Eqn. A47

Substituting Eqns. A39, A40, A45, A46, and A47 into Eqn. A44,

$$\dot{Q}_j(t) = \mu \left\{ A_j(t_A) e^{-(\lambda_j+L+P)(t-t_A)} - \delta e^{-(\lambda_j+L+P)(t-t_A)} + \delta e^{-(\lambda_p+L+P)(t-t_A)} \right\}$$
$$+ \nu \left\{ \left[C_j(t_A) + \alpha - \beta - \gamma\right] e^{-(\lambda_j+\frac{E}{M})(t-t_A)} + \left[\gamma - \alpha\right] e^{-(\lambda_p+\frac{E}{M})(t-t_A)} + \left[\beta - \alpha\right] e^{-(\lambda_j+L+P)(t-t_A)} + \alpha e^{-(\lambda_p+L+P)(t-t_A)} \right\}$$ Eqn. A48

The total release to the environment during the time period t_A to t_B is

$$Q_j(t_A, t_B) = \int_{t_A}^{t_B} \dot{Q}_j(t)\, dt$$ Eqn. A49

$$Q_j(t_A,t_B) = \mu \left\{ \left[A_j(t_A) - \delta\right]\left[1 - e^{-(\lambda_j+L+P)(t-t_A)}\right] / \left[\lambda_j + L + P\right] + \delta\left[1 - e^{-(\lambda_p+L+P)(t-t_A)}\right] / \left[\lambda_p + L + P\right] \right\}$$
$$+ \nu \left\{ \left[C_j(t_A) + \alpha - \beta - \gamma\right]\left[1 - e^{-(\lambda_j+\frac{E}{M})(t-t_A)}\right] / \left[\lambda_j + \frac{E}{M}\right] + \left[\gamma - \alpha\right]\left[1 - e^{-(\lambda_p+\frac{E}{M})(t-t_A)}\right] / \left[\lambda_p + \frac{E}{M}\right] + \left[\beta - \alpha\right]\left[1 - e^{-(\lambda_j+L+P)(t-t_A)}\right] / \left[\lambda_j + L + P\right] + \alpha\left[1 - e^{-(\lambda_p+L+P)(t-t_A)}\right] / \left[\lambda_p + L + P\right] \right\}$$ Eqn. A50

Eqn. A50 should replace Eqn. A8 when parent effects are to be considered for nuclide j .

Rearranging Eqn. A48, the activity release rate,

$$\begin{aligned}\dot{Q}_j(t) = & \left\{\nu[\beta-\alpha] + \mu[A_j(t_A)-\delta]\right\} e^{-(\lambda_j+L+P)(t-t_A)} \\ & + \left\{\nu\alpha+\mu\delta\right\} e^{-(\lambda_p+L+P)(t-t_A)} + \left\{\nu[C_j(t_A)+\alpha-\beta-\gamma]\right\} e^{-(\lambda_j+\frac{E}{M})(t-t_A)} \\ & + \left\{\nu[\gamma-\alpha]\right\} e^{-(\lambda_p+\frac{E}{M})(t-t_A)}\end{aligned} \qquad \text{Eqn. A51}$$

Eqn. A51 should replace Eqn. A6 when parent effects are to be considered for nuclide j .

The derivative of $\dot{Q}_j(t)$ (Eqn. A51) is

$$\begin{aligned}\ddot{Q}_j(t) = & \left\{\lambda_j+L+P\right\}\left\{\nu[\alpha-\beta]\ \mu[\delta-A_j(t_A)]\right\} e^{-(\lambda_j+L+P)(t-t_A)} \\ & - \left\{\lambda_p+L+P\right\}\left\{\nu\alpha+\mu\delta\right\} e^{-(\lambda_p+L+P)(t-t_A)} \\ & + \left\{\lambda_j+\tfrac{E}{M}\right\}\left\{\nu[\beta+\gamma-\alpha-C_j(t_A)]\right\} e^{-(\lambda_j+\frac{E}{M})(t-t_A)} \\ & + \left\{\lambda_p+\tfrac{E}{M}\right\}\left\{\nu[\alpha-\gamma]\right\} e^{-(\lambda_p+\frac{E}{M})(t-t_A)}\end{aligned} \qquad \text{Eqn. A52}$$

Eqn. A52 should replace the quantity within the braces in Eqn. A25 when j in the summation corresponds to a nuclide for which parent effects are to be considered.

A.3.7 Atmospheric Relative Concentration, $(\chi/Q')_{id}$

The atmospheric disperison model used is that for a semi-infinite cloud whose concentration is that for the center of a Gaussian plume a distance d meters downwind from the ground level release point. The lateral and the vertical plume spreads, m meters, are termed $\sigma_{iy}(d)$ and $\sigma_{iz}(d)$ respectively and are functions of the Pasquill stability class i and the downwind distance d .

