APPENDIX 15A

ACCIDENT ANALYSIS RADIOLOGICAL CONSEQUENCES EVALUATION MODELS AND PARAMETERS

15A.1 GENERAL ACCIDENT PARAMETERS

This appendix contains the parameters used in analyzing the radiological consequences of postulated accidents. Table 15A-1 contains the general parameters used in all the accident analyses. For parameters specific only to particular accidents, refer to that accident parameter section. The site specific, ground-level release, short-term dispersion factors (For accidents, ground-level releases are assumed.) are based on Regulatory Guide 1.145 (reference 1) methodology and represent the 0.5-percent worst-sector meteorology and these are given in table 15A-2 (See section 2.3.4 of the "Introduction/Site" Module for additional details on meteorology). The core and gap inventories are given in table 15A-3. The thyroid (via inhalation pathway), beta-skin, and gamma body (via submersion pathway) dose factors based on reference 2 are given in Table 15A-4.

Reactor coolant iodine concentrations for the Technical Specificaton limit of 1 μCi/gm of dose equivalent (D.E.) I-131 and for the assumed pre-accident iodine spike concentration of 60 μ Ci/gm of D.E. I-131 are presented in table 15A-5. Iodine appearance rates in the reactor coolant, for normal steady state operation at 1 μCi/gm of D.E. I-131, and for an assumed accident initiated iodine spike are presented in table 15A-6. Reactor coolant noble gas concentrations based on 1 percent fuel defects are presented in Table 15A-7.

15A.2 OFFSITE RADIOLOGICAL CONSEQUENCES CALCULATIONAL MODELS

This section presents the models and equations used for calculating the integrated activity released to the environment, the accident flowpaths, and the equations for dose calculations. Two major release models are considered:

1. A single holdup system with no internal cleanup.

2. A holdup system wherein a two-region spray model is used for internal cleanup.

15A.2.1 ACCIDENT RELEASE PATHWAYS

The release pathways for the major accidents are given in figure 15A-1. The accident and their pathways are as follows:

A. Loss-of-Coolant Accident (LOCA)

Immediately following a postulated LOCA, the release of radioactivity from the containment is to the environment with the Integrated Safeguards System (ISS) in full operation. The release in this case is calculated using equations 6a and 6b which take into account a two-region spray model within the containment.

B. Control Assembly Ejection (CAE)

Radioactivity release to the environment due to the CAE accident is direct and unfiltered. The releases from the primary system are calculated using equation 5 which considers holdup in the single-region primary system (the spray removal is not assumed); the secondary (steam) releases via the relief valves are calculated without any holdup. The pathways for these releases are A-B and A'-B.

15A.2.2 SINGLE-REGION RELEASE MODEL

It is assumed that any activity released to the holdup system instantaneously diffuses to uniformly occupy the system volume.

The following equations are used to calculate the integrated activity released from postulated accidents.

$$A_1(t) = A_1(0)e^{-\lambda t} \tag{1}$$

where $A_1(0)$ = initial source activity at time t_o, Ci

$A_1(t)$ = source activity at time t, Ci

λ_1 = total removal constant from primary holdup system, S^{-1}

$$\lambda_1 = \lambda_d + \lambda_{1\ell} + \lambda_r \tag{2}$$

where

λ_d = decay removal constant, S^{-1}

$\lambda_{1\ell}$ = primary holdup leak or release rate, S^{-1}

λ_r = internal removal constant, i.e., sprays, plateout, etc.; S^{-1}

Thus, the direct release rate to the atmosphere from the primary holdup system

$$R_U(t) = \lambda_{1\ell} [A_1(t)] \tag{3}$$

where:

$R_u(t)$ = unfiltered release rate (Ci/s)

The integrated activity release is the integral of the above equation.

$$IAR\ (t) = \int_0^t R_u(t)\,dt = \int_0^t \lambda_{1\ell}\, A_1(o)e^{-\lambda_1 t}\,dt \tag{4}$$

This yields:

$$IAR(t) = (\lambda_{1\ell} A_1(o)/\lambda_1)\ (1 - e^{-\lambda_1 t}) \tag{5}$$

15A.2.3 TWO-REGION SPRAY MODEL IN CONTAINMENT (LOCA)

A two-region spray model is used to calculate the integrated activity released to the environment. The model consists of sprayed and unsprayed regions in containment and a constant mixing rate between them.

