APPENDIX 15B

DOSE MODELS USED TO EVALUATE THE ENVIRONMENTAL CONSEQUENCES OF ACCIDENTS

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APPENDIX 15B

DOSE MODELS USED TO EVALUATE THE ENVIRONMENTAL CONSEQUENCES OF ACCIDENTS

15B.1 INTRODUCTION

This section identifies the models used to calculate control room and offsite radiological doses, not calculated in CESSAR, that would result from releases of radioactivity due to various postulated accidents.

15B.2 ASSUMPTIONS

The following assumptions are basic to the model for the whole body dose due to immersion in a cloud of radioactivity and to the model for the thyroid dose due to inhalation of radioactivity:

A. All radioactive releases are treated as ground level releases regardless of the point of discharge.

B. The dose receptor is a standard man, as defined by the International Commission on Radiological Protection (ICRP), (reference 1).

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

D. Radionuclide data, including decay constants and decay energies presented in table 15B-1, are taken from references 2 through 6.

15B.3 WHOLE BODY GAMMA AND BETA SKIN DOSE

The whole body gamma dose delivered to an offsite dose receptor is calculated by assuming the receptor to be immersed in a hemispherical radioactive cloud that is infinite in all

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Table 15B-1
RADIONUCLIDE PARAMETERS

Nuclide	Half-Life	MeV/Disintegration (gamma)	Average MeV/Disintegration (beta)
I-131	8.06 D	0.381	0.194
I-132	2.28 H	2.333	0.519
I-133	21 H	0.608	0.403
I-134	52 M	2.529	0.558
I-135	6.7 H	1.635	0.475
Kr-83m	1.86 H	0.002	0.037
Kr-85m	4.48 H	0.159	0.253
Kr-85	10.73 Y	0.002	0.251
Kr-87	76.31 M	0.793	1.324
Kr-88	2.80 H	1.950	0.375
Kr-89	3.16 M	1.712	1.001
Xe-131m	11.9 D	0.02	0.143
Xe-133m	2.25 D	0.0416	0.190
Xe-133	5.29 D	0.0454	0.135
Xe-135m	15.65 M	0.432	0.095
Xe-135	9.15 H	0.247	0.316
Xe-137	3.83 M	0.194	1.642
Xe-138	14.17 M	1.183	0.606

directions above the ground plane; i.e., a semi-infinite cloud. The concentration of radioactive material within this cloud is uniform and equal to the maximum centerline ground level concentration that would exist in the cloud at the appropriate distance from the point of release.

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The gamma dose to an offsite receptor due to gamma radiation for a given time period is:

$$D_{wb} = \chi/Q \cdot \sum_i DCF_{wbi} \cdot Q_i \qquad (1)$$

where

D_{wb} = whole body dose to an offsite receptor from gamma radiation, (rem)

χ/Q = site atmospheric dispersion factor effective during the time period at the point of exposure, (s/m^3)

DCF_{wbi} = whole body dose conversion factor for the semi-infinite cloud model for nuclide i, $(rem\text{-}m^3/Ci\text{-}s)$. (See table 15B-2)

Q_i = total activity of nuclide i released during the time period, (Ci)

The gamma dose to the control room personnel is calculated assuming a finite hemispherical cloud model. The gamma dose due to gamma radiation in the control room for a given time period is:

$$D_{wb} = \frac{(CRVOL)^{0.338}}{1173} \sum_i DCF_{wbi} \frac{(IQ_i)(3600)(CRO)}{(CRVOL)(0.02832)} \qquad (2)$$

where

D_{wb} = whole body gamma dose to control room personnel from gamma radiation, (rem)