The atmospheric relative concentration times the wind speed $\bar{u}$ in meters/second for the desired model, excluding a building wake correction and excluding plume rise is (Ref. 1)

$$\bar{u}\left(\chi/Q'\right)_{id} = \frac{1}{\pi\,\sigma_{iy}(d)\,\sigma_{iz}(d)} \qquad \text{Eqn. A53}$$

The next subsections will describe the determination of

(a) $\sigma_{iy}(d)$ and $\sigma_{iz}(d)$

(b) $\bar{u}\left(\chi/Q'\right)_{id}$ with building wake correction

(c) d when given a value of $\bar{u}\left(\chi/Q'\right)_{id}$

A.3.7.1 Determination of $\sigma_{iy}(d)$ and $\sigma_{iz}(d)$

The algorithms, Reference 12, for determining $\sigma_{iy}(d)$ and $\sigma_{iz}(d)$ were

$$\sigma_{iy}(d) = A_{iy} d^{B_{iy}}$$ Eqn. A54

$$\sigma_{iz}(d) = A_{iz} d^{B_{iz}} + C_{iz} \quad \text{if} \quad \sigma_{iz}(d) \leq 1000.0\text{m}$$ Eqn. A55

$$\sigma_{iz}(d) = 1000.0\text{m if Eqn. A55 fails}$$ Eqn. A56

The inequality test for Eqn. A55 results from the assumption of 1000.0 meters for the planetary boundary layer thickness (maximum mixing depth). The parameters for these equations are given in Table A1 and Table A2. All parameters for Pasquill class G (i = 7) were calculated from the parameters for Pasquill class F (i = 6) using the following equations from Reference 13.

$$\sigma_{7y}(d) = 0.667\,\sigma_{6y}(d)$$ Eqn. A57

$$\sigma_{7z}(d) = 0.6\,\sigma_{6z}(d)$$ Eqn. A58

TABLE A1

Parameters for $\sigma_{iy}(d)$ Algorithm

(From Reference 12 and Eqn. A57)

Pasquill Class	Class Index i	A_{iy}	B_{iy}
A	1	.3658	.9031
B	2	.2751	.9031
C	3	.2089	.9031
D	4	.1471	.9031
E	5	.1046	.9031
F	6	.0722	.9031
G	7	.0481	.9031

TABLE A2

Parameters for $\sigma_{iz}(d)$ Algorithm

(From Reference 12 and Eqn. A58)

Pasquill	Class	$d < 100m$			$100 \le d < 1000m$			$d \ge 1000$ m		
Class	Index i	A_{iz}	B_{iz}	C_{iz}	A_{iz}	B_{iz}	C_{iz}	A_{iz}	B_{iz}	C_{iz}
A	1	.192	.936	0	.00066	1.941	9.27	.00024	2.094	-9.6
B	2	.156	.922	0	.0382	1.149	3.3	.0055	1.098	2.0
C	3	.116	.905	0	.113	.911	0	.113	.911	0
D	4	.079	.881	0	.222	.725	-1.7	1.26	.516	-13.0
E	5	.063	.871	0	.211	.678	-1.3	6.73	.305	-33.8*
F	6	.053	.814	0	.086	.74	- .35	18.05	.18	-48.6
G	7	.032	.814	0	.052	.74	- .21	10.83	.18	-29.13*

*Adjusted values to give a better match at the interval boundary, z = 1000m

A.3.7.2 Determination of $\bar{u}(\chi/Q')_{id}$ With Building Wake Correction

Let A_R = smallest vertical plane cross-sectional area, m^2, of the reactor building.*

Then from Reference 13, conservatively assuming no plume meander,

$$\bar{u}(\chi/Q')_{id} = \frac{1}{[\pi \sigma_{iy}(d)\sigma_{iz}(d) + A_R/2]} \qquad \text{Eqn. A59}$$

or

$$\bar{u}(\chi/Q')_{id} = \frac{1}{3\pi \sigma_{iy}(d)\sigma_{iz}(d)} \qquad \text{Eqn. A60}$$

whichever is the larger.

Define $K_c \equiv \frac{A_R}{2\pi}$ Eqn. A61

Define $F_{id} \equiv 1 + \frac{K_c}{\sigma_{iy}(d)\,\sigma_{iz}(d)}$ Eqn. A62

which is the building wake correction factor.

Then, if $F_{id} \geq 3$,

$$\bar{u}(\chi/Q')_{id} = \frac{1}{3\pi \sigma_{iy}(d)\sigma_{iz}(d)} \qquad \text{Eqn. A63}$$

or if $F_{id} < 3$,

$$\bar{u}(\chi/Q')_{id} = \frac{1}{\pi[\sigma_{iy}(d)\sigma_{iz}(d) + K_c]} \qquad \text{Eqn. A64}$$

---

*For the Enrico Fermi Atomic Power Plant - Unit 2, the value of A_R was found to be 160 (ft.) x 152.5 (ft) x $(.3048)^2$ $(m/ft)^2$ from The Detroit Edison Co. Architectural Drawings #7A721-2001 and #7A721-2003. Thus, A_R = 2266.83 m^2 and K_c = 360.78 m^2.

A.3.7.3 Determination of Distance When Given a Value of $\bar{u}\left(\chi/Q'\right)_{id}$

Solving for the product $\sigma_{iy}(d)\sigma_{iz}(d)$ in both Eqns. A63 and A64,

$$\sigma(d)\sigma(d) = \frac{1}{3\pi\bar{u}\left(\chi/Q'\right)_{id}}$$ Eqn. A65

to be used if $\sigma_{iy}(d)\sigma_{iz}(d) \leq K_c/2$

and

$$\sigma(d)\sigma(d) = \frac{1}{\pi\bar{u}\left(\chi/Q'\right)_{id}} - K_c$$ Eqn. A66

to be used if $\sigma_{iy}(d)\sigma_{iz}(d) > K_c/2$

The appropriate equation (Eqn. A65 or Eqn. A66) may be solved for the distance, d, by a method of interpolation (regula falsi) when given a value of $\left(\chi/Q'\right)_{id}$. The following steps are used.

Step 1: Evaluate $S = \sigma_{iy}(d)\sigma_{iz}(d)$ using both Eqn. A65 and Eqn. A66, and select the appropriate value according to the inequalities associated with each of these equations.

Step 2: Select the range $100 \leq d < 1000$ m. for the parameters to be used in Eqns. A54 through A56.