As it is assumed that there are no sources after initial release of the fission products, the remaining processes are removal and transfer so that the multivolume containment is described by a system of coupled first-order differential equations.

For a two-region model, the above system reduces to

$$\frac{dA_1}{dt} = -\sum_{j=1}^{K_1} \lambda_{1j} A_1 - Q_{12} \frac{A_1}{V_1} + Q_{21} \frac{A_2}{V_2} \tag{6a}$$

$$\frac{dA_2}{dt} = -\sum_{j=1}^{K_2} \lambda_{2j} A_2 - Q_{21} \frac{A_2}{V_2} + Q_{12} \frac{A_1}{V_1} \tag{6b}$$

where

A_i = fission product activity in volume i, Ci

$Q_{i\ell}$ = transfer rate from volume i to volume ℓ, cc/s

V_i = volume of the ith compartment, cc

λ_{ij} = removal rate of the jth removal process in volume i, s^{-1}

K_i = total number of removal processes in the volume i

To calculate the integrated activity released to the atmosphere, the release rate of activity is first calculated. This is found from

$$R(t) = \sum_{i=1}^{2} \lambda_{1\ell} \ A(t) \tag{7}$$

The integrated activity released from time $t_0 - t_1$ is then

$$IAR = \int_{t_0}^{t_1} R(t)\, dt$$

15A.2.4 OFFSITE THYROID DOSE CALCULATION MODEL

Offsite thyroid doses are calculated using the equation:

$$D_{TH} = \sum_i DCF_{THi} \sum_j (IAR)_{ij} \ (BR)_j \ (\chi/Q)_j \tag{8}$$

where

$(IAR)_{ij}$ = integrated activity of isotope i released[a] during the time interval j, Ci

$(BR)_j$ = breathing rate during time interval j, m^3/s

$(\chi/Q)_j$ = offsite atmospheric dispersion factor during time interval j, s/m^3

DCF_{THi} = thyroid dose conversion factor via inhalation for isotope i rem/Ci

D_{TH} = thyroid dose via inhalation, rems

15A.2.5 OFFSITE BETA-SKIN DOSE CALCULATIONAL MODEL

Assuming a semi-infinite cloud of beta emitters, off-site beta-skin doses are calculated using the equation:

$$D_{\beta S} = \sum_i DCF_{\beta i} \sum_j (IAR)_{ij} \; (\chi/Q)_j$$

where

$D_{\beta S}$ = beta-skin dose in rem

$DCF_{\beta i}$ = beta-skin dose conversion factor for the ith isotope in rem-m^3/Ci-s

and $(IAR)_{ij}$ and $(\chi/Q)_j$ are defined in Section 15A.2.4.

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a. No credit is taken for cloud depletion by ground deposition and radioactive decay during transport to the exclusion area boundary or the outer boundary of the low-population zone.

15A.2.6 OFFSITE GAMMA-BODY DOSE CALCULATIONAL MODEL

Assuming a semi-infinite cloud of gamma emitters, offsite gamma-body doses are calculated using the equation:

$$D_{\gamma B} = \sum_i DCF_{\gamma i} \sum_j (IAR)_{ij} \quad (\chi/Q)_j$$

where

$(IAR)_{ij}$ and $(\chi Q)_j$ are defined in Section 15A.2.4.

and

$DCF_{\gamma i}$ = gamma-body dose conversion factor for the ith isotope in rem-m^3/Ci-s