CRO = the control room occupancy factor ≤ 1

3600 = conversion factor, s/h

.02832 = conversion factor, ft^3/m^3

CRVOL = control room volume, ft^3

Table 15B-2

WHOLE BODY GAMMA AND BETA SKIN DOSE CONVERSION FACTORS

Radionuclide	Beta Skin DCF (rem - m^3/Ci - h)	Whole Body Gamma DCF (rem - m^3/Ci - s)
I-131	1.14E2	8.72E-2
I-132	4.75E2	5.13E-1
I-133	2.65E2	1.55E-1
I-134	3.32E2	5.32E-1
I-135	4.64E2	4.21E-1
Kr-83m	0	5.02E-6
Kr-85	1.53E2	5.25E-4
Kr-85m	1.67E2	3.72E-2
Kr-87	1.11E3	1.87E-1
Kr-88	2.70E2	4.64E-1
Kr-89	1.15E3	5.25E-1
Xe-131m	5.43E1	2.92E-3
Xe-133m	1.13E2	8.00E-3
Xe-133	3.49E1	9.33E-3
Xe-135m	8.11E1	9.92E-2
Xe-135	2.12E2	5.72E-2
Xe-137	1.39E3	4.53E-2
Xe-138	4.71E2	2.81E-1

IQ_i = total integrated activity for nuclide i in control room for the time period, (Ci-hr)

DCF_{wbi} = the semi-infinite cloud whole body gamma dose conversion factor for nuclide i, (rem-m^3/Ci-s). (See table 15B-2)

The expression $\frac{(CRVOL)^{.338}}{1173}$ is a geometrical correction factor to ratio a finite cloud to infinite cloud (reference 7).

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The beta skin dose to control room personnel is calculated assuming a tissue depth of 7 mg/cm^2. The beta skin dose to control room personnel for a given time period is:

$$D_{\beta s} = \frac{CRO}{(CRVOL)(.02832)} \sum_i D_{\beta si} \cdot IQ_i \qquad (3)$$

where

$D_{\beta si}$ = the beta skin dose conversion factor for nuclide i, (rem-m^3/Ci-h). (See table 15B-2 for factor)

and all other parameters are as previously defined.

15B.4 THYROID INHALATION DOSE

The thyroid dose to an offsite receptor for a given time period is obtained from the following expression:

$$D = \chi/Q \cdot B \cdot \sum_i (Q_i \cdot DCF_i) \qquad (4)$$

where:

D = thyroid inhalation dose, (rem)

χ/Q = site atmospheric dispersion factor during the time period, (s/m^3)

B = breathing rate during the time period, (m^3/s) (See table 15B-3)

Q_i = total activity of nuclide i released during time period, (Ci)

DCF_i = thyroid dose conversion factor for nuclide i, (rem/Ci inhaled). (See table 15B-4)

The radionuclide data are given in table 15B-1. The atmospheric dispersion factors used in the analysis of the environmental consequences of accidents are given in section 2.3.

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Breathing rates and dose conversion factors for radioactive iodines required for computing thyroid inhalation doses are tabulated in tables 15B-3 and 15B-4, respectively.

Table 15B-3
BREATHING RATES[a]

Time After Accident	m^3/s
0 to 8 hours	3.47(-04)
8 to 24 hours	1.75(-04)
1 to 30 days	2.32(-04)
a. From Regulatory Guide 1.4	

Table 15B-4
IODINE DOSE CONVERSION FACTORS[a]

Iodine Isotope	(rem-thyroid/Curie Inhaled)
I-131	1.48(+06)
I-132	5.35(+04)
I-133	4.00(+05)
I-134	2.50(+04)
I-135	1.24(+05)
a. See reference 8	

15B.5 CONTROL ROOM DOSE

During the course of an accident, control room personnel may receive doses from the following sources:

A. Direct whole body gamma dose from the radioactivity present in the containment building

B. Direct whole body gamma dose from the radioactive cloud surrounding the control room

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C. Whole body gamma, thyroid inhalation, and beta skin doses from the airborne radioactivity present in the control room.

In calculating the exposure to control room personnel, occupancy factors were obtained from reference 7 as follows:

0 to 24 hours: occupancy factor = 1

1 to 4 days: occupancy factor = 0.6

4 to 30 days: occupancy factor = 0.4

The dose model for each of the radiation sources are discussed below:

A. Direct whole body gamma dose from the radioactivity present in the containment building (direct containment dose).

Time integrated (0 to 30 days) radionuclide concentrations in the containment are calculated. For conservati[illegible]redit is taken for reduction of the containmen[illegible]ctivity by means other than radioactive decay. The containment is modeled by an equivalent volume cylindrical source having a diameter of 146 feet and a height of 155 feet. The radioactivity present in the containment is assumed to be uniformly distributed in the cylindrical source. Shielding is provided by the 4-foot concrete containment walls, 120 feet of air separating the containment building from the control building, and 2-foot thick control room walls.