Step 3: Let the first guess for the distance be d_1 = 200 m.

Step 4: Let the second guess for the distance be d_2 = 800 m.

Step 5: Set the iteration counter equal to zero.

Step 6: Calculate $S_1 = \sigma_{iy}(d_1)\sigma_{iz}(d_1)$ from Eqns. A54 through A56.

Step 7: Increment the iteration counter by 1.

Step 8: Calculate $S_2 = \sigma_{iy}(d_2)\sigma_{iz}(d_2)$ from Eqns. A54 through A56.

Step 9: Calculate new distance d by log-log interpolation; thus, $d = \exp\left\{ \ln(d_1) + \ln\left(\frac{d_2}{d_1}\right)\ln\left(\frac{S}{S_1}\right) / \ln\left(\frac{S_2}{S_1}\right) \right\}$

Step 10: If $|d-d_2|/d <$ 0.0001 then go to Step 15.

Step 11: If iteration counter exceeds 30 then go to Step 15.

Step 12: If $|S_1-S| > |S_2-S|$, then go to Step 14.

Step 13: Set $d_2 = d$; then go to Step 7.

Step 14: Set $S_1 = S_2$; set $d_1 = d_2$; set $d_2 = d$; then go to Step 7.

Step 15: If $d \geq 1000$ m. and the parameters in use for Eqns. A54 through A56 are not for the range $d \geq 1000$ m., go to Step 18.

Step 16: If $d < 100$ m. and the parameters in use for Eqns. A54 through A56 are not for the range $d < 100$ m., go to Step 19.

Step 17: Finished.

Step 18: Select the range $d \geq 1000$ m. for the parameters to be used in Eqns. A54 through A56; Set d_1 = 2000 m.; Set d_2= 8000 m.; go to Step 5.

Step 19: Select the range $d < 100$ m. for the parameters to be used in Eqns. A54 through A56; Set d_1 = 10 m.; Set d_2 = 90 m.; go to Step 5.

A.3.8 Total Downwind Doses

A.3.8.1 Environmental Protection Agency Protective Action Guide Limits

In Reference 1, Protective Action Guides (PAG), recommended protective actions to reduce whole body and thyroid dose from exposure to a gaseous plume are given based on projected whole body and thyroid inhalation doses to the population (see Table 5.1 in Reference 1). Table A3 summarizes these actions. Table A4 condenses the limits of Table A3 into Red, Yellow, White, and No emergency conditions. The White energency condition does not exist in Reference 1.

TABLE A3

Recommended Protective Actions to Reduce Whole Body and Thyroid Dose From Exposure to a Gaseous Plume (Ref. 1)

Projected Dose (Rem) to the Population	Recommended Actions[a]	Comments
Whole body, <1 Thyroid, <5	No planned protective actions.[b] State may issue an advisory to seek shelter and await further instructions. Monitor environmental radiation levels.	Previously recommended protective actions may be reconsidered or terminated.
Whole body, 1 to < 5 Thyroid, 5 to < 25	Seek shelter as a minimum. Consider evacuation. Evacuate unless constraints make it impractical. Monitor environmental radiation levels. Control access.	If constraints exist, special consideration should be given for children and pregnant women.
Whole body, 5 and above Thyroid, 25 and above	Conduct mandatory evacuation. Monitor environmental radiation levels and adjust area for mandatory evacuation based on these levels. Control access.	Seeking shelter would be an alternative if evacuation were not immediately possible.

(a) These actions are recommended for planning purposes. Protective action decision at the time of the incident must take existing conditions into consideration.

(b) At the time of the incident, officials may implement low impact protective actions in keeping with the principle of maintaining radiation exposure as low as reasonably achievable.

TABLE A4

Protective Action Guide Dose Limits

Projected Dose (Rem) to the Population	Emergency Condition	Relation to Table A3
Whole Body < 0.05 Thyroid < 0.3	No No	Corresponds to the first set of entries.
0.05 ≤ Whole Body < 1.0 0.3 ≤ Thyroid < 5.0	White White	Corresponds to the first set of entries.
1.0 ≤ Whole Body < 5.0 5.0 ≤ Thyroid < 25.0	Yellow Yellow	Corresponds to the second set of entries.
5.0 ≤ Whole Body 25.0 ≤ Thyroid	Red Red	Corresponds to the third set of entries.

A.3.8.2 Dose Calculations

The projected whole body (γ) dose for the time period t_A to t_B at a distance d for Pasquill class i as determined by the drywell monitor reading is

$$ {}_{D}D_{id\gamma}(t_A, t_B) = K\left[{}_{AD}Q_{eff\,Xe\text{-}133}(t_A, t_B)\right]\overline{E}_{\gamma Xe\text{-}133}\left[\bar{u}\left(\chi/Q'\right)_{id}\right]/\bar{u} \qquad \text{Eqn. A67} $$

where $K = 0.253\ (\text{Rem} \cdot \text{m}^3)/(\text{ci}\cdot\text{Mev}\cdot\text{sec})$,

$\left[{}_{AD}Q_{eff\,Xe\text{-}133}(t_A, t_B)\right]$ is found from Eqn. A17,

and $\left[\bar{u}\left(\chi/Q'\right)_{id}\right]$ is found from Eqns. A62 through A64.

As determined by the SGTS monitor reading, it is

$$ {}_{S}D_{id\gamma}(t_A, t_B) = K\left[{}_{AS}Q_{eff\,Xe\text{-}133}(t_A, t_B)\right]\overline{E}_{\gamma Xe\text{-}133}\left[\bar{u}\left(\chi/Q'\right)_{id}\right]/\bar{u} \qquad \text{Eqn. A68} $$

where $\left[{}_{AS}Q_{eff\,Xe\text{-}133}(t_A, t_B)\right]$ is found from Eqn. A21.