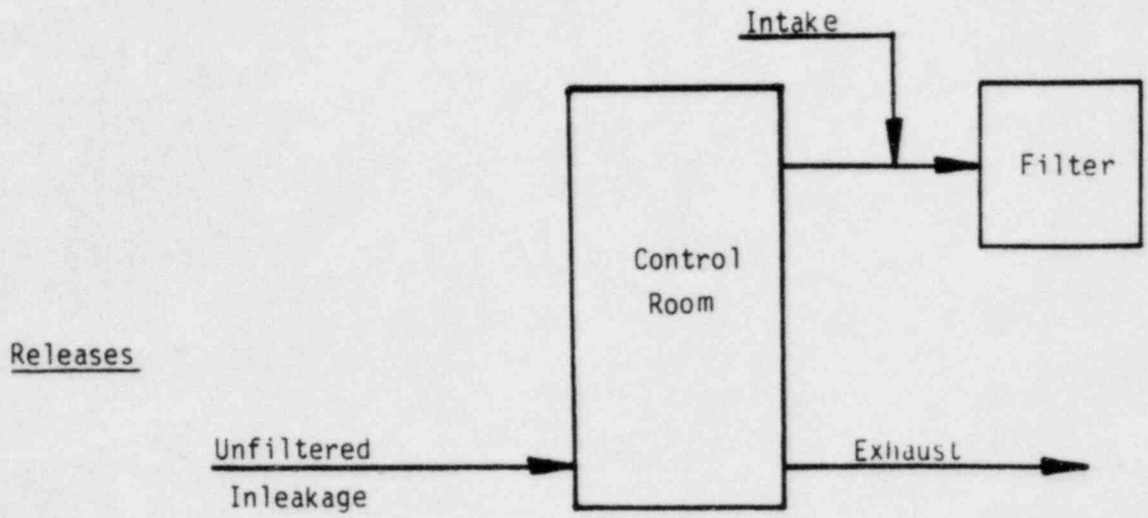
$D_{\gamma B}$ = gamma-body dose in rem

15A.3 CONTROL ROOM RADIOLOGICAL CONSEQUENCES CALCULATIONAL MODELS

Radiation doses to a control room operator as a result of a postulated LOCA are presented in this chapter. (A study of the radiological consequences in the control room due to various postulated accidents indicate that the LOCA is the limiting case.)

15A.3.1 INTEGRATED ACTIVITY IN CONTROL ROOM

The integrated activity in the control room during each time interval is found by multiplying the release by the appropriate χ/Q to give the concentration at the control room intake. This activity is brought into the control room through the filtered intake and by unfiltered inleakage. The control room ventilation system recirculates control room air through charcoal filters and exhausts a portion to the atmosphere.



From this we can calculate the total integrated activity in the control room during any time interval.

The activity in the control room can be calculated by the same method used to calculate activity in the containment.

15A.3.2 INTEGRATED ACTIVITY CONCENTRATION IN CONTROL ROOM FROM SINGLE-REGION SYSTEM

To calculate the integrated activity concentration in the control room we must first calculate the activity in the control room at any time t, and then integrate again to find the integrated activity.

$$\frac{dA_{CR}(t)}{dt} = [F_2 R_{FIN} + R_{UIN} \frac{\chi}{Q} R(t) - \lambda_3 A_{CR}(t)$$

where:

$A_{CR}(t)$ = activity in the control room at any time t, Ci

F_2 = filter nonremoval fraction on intake

$R_{F\,IN}$ = filtered intake rate in m^3/s

$R_{U\,IN}$ = unfiltered intake rate in m^3/s

$R(t)$ = activity of release in Ci/s given in equation 3 of subsection 15A.2.2

$$\lambda_3 = \lambda_{3\ell} + \lambda_d + \lambda_r$$

where

λ_3 = total removal rate from control room in s^{-1}

$\lambda_{3\ell}$ = exhaust rate from control room in s^{-1}

λ_d = isotopic decay constant in s^{-1}

λ_r = recirculation removal rate in s^{-1}

The integrated activity in the control room (IA_{CR}) is determined by the expression

$$IA_{CR}(t) = \frac{1}{V_{CR}} \int_0^t A_{CR}(t)\ dt$$

Where: V_{CR} = control room volume

This $IA_{CR}(t)$ is used to calculate the doses to the operator in the control room. This activity is multiplied by an occupancy factor which accounts for the time fraction the operator is in the control room.

15A.3.3 CONTROL ROOM THYROID DOSE CALCULATIONAL MODEL

Control room thyroid doses via inhalation pathway are calculated using the following equation:

$$D_{TH-CR} = BR \sum_i DCF_{THi} \sum_j (IA_{CRij}) (O_j)$$

where

D_{TH-CR} = control room thyroid dose in rem

BR = breathing rate assumed to be always 3.47×10^{-4} m^3/s

DCF_{THi} = thyroid dose conversion factor for adult via inhalation in rem/Ci for isotope i

IA_{CRij} = integrated activity concentration in control room, Ci-s/m^3 for isotope i during time interval j

o_j = control room occupancy fraction during time interval j

15A.3.4 CONTROL ROOM BETA-SKIN DOSE CALCULATIONAL MODEL

The beta-skin doses to a control room operator are calculated using the following equation:

$$D_{\beta-CR} = \sum_i DCF_{\beta i} \sum_j (IA_{CRij}) \times o_j$$

$D_{\beta-CR}$ = beta skin dose in the control room (rem).