No credit is taken for any shielding that would be provided by the auxiliary building.

B. Direct whole body gamma dose from the radioactive cloud surrounding the control room (outside cloud dose).

Leakage from the containment building, or any building will result in the formation of a radioactive plume. For conservatism it is assumed that this plume forms a cloud surrounding the control room. Gamma radiation from this cloud, although attenuated, can penetrate the control room roof and walls resulting in a whole body gamma dose to control room personnel. The radius of the cloud is computed using a mass balance of the radioactivity released due to leakage and the volume of the cloud; therefore, the radioactive cloud is time variant and expands for the duration of the accident.

Radioactivity concentration (Ci/m^3) in the radioactive cloud surrounding the control room is the product of the building leak rate (Ci/s) and the control room atmospheric dispersion factor, χ/Q (s/m^3). Exclusion area boundary and low population zone χ/Q's are presented in section 2.3. A tabulation of control room χ/Q's is presented in table 15B-5.

The calculational model for the control room is an equivalent volume hemisphere of radius 42 feet. Credit is taken for concrete shielding provided by the control room walls and ceiling.

Table 15B-5

ATMOSPHERIC DISPERSION FACTORS

Time Period	Control Room χ/Q (s/m^3)
0 to 8 hours	1.97(-3)
8 to 24 hours	1.16(-3)
1 to 4 days	4.53(-4)
4 to 30 days	1.30(-4)

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C. Dose from the airborne radioactivity present in the control room (occupancy dose).

Airborne radioactivity will be drawn into the control room due to the intake of outside air required to maintain a positive pressure in the control room. This contributes to the whole body gamma, thyroid inhalation, and beta skin doses. The major parameters of the control room ventilation system are presented in table 15B-6.

The whole body gamma dose is computed using a finite cloud model. The calculational model is an equivalent volume hemisphere of 42-foot radius.

A thyroid inhalation dose results from the radioactive iodine present in the control room. The control room habitability system, designed to remove iodine from the air, is described in table 15B-6.

15B.6 ACTIVITY RELEASE MODELS

15B.6.1 GENERAL EQUATION

The activity released from a postulated accident is calculated by using the following matrix equation for each isotope and each specie of iodine:

$$\frac{d\overline{A}}{dt} + \overline{C}\,\overline{A} = \overline{S};\ \text{Initial Condition } \overline{A}(t_o) = \overline{A}_o \qquad (5)$$

$$Q = \overline{L} \cdot \overline{AI}$$

where:

$\overline{A}(t)$ = $(a_i(t))$

a_i = the activity in the ith node, (Ci)

$\overline{C}$ = (C_{ij}) matrix

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Table 15B-6

CONTROL ROOM ESSENTIAL VENTILATION SYSTEM PARAMETERS[a]

Parameter	Assumption
Number of emergency ventilation systems operating	1
Filtered Intake rate, standard ft^3/min	1,000
Unfiltered intake rate, standard ft^3/min	0
Intake cleanup filter efficiency	
Iodine, elemental, %	95
Iodine, organic, %	95
Iodine, particulate, %	99
Recirculation rate, standard ft^3/min	27,410
Recirculation cleanup filter efficiency	
Iodine, elemental, %	95
Iodine, organic, %	95
Iodine, particulate %	99
Leak rate, standard ft^3/min (out leakage)	1,000
Control room volume, standard ft^3	161,000

a. There are two completely redundant emergency control room ventilation systems.

For a more detailed description of this system, refer to section 9.4.2. The dose model employed in this analysis is consistent with the thyroid inhalation model discussed in section 15B.4.

The beta skin dose model is consistent with the "infinite hemispherical cloud" model described in section 15B.3.