The projected thyroid inhalation dose for the time period t_A to t_B at a distance d for Pasquill class i as determined by the drywell monitor reading is

$$ {}_{D}D_{id\,Thyroid}(t_A, t_B) = D_{C\,I\text{-}131}\,B_R\left[{}_{AD}Q_{eff\,I\text{-}131}(t_A, t_B)\right]\left[\bar{u}\left(\chi/Q'\right)_{id}\right]/\bar{u} \qquad \text{Eqn. A69} $$

where $\left[{}_{AD}Q_{eff\,I\text{-}131}(t_A, t_B)\right]$ is found from Eqn. A18.

As determined by the SGTS monitor reading, it is

$$ {}_{S}D_{id\,Thyroid}(t_A, t_B) = D_{C\,I\text{-}131}\,B_R\left[{}_{AS}Q_{eff\,I\text{-}131}(t_A, t_B)\right]\left[\bar{u}\left(\chi/Q'\right)_{id}\right]/\bar{u} \qquad \text{Eqn. A70} $$

where $\left[{}_{AS}Q_{eff\,I\text{-}131}(t_A, t_B)\right]$ is found from Eqn. A22.

The doses as calculated by Eqns. A67 through A70 can be compared to the PAG dose limits in Table A4, and the associated Emergency Condition can be assigned.

A.3.8.3 Distances to Protective Action Guides Dose Limits

Let k be an index denoting the lower PAG dose limit for the PAG emergency conditions in Table A4 excluding the no emergency condition; thus,

k = 1 for lower dose limit of Red emergency condition,
k = 2 for lower dose limit of Yellow emergency condition,
and k = 3 for lower dose limit of White emergency condition.

Let $D_{k\gamma}$ be the whole body dose for lower dose limit k and $D_{k\,Thyroid}$ be the thyroid inhalation dose for lower dose limit k.

As determined by the drywell monitor reading let ${}_Dd_{k\gamma}$ be the maximum distance to which the whole body emergency condition k extends; thus,

from 0 to ${}_Dd_{1\gamma}$ the Red emergency condition exists,
from ${}_Dd_{1\gamma}$ to ${}_Dd_{2\gamma}$ the Yellow emergency condition exists,
and from ${}_Dd_{2\gamma}$ to ${}_Dd_{3\gamma}$ the White emergency condition exists.

Similarly let ${}_Dd_{k\,Thyroid}$ be the maximum distance to which the thyroid inhalation emergency condition k extends.

As determined by the SGTS monitor reading define ${}_Sd_{k\gamma}$ and ${}_Sd_{k\,Thyroid}$ in a similar manner.

The distances to the Protective Action Guide dose limits are found by substituting $D_{k\gamma}$ or $D_{k\,Thyroid}$ into the appropriate Eqn. A67, A68, A69, or A70 and solving for $\bar{u}(\chi/Q')_{ix}$ where x is the appropriate distance designation ${}_Dd_{k\gamma}$, ${}_Sd_{k\gamma}$, ${}_Dd_{k\,Thyroid}$, or ${}_Sd_{k\,Thyroid}$.

Solving Eqn. A67,

$$\bar{u}\left(\chi/Q'\right)_{ix} = \frac{\bar{u}\, D_{k\gamma}}{K\left[{}_{AD}Q_{eff\,Xe\text{-}133}(t_A, t_B)\right]\bar{E}_{\gamma Xe\text{-}133}} \qquad \text{Eqn. A71}$$

where $X = {}_{D}d_{k\gamma}$ which may be found from the procedure in Section A.3.7.3.

Solving Eqn. A68,

$$\bar{u}\left(\chi/Q'\right)_{ix} = \frac{\bar{u}\,D_{k\gamma}}{K\left[{}_{AS}Q_{eff\,Xe\text{-}133}(t_A, t_B)\right]\bar{E}_{\gamma\,Xe\text{-}133}}$$ Eqn. A72

where $X = {}_{S}d_{k\gamma}$ which may be found from the procedures in Section A.3.7.3.

Solving Eqn. A69,

$$\bar{u}\left(\chi/Q'\right)_{ix} = \frac{\bar{u}\,D_{k\,Thyroid}}{\left[{}_{AD}Q_{eff\,I\text{-}131}(t_A, t_B)\right]D_{c\,I\text{-}131}\,B_R}$$ Eqn. A73

where $X = {}_{D}d_{k\,Thyroid}$ which may be found from the procedures in Section A.3.7.3.

Solving Eqn. A70,

$$\bar{u}\left(\chi/Q'\right)_{ix} = \frac{\bar{u}\,D_{k\,Thyroid}}{\left[{}_{AS}Q_{eff\,I\text{-}131}(t_A, t_B)\right]D_{c\,I\text{-}131}\,B_R}$$ Eqn. A74

where $X = {}_{S}d_{k\,Thyroid}$ which may be found from the procedures in Section A.3.7.3.

A.3.9 Total Downwind Dose Rates

A.3.9.1 NUREG-0654 Emergency Dose Rate Limits

In Reference 2, (NUREG-0654), Licensee and State and/or Local Offsite Authority actions are given for several emergency classifications. One method of defining these classifications is by specifying dose rate limits at the site boundary. Table A5 summarizes these dose rate limits.