$DCF_{\beta i}$ = beta skin dose conversion factor for isotope i (rem-m^3/Ci-s)

IA_{CRij} = integrated activity concentration in the control room, Ci-s for isotope i during time interval jm^3.

o_j = control room occupancy fraction during time interval j.

15A.3.5 CONTROL ROOM GAMMA-BODY DOSE CALCULATION

Due to the finite structure of the control room, the gamma-body doses to a control room operator will be substantially less than what they would be due to immersion in an infinite cloud of gamma emitters. The finite cloud gamma doses are calculated using Murphy's method (reference 3) which models the control room at a hemisphere. The following equation is used:

$$D_{B-CR} = \frac{1}{GF} \sum_i DCF_i \sum_j (IA_{CRij}) \; (0_j)$$

where

GF = dose reduction due to control room geometry factor

GF $= 1173/V_1^{\;0.338}$

V_1 = volume of the control room, ft^3

DCF_1 = gamma-body dose conversion factor for isotope i, rem-m^3/Ci-s

D_{B-CR} = gamma-body dose in the control room, rem

Other symbols have been defined in subsections 15A.2.5 and 15A.3.3.

15A.3.5.1 Model for Radiological Consequences Due to Radioactive Cloud External to the Control Room

This dose is calculated based on the semi-infinite cloud model which is modified using the protection factors described in subsection 7.5.4 of reference 4 to account for the control room walls.

15A.4 REFERENCES

1. USNRC Regulatory Guide 1.145, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants," August 1979.

2. USNRC Regulatory Guide 1.109, Rev. 1, "Calculation of Annual Doses to Man From Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50 Appendix I," October 1977.

3. Murphy, K. G., and Campe, K. M., "Nuclear Power Plant Control Room Ventilation System Design for Meeting General Criterion 19," Paper presented at the 13th AEC Air Cleaning Conference.

4. "Meteorology and Atomic Energy 1968," D. H. Slade (ed.), USAEC Report, TID 24190, 1968.

TABLE 15A-1 (SHEET 1 OF 2)

PARAMETERS USED IN ACCIDENT ANALYSIS

General	
Core power level, MWt	3800
Full-power operation, effective full-power days (EFPD)	900
Maximum radial peaking factor	1.65
Steam generator tube leak, gal/min	1.0
Sources	
Core inventories, Ci	Table 15A-3
Gap inventories, Ci	Table 15A-3
Primary coolant specific activities for 1% fuel defects, μCi/g	Section 11
Primary coolant activity, technical specification limit for iodines - I-131 dose equivalent, μCi/g	1.0
Secondary coolant activity, technical specification limit for iodines - I-131 dose equivalent, μCi/g	0.1
Activity Release Parameters	
Free volume of containment, ft^3	2.75×10^6
Containment leak rate	
0-24 h, percent per day	0.1
After 24 h, percent per day	0.05
Control room	
Free volume, ft^3	1.75×10^5
Unfiltered infiltration rate, ft^3/min	10.0
Filtered intake rate, ft^3/min	500
Internal recirculation rate through filters, ft^3/min	25,000
Iodine removal efficiency for recirculation filters (all forms of iodine), percent	95
Iodine removal efficiency for intake filters (all forms of iodine), percent	95
High efficiency particulate air filter efficiency, percent	99

TABLE 15A-1 (SHEET 2 OF 2)

Miscellaneous

Atmospheric dispersion factors (χ/Q), s/m^3	Table 15A-2
Dose conversion factors	
Gamma-body and beta skin, rem-m^3/Ci-s	Table 15A-4
Thyroid, rem/Ci	Table 15A-4

TABLE 15A-2

LIMITING SHORT-TERM ATMOSPHERIC DISPERSION FACTORS FOR ACCIDENT ANALYSIS (s/m^3)*

Location Type/ Time Interval (h)	(χ/Q)
Site boundary	
0-2	2.0E-4
Low-population zone	
0-2	7.0E-5
2-8	3.5E-5
8-24	2.0E-5
24-96	9.0E-6
96-720	3.0E-6
Control room	
0-2	4.0E-3
2-8	3.0E-3
8-24	2.8E-3
24-96	2.0E-3
96-720	1.5E-3

* For the A. W. Vogtle Site.