TABLE A5

NUREG-0654, Rev. 1, Appendix 1, (Ref. 2)

Emergency Dose Rate Limits

Projected Dose Rate Limit, Rem/hr, at the Site Boundary	Minimum Duration	Pasquill Class	Wind Speed, m/sec	Emergency Classification
Whole Body = 0.05 Thyroid = 0.25	½ hour	G*	1.0*	Site
Whole Body = 0.5 Thyroid = 2.5	2 minutes	G*	1.0*	Site
Whole Body = 1.0 Thyroid = 5.0	N/A	Actual**	Actual**	General

*Values assumed to be "adverse meteorology"

**Actual site meteorology

A.3.9.2 Dose Rate Calculations

The projected whole body (γ) dose rate at the time of maximum release rate at a distance d for Pasquill class i as determined by the drywell monitor reading is

$$_{D}\dot{D}_{id\gamma}(T_{max\,Xe-133}) = K\left[{}_{AD}\dot{Q}_{eff\,Xe-133}(T_{max\,Xe-133})\right]\overline{E}_{\gamma\,Xe-133}\left[\bar{u}\left(\chi/Q'\right)_{id}\right]\Big/\bar{u} \qquad \text{Eqn. A75}$$

where $K = 0.253\ (\text{Rem}\cdot\text{m}^3)/(\text{ci}\cdot\text{Mev}\cdot\text{sec})$,

$\left[{}_{AD}\dot{Q}_{eff\,Xe-133}(T_{max\,Xe-133})\right]$ is found from Eqn. A31

$T_{max\,Xe-133}$ is found by the methods of Section A.3.4,

and $\left[\bar{u}\left(\chi/Q'\right)_{id}\right]$ is found from Eqns. A62 through A64.

As determined by the SGTS monitor reading, it is

$$_{S}\dot{D}_{id\gamma}(T_{max\,Xe-133}) = K\left[{}_{AS}\dot{Q}_{eff\,Xe-133}(T_{max\,Xe-133})\right]\overline{E}_{\gamma\,Xe-133}\left[\bar{u}\left(\chi/Q'\right)_{id}\right]\Big/\bar{u} \qquad \text{Eqn. A76}$$

where $\left[{}_{AS}\dot{Q}_{eff\,Xe-133}(T_{max\,Xe-133})\right]$ is found from Eqn. A33.

The projected thyroid inhalation dose rate at the time of maximum release rate at a distance d for Pasquill class i as determined by the drywell monitor reading is

$$_{D}\dot{D}_{id\,Thyroid}(T_{max\,I-131}) = D_{C\,I-131}\,B_R\left[{}_{AD}\dot{Q}_{eff\,I-131}(T_{max\,I-131})\right]\left[\bar{u}\left(\chi/Q'\right)_{id}\right]\Big/\bar{u} \qquad \text{Eqn. A77}$$

where $\left[{}_{AD}\dot{Q}_{eff\,I-131}(T_{max\,I-131})\right]$ is found from Eqn. A32 and

$T_{max\,I-131}$ is found by the methods of Section A.3.4.

As determined by the SGTS monitor reading, it is

$$_{S}\dot{D}_{id\,Thyroid}(T_{max\,I-131}) = D_{C\,I-131}\,B_R\left[{}_{AS}\dot{Q}_{eff\,I-131}(T_{max\,I-131})\right]\left[\bar{u}\left(\chi/Q'\right)_{id}\right]\Big/\bar{u} \qquad \text{Eqn. A78}$$

where $\left[{}_{AS}\dot{Q}_{eff\,I-131}(T_{max\,I-131})\right]$ is found from Eqn. A34.

The dose rates at the site boundary as calculated by Eqns. A75 through A78 can be compared to the NUREG-0654 dose rate limits and the associated Emergency Classification can be assigned. Another approach would be to calculate the monitor reading which would result in the dose rate limit at the site boundary. This approach is now described; however, the subscript Xe-133 or I-131 will be dropped because this description applies to both Xe-133 and I-131.

Eqn. A23 or Eqn. A24 can be interpreted to be the calculation of the effective activity release rate to achieve the dose rate limit at the site boundary $\dot{Q}_{eff\,\ell}(t)$ divided by the fraction of the design basis accident release that is actually released to the primary containment F_ℓ ; thus,

$$\frac{\dot{Q}_{eff\,\ell}(t)}{F_\ell} = \dot{Q}_{eff}(t) \qquad \text{Eqn. A79}$$

For simplicity the functional dependence on time will no longer be indicated; all time dependent quantities will be understood to be evaluated at the time of the maximum release rate. Also, the distinction between whole body and thyroid inhalation dose rates will be dropped as well as the indication of the monitor location. Distance d will be the distance to the site boundary; the subscript d will be dropped.

Let $\dot{D}_\ell$ be the dose rate limit at the site boundary. Then

$$\dot{D}_\ell = K_1 \dot{Q}_{eff\,\ell} \left[\bar{u}\left(\chi/Q'\right)_i\right] / \bar{u} \qquad \text{Eqn. A80}$$

where K_1 is a constant.

Solving Eqn. A80 for $\frac{\dot{Q}_{eff\,\ell}}{\bar{u}}$,

$$\frac{\dot{Q}_{eff\,\ell}}{\bar{u}} = \frac{\dot{D}_\ell}{K_1\left[\bar{u}\left(\chi/Q'\right)_i\right]} \qquad \text{Eqn. A81}$$

Dividing Eqn. A81 by Eqn. A79,

$$\frac{F_\ell}{\bar{u}} = \frac{\dot{D}_\ell}{K_1\left[\bar{u}(\chi/Q')_i\right]\dot{Q}_{eff}}$$ Eqn. A82

The monitor reading R_ℓ which would result in the dose rate limit at the site boundary is

$$R_\ell = \frac{F_\ell}{\bar{u}} R_c \bar{u}$$ Eqn. A83

where the R_c is obtained from Eqn. A13 or Eqn. A14.

Substituting Eqn. A82 into Eqn. A83,

$$R_\ell = \frac{\dot{D}_\ell R_c \bar{u}}{K_1\left[\bar{u}(\chi/Q')_i\right]\dot{Q}_{eff}}$$ Eqn. A84

The actual monitor reading can be compared to R_ℓ to determine the emergency classification.

Eqn. A84 should now be recognized as the design basis accident calculated monitor reading times the ratio of the dose rate limit to the design basis accident dose rate.

A.3.9.3 Distances to NUREG-0654 Emergency Dose Rate Limits

Let ℓ be an index denoting the NUREG-0654 (Ref. 2) dose rate limit for the emergency classifications in Table A5; thus,

ℓ = 1 for General Emergency

ℓ = 2 for Site Emergency with duration 2 minutes

ℓ = 3 for Site Emergency with duration ½ hour.

Let $\dot{D}_{\ell\gamma}$ be the whole body dose rate for classification ℓ and $\dot{D}_{\ell\,Thyroid}$ be the thyroid inhalation dose rate for classification ℓ.

As determined by the drywell monitor reading, let ${}_{D}d_{\ell\gamma}$ be the distance at which classification ℓ for the whole body emergency occurs. Similarly let ${}_{D}d_{\ell\,Thyroid}$ be the distance at which classification ℓ for the thyroid inhalation emergency occurs.

As determined by the SGTS monitor reading define ${}_{S}d_{\ell\gamma}$ and ${}_{S}d_{\ell\,Thyroid}$ in a similar manner.

The distances to the NUREG-0654 dose rate limits are found by substituting $\dot{D}_{\ell\gamma}$ and $\dot{D}_{\ell\,Thyroid}$ into the appropriate Eqn. A75, A76, A77, or A78 and solving for $\bar{u}(\chi/Q')_{ix}$ where x is the appropriate distance designation ${}_{D}d_{\ell\gamma}$, ${}_{S}d_{\ell\gamma}$, ${}_{D}d_{\ell\,Thyroid}$, or ${}_{S}d_{\ell\,Thyroid}$.

Solving Eqn. A75,

$$\bar{u}\left(\chi/Q'\right)_{ix} = \frac{\bar{u}\,\dot{D}_{\ell\gamma}}{K\left[{}_{AD}\dot{Q}_{eff\,Xe\text{-}133}(T_{max\,Xe\text{-}133})\right]\bar{E}_{\gamma\,Xe\text{-}133}} \qquad \text{Eqn. A85}$$

where $x = {}_{D}d_{\ell\gamma}$ which may be found from the procedures in Section A.3.7.3.

Solving Eqn. A76,

$$\bar{u}\left(\chi/Q'\right)_{ix} = \frac{\bar{u}\,\dot{D}_{\ell\gamma}}{K\left[{}_{AS}\dot{Q}_{eff\,Xe\text{-}133}(T_{max\,Xe\text{-}133})\right]\bar{E}_{\gamma\,Xe\text{-}133}} \qquad \text{Eqn. A86}$$

where $x = {}_{S}d_{\ell\gamma}$ which may be found from the procedures in Section A.3.7.3.

Solving Eqn. A77,

$$\bar{u}\,(\chi/Q')_{ix} = \frac{\bar{u}\,\dot{D}_{\ell\,Thyroid}}{\left[{}_{AD}\dot{Q}_{eff\,I\text{-}131}\left(T_{max\,I\text{-}131}\right)\right] D_{c\,I\text{-}131}\,B_R} \qquad \text{Eqn. A87}$$

where $x = {}_{D}d_{\ell\,Thyroid}$ which may be found from the procedures in Section A.3.7.3.

Solving Eqn. A78,

$$\bar{u}\,(\chi/Q')_{ix} = \frac{\bar{u}\,\dot{D}_{\ell\,Thyroid}}{\left[{}_{AS}\dot{Q}_{eff\,I\text{-}131}\left(T_{max\,I\text{-}131}\right)\right] D_{c\,I\text{-}131}\,B_R} \qquad \text{Eqn. A88}$$

where $x = {}_{S}d_{\ell\,Thyroid}$ which may be found from the procedures in Section A.3.7.3.

A.3.10 Projections Based on Constant SGTS Monitor Reading with No Shutdown

This section deals with the special case of a constant SGTS monitor reading. The special assumptions of no reactor shutdown and no reactor building mixing will apply.

Let R_{AS} = the actual SGTS monitor reading, ci/m^3, (effective Xe-133); since R_{AS} is assumed to be constant, the functional dependence on t will be dropped.

Then the effective Xe-133 activity, ci, released during the time period T_A to T_B is

$$_{AS}Q_{eff\,Xe-133}(T_A,T_B) = R_{AS} V_{sc} E \left[T_B - T_A\right]\left[0.3048 \frac{m}{ft}\right]^3$$ Eqn. A89

The total noble gas activity, ci, released during the time period is

$$_{AS}Q_{T\,Nobles}(T_A,T_B) = {}_{AS}Q_{eff\,Xe-133}(T_A,T_B)\,\overline{E}_{\gamma Xe-133}\left\{\frac{\sum_{j=6}^{18} A_j}{\sum_{j=1}^{18} \overline{E}_{\gamma j}(1-\varepsilon_j) f_j A_j}\right\}^{*}$$ Eqn. A90

where A_j is independent of time because no reactor shutdown was assumed. (Eqn. A90 becomes obvious if the definition of $Q_{eff\,Xe-133}$ is recalled).