TABLE 15A-3

FUEL AND ROD GAP INVENTORIES - CORE (Ci)[a]

Nuclide	Fuel	Gap[b]
I-131	9.8E+7	9.8E+6
I-132	1.4E+8	1.4E+7
I-133	2.0E+8	2.0E+7
I-134	2.2E+8	2.2E+7
I-135	1.9E+8	1.9E+7
Kr-85m	2.7E+7	2.7E+6
Kr-85	6.6E+5	2.0E+5
Kr-87	4.9E+7	4.9E+6
Kr-88	7.0E+7	7.0E+6
Xe-131m	7.0E+5	7.0E+4
Xe-133m	2.9E+7	2.9E+6
Xe-133	1.9E+8	1.9E+7
Xe-135m	4.0E+7	4.0E+6
Xe-135	4.2E+7	4.2E+6
Xe-138	1.6E+8	1.6E+7
I-127	2.8 Kg	0.84 Kg
I-129	11.4 Kg	3.4 Kg

a. Three-region equilibrium cycle core at end of life. The three regions have operated at a specific power of 40.03 MW/MTU for 300, 600, and 900 EFPD, respectively.

b. Regulatory Guide 1.25 assumption gap activity is assumed to be 10 percent of core activity for all isotopes except for Kr-85, I-127, and I-129; for Kr-85, I-127, and I-129, it is assumed to be 30 percent of the core activity.

TABLE 15A-4

DOSE CONVERSION FACTORS USED IN ACCIDENT ANALYSIS

Nuclide	Gamma-Body $\frac{Rem\text{-}m^3}{Ci\text{-}s}$	Beta-Skin $\frac{Rem\text{-}m^3}{Ci\text{-}s}$	Thyroid (Rem/Ci)
I-131	NA	NA	1.49E+6
I-132	NA	NA	1.43E+4
I-133	NA	NA	2.69E+5
I-134	NA	NA	3.73E+3
I-135	NA	NA	5.60E+4
Kr-85m	3.71E-2	4.63E-2	NA
Kr-85	5.11E-4	4.25E-2	NA
Kr-87	1.88E-1	3.09E-1	NA
Kr-88	4.67E-1	7.52E-2	NA
Xe-131m	2.91E-3	1.51E-2	NA
Xe-133m	7.97E-3	3.15E-2	NA
Xe-133	9.33E-3	9.70E-3	NA
Xe-135m	9.91E-2	2.25E-2	NA
Xe-135	5.75E-2	5.90E-2	NA
Xe-138	2.80E-1	1.31E-1	NA

TABLE 15A-5

REACTOR COOLANT IODINE CONCENTRATIONS FOR 1 μCi/GRAM AND 60 μCI/GRAM OF DOSE EQUIVALENT I-131

Nuclide	Reactor Coolant Concentration (Ci/gm)	
	1 μCi/gm D.E. I-131	60 μCi/gm D.E. I-131
I-131	0.76	45.6
I-132	0.76	45.6
I-133	1.14	68.4
I-134	0.195	11.7
I-135	0.63	37.8

TABLE 15A-6

IODINE APPEARANCE RATES IN THE REACTOR COOLANT (Curies/sec)

	*Equilibrium Appearance Rates due to Fuel Defects	**Appearance Rates Due to an Accident Initiated Iodine Spike
I-131	2.6×10^{-3}	1.3
I-132	1.4×10^{-2}	7.0
I-133	5.65×10^{-3}	2.8
I-134	8.33×10^{-3}	4.2
I-135	5.33×10^{-3}	2.7

* Based on RCS concentration of 1 μCi/gm of dose equivalent I-131

** 500 x equilibrium appearance rate

TABLE 15A-7

REACTOR COOLANT NOBLE GAS SPECIFIC ACTIVITY BASED ON ONE PERCENT DEFECTIVE FUEL

Nuclide	Activity (μc/gram)
Kr-85m	2.0
Kr-85	7.3
Kr-87	1.3
Kr-88	3.6
Xe-131m	2.2
Xe-133m	1.7×10^{1}
Xe-133	2.7×10^{2}
Xe-135m	4.8×10^{-1}
Xe-135	7.2
Xe-138	6.4×10^{-1}