Similarly the total iodine activity, ci, released during the time period is

$$_{AS}Q_{T\,Iodine}(T_A,T_B) = {}_{AS}Q_{eff\,Xe-133}(T_A,T_B)\,\overline{E}_{\gamma Xe-133}\left\{\frac{\sum_{j=1}^{5}(1-\varepsilon_j)A_j}{\sum_{j=1}^{18}\overline{E}_{\gamma j}(1-\varepsilon_j)A_j}\right\}$$ Eqn. A91

*When using the results of this section as input to the methodology of Reference 1, all summations including values of $j \geq 6$ should use only those nuclides in Table 3.1, Appendix D, page D-25 of Reference 1.

However, it will be noted that the f_j in the denominator of Eqn. A90 was omitted from the denominator of Eqn. A91. This is because the definition of $Q_{eff\ Xe-133}$ is different when determining iodine releases; in this case all of the design basis accident iodine is assumed to be present and, therefore, $f_j \equiv 1.0$. The effective I-131 activity, ci, release during the time period is

$$ {}_{AS}Q_{eff\ I-131}(T_A,T_B) = {}_{AS}Q_{T\ Iodines}(T_A,T_B)\left\{\frac{\sum_{j=1}^{5} D_{cj}(1-\varepsilon_j)A_j}{\sum_{j=1}^{5}(1-\varepsilon_j)A_j}\right\}\Big/ D_{c\ I-131} $$ Eqn. A92

The average effective activity release rates for the time period are

$$ {}_{AS}\hat{Q}_{eff\ Xe-133}(T_A,T_B) = {}_{AS}Q_{eff\ Xe-133}(T_A,T_B)\Big/\left[T_B - T_A\right] $$ Eqn. A93

and

$$ {}_{AS}\hat{Q}_{eff\ I-131}(T_A,T_B) = {}_{AS}Q_{eff\ I-131}(T_A,T_B)\Big/\left[T_B - T_A\right] $$ Eqn. A94

The results of Eqns. A89 and A92 can be used in Eqns. A68 and A70 to obtain downwind doses. The results of Eqns. A93 and A94 can be used in Eqns. A76 and A78 to obtain downwind dose rates. The results of Eqns. A89 and A92 can be used in Eqns. A72 and A74 to obtain the distances to the Protective Action Guides (Ref. 1) dose limits.

A.4 Drywell Finite Gamma Cloud Corrections

Since the drywell monitor calculated readings, Eqn. A13, are based on the semi-infinite cloud equation, the division by a correction factor H_j was required to effect a finite cloud. This correction factor is the ratio of the semi-infinite gamma cloud dose rate to that for a finite cloud. This ratio is dependent only on the nuclide j and the geometry of the finite cloud; thus, for a given monitor location, ratios need to be calculated only once.

For a BWR drywell monitor located on the outer wall of the drywell, a simple model of the geometry of the finite cloud will be a cylindrical annulus. This section provides a reference for the theory of infinite to finite gamma cloud dose rate ratios as well as documentation for extending the theory to a cylindrical annulus cloud. Calculation of the ratios are done by an independent computer program; the ratios are then available as default values in the Accident Radiological Dose Assessment Program. Any input values may override the default ratios.

Reference 14, Section 2.1 provides the theory of infinite to finite gamma cloud dose rate ratios. The equations developed in Ref. 14, Section 2.1.3.4 (Finite Rectangular Parallelopiped Cloud Dose) can be modified in order to apply to a cylindrical annulus cloud by replacing the function $R(\theta)$ by a function $r(\alpha)$ to be derived in this Section.

Let R_1 be the radius of the outer cylinder.
Let R_2 be the radius of the inner cylinder.
Define r to be the distance from a point on the outer cylinder to the outer or inner cylinder whichever is shorter in a direction whose angle is α from the tangent to the point on the outer cylinder (see Figure A2). Also, define

$$\alpha_0 = \cos^{-1}(R_2/R_1),$$

the angle of the direction of r when r is tangent to the inner cylinder.

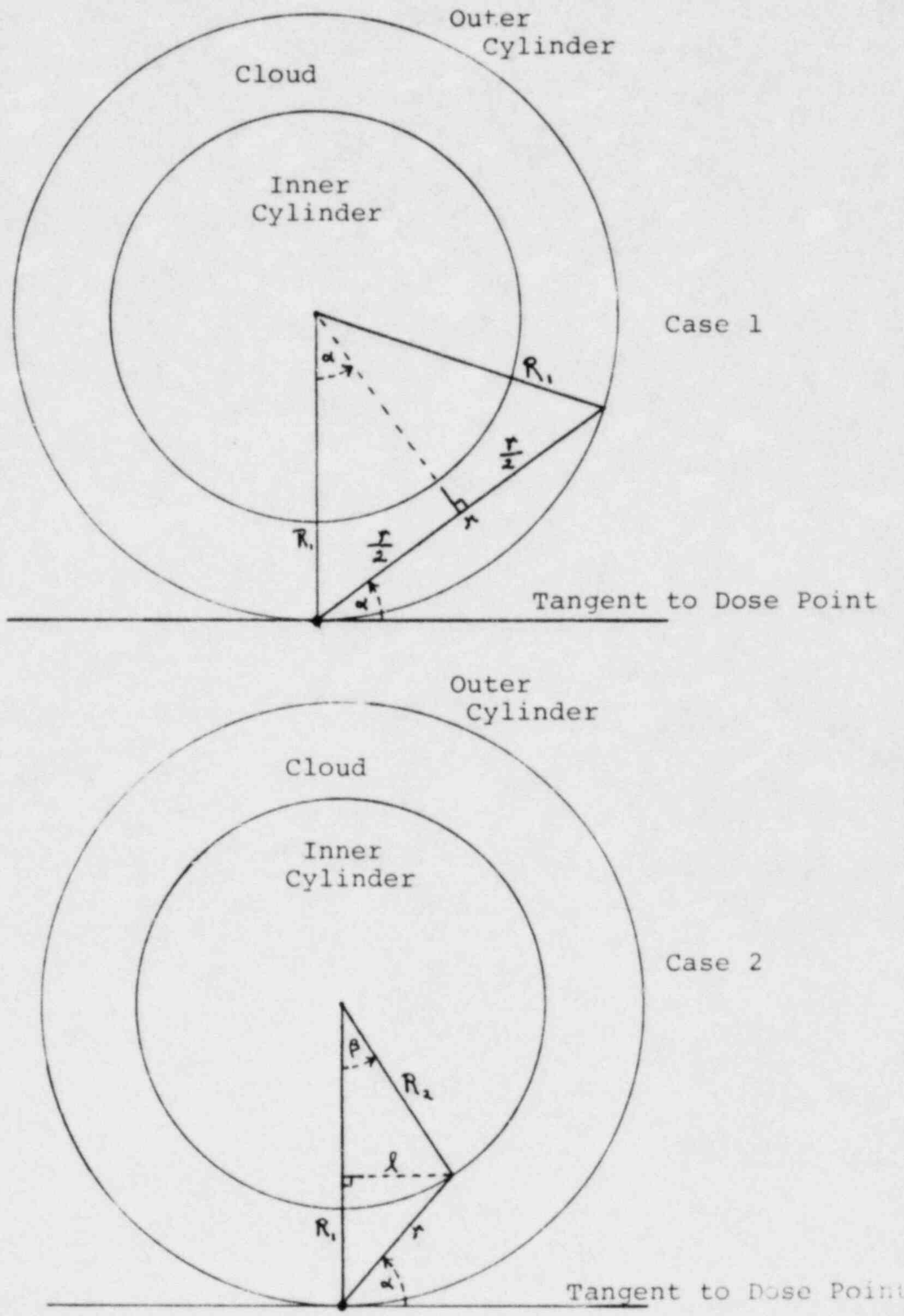

Figure A2. Cylindrical Annulus Cloud Geometry

Two cases must be considered. Case 1 applies when the distance r is from the point on the outer cylinder to another point on the outer cylinder. From Figure A2, Case 1,

$$0 \leq \alpha < \alpha_0$$

$$\sin\alpha = (r/2)/R_1$$

Therefore, $r = 2R_1 \sin\alpha$ Eqn. A95

Case 2 applies when the distance r is from the point on the outer cylinder to a point on the inner cylinder. From Figure A2, Case 2,

$$\alpha_0 \leq \alpha \leq \pi/2$$

$$R_1 = r\sin\alpha + R_2\cos\beta$$

where β is defined in Figure A2, Case 2. Therefore,

$$R_2^2\cos^2\beta = R_1^2 - 2R_1 r\sin\alpha + r^2\sin^2\alpha$$ Eqn. A96

But $\sin\beta = \ell/R_2$ and $\cos\alpha = \ell/r$ where ℓ is defined in Figure A2, Case 2. Solving for ℓ and equating the two results,

$$r\cos\alpha = R_2\sin\beta$$

$$r^2\cos^2\alpha = R_2^2\left[1 - \cos^2\beta\right]$$

$$R_2^2\cos^2\beta = R_2^2 - r^2\cos^2\alpha$$ Eqn. A97

Substituting Eqn. A96 into Eqn. A97

$$R_1^2 - 2R_1 r\sin\alpha + r^2\sin^2\alpha = R_2^2 - r^2\cos^2\alpha$$

$$R_1^2 - 2R_1 r\sin\alpha + r^2 = R_2^2$$

Dividing by R_1^2 and applying the definition of α_0

$$1 - \frac{2r}{R_1}\sin\alpha + \frac{r^2}{R_1^2} = \cos^2\alpha_0$$

$$1 - \frac{2r}{R_1}\sin\alpha + \frac{r^2}{R_1^2} = 1 - \sin^2\alpha_0$$

Multiplying by R_1^2 and rearranging,

$$r^2 - 2rR_1\sin\alpha + R_1^2\sin^2\alpha_0 = 0$$

Applying the quadratic formula,

$$r = \left[2R_1\sin\alpha \pm \sqrt{4R_1^2\sin^2\alpha - 4R_1^2\sin^2\alpha_0}\right]/2$$

$$r = R_1\left[\sin\alpha - \sqrt{\sin^2\alpha - \sin^2\alpha_0}\right]$$ Eqn. A98

where the negative sign was chosen because the shortest distance to the inner cylinder is wanted.

From Eqns. A95 and A98, the function $r(\alpha)$ is

$$r(\alpha) = 2R_1 \sin\alpha \qquad \text{for} \quad 0 \le \alpha < \alpha_0$$

$$r(\alpha) = R_1\left[\sin\alpha - \sqrt{\sin^2\alpha - \sin^2\alpha_0}\right] \qquad \text{for} \quad \alpha_0 \le \alpha \le \pi/2$$

The function $r(\alpha)$ replaces the function $R(\theta)$ in Section 2.1.3.4 of Ref. 14. The integration over θ in that Reference is replaced by an integration over α for $0 \le \alpha \le \pi/2$; the result is multiplied by two to account for the interval $\pi/2 \le \alpha \le \pi$. For the interval $\pi \le \alpha \le 2\pi$, the integral is zero.