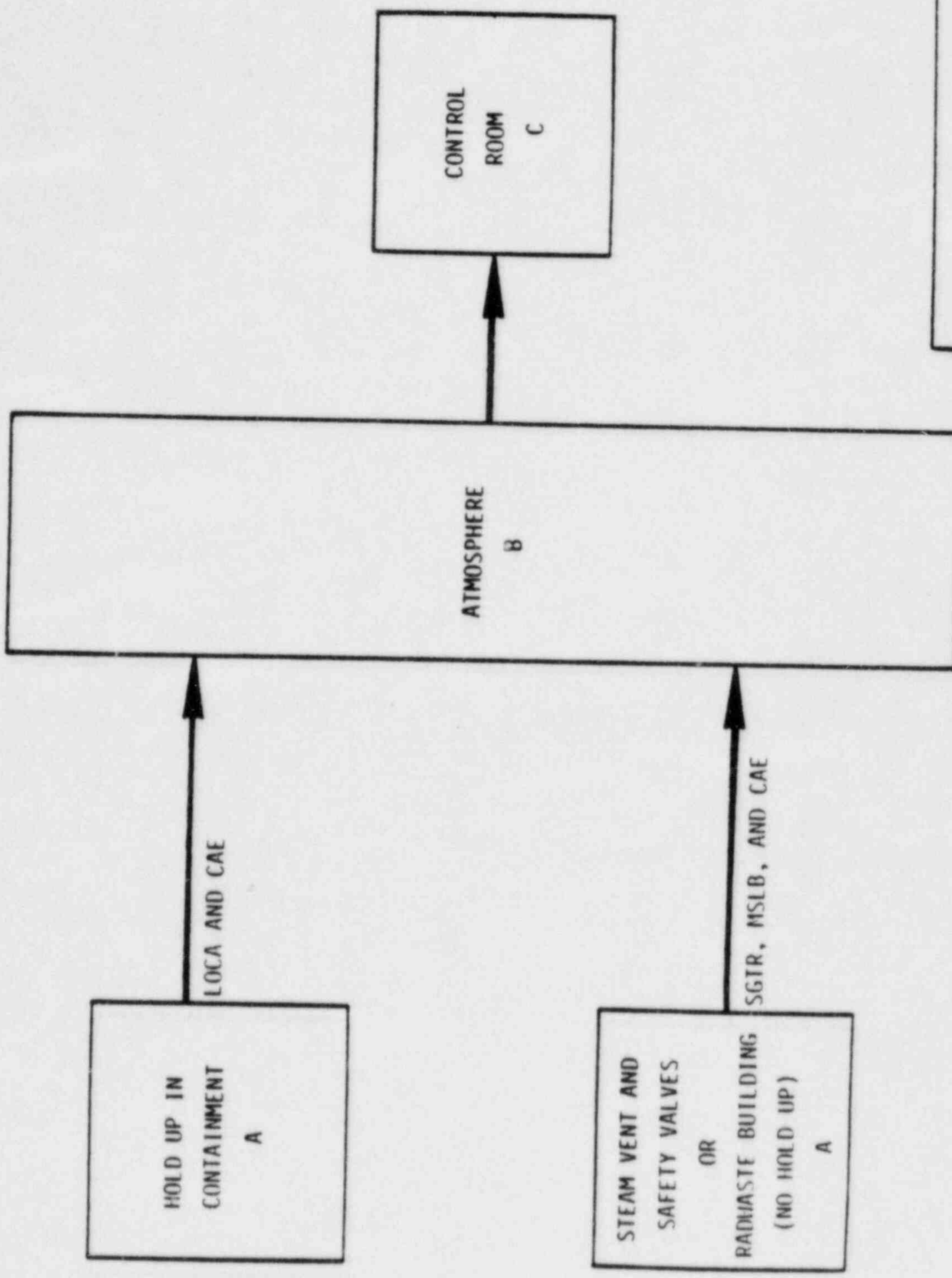


FIGURE 15.A-1
RELEASE PATHWAYS