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C_{ij} = the transfer rate from the ith node to the jth node, (s^{-1})

$\bar{S}$ = (S_i) vector

S_i = the production rate in the ith node (Ci/sec)

Q = the activity released to the environment over the time period t_o to t_i, (Ci)

$\bar{L}$ = (ℓ_i) matrix

ℓ_i = the leak rate from the ith node to environment (/sec)

$\overline{AI}$ = $\int_{t_o}^{t_1} \bar{A}(t)\, dt$ (Ci-sec)

Each node represents a volume where activity can be accumulated. The environment and the control room are each represented by a node. To ensure that the system of differential equations has constant coefficients, the time scale is broken up into time intervals over which all parameters are constant. Thus, all coefficients and sources are assumed to be representable by step functions.

The matrix equation is solved using matrix techniques. The particular solution is obtained by Gaussian elimination. The homogenous solution is obtained by solving for the eigenvectors and the eigenvalues of the coefficient matrix C. They are determined by using QR transformation techniques.

The following sections describe how the coefficient matrix and the source vector are calculated for the different accident calculations.

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15B.6.2 THE MODEL FOR CONTAINMENT LEAKAGE

The model for LOCA containment leakage is shown in figure 15B-1. The system of differential equations for estimating the released activity is as follows:

$$\frac{dA_1}{dt} + \lambda_d A_1 - L_{21}A_2 - L_{31}A_3 = 0 \quad (6a)$$

$$\frac{dA_2}{dt} + (\lambda_d + \lambda_s + L_{21} + L_{23})A_2 - L_{32}A_3 = 0 \quad (6b)$$

$$\frac{dA_3}{dt} - L_{23}A_2 + (\lambda_d + L_{31} + L_{32})A_3 = 0 \quad (6c)$$

$$\frac{dA_4}{dt} - \frac{X}{Q}(L_u + (1-f_L)L_f)L_{21}\ A_2 - \frac{X}{Q}(L_u + (1-f_L)L_f)L_{31}\ A_3 + (L_f + L_u + f_R R_c + \lambda_d)\ A_4 = 0 \quad (6d)$$

$$Q = \int_{t_o}^{t_1} (L_{21}\ A_2 + L_{31}\ A_3)\ dt \quad (7)$$

where:

$A_1(t)$ = activity in the environment, (Ci)

$A_2(t)$ = activity in the sprayed region of the containment, (Ci)

$A_3(t)$ = activity in the unsprayed region of the containment, (Ci)

$A_4(t)$ = activity in the control room, (Ci)

λ_d = radioactive decay constant, (s^{-1})

L_{21} = $\frac{T_{21}}{(100)(24)(3600)}$, (s^{-1})

T_{21} = leak rate from the sprayed volume to the environment (%/day)

L_{31} = $\frac{T_{31}}{(100)(24)(3600)}$, (s^{-1})

T_{31} = leak rate from the unsprayed volume to the environment (%/day)

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λ_s	=	the spray removal constant, (s^{-1})
L_{23}	=	$\frac{T_{23}}{(V_2)(60)}$, (s^{-1})
T_{23}	=	transfer rate from the sprayed region to the unsprayed region, (ft^3/min)
V_2	=	volume of the sprayed region, (ft^3)
L_{32}	=	$\frac{T_{32}}{(V_3)(60)}$, (s^{-1})
T_{32}	=	transfer rate from the unsprayed region to the sprayed region, (ft^3/min)
V_3	=	volume of the unsprayed region, (ft^3)
L_u	=	$\frac{T_u \cdot (.3048)^3}{60}$, (m^3/s)
T_u	=	unfiltered inleakage into the control room, (ft^3/min)
L_f	=	$\frac{T_f\ (.3048)^3}{60}$, (m^3/sec)
T_f	=	filtered air intake rate into the control room, (ft^3/min)
f_L	=	filter efficiency of the filters on the intake units
χ/Q	=	atmospheric dispersion factor for the control room, (s/m^3)
R_c	=	$\frac{T_r}{(V_c)(60)}$, (s^{-1})
T_R	=	filtered recirculation rate in the control room, (ft^3/min)
V_c	=	control room free volume, (ft^3)
f_R	=	filter efficiency of the filter on the recirculation unit
Q	=	activity released to the environment, (Ci)

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The coefficient matrix is:

$\overline{C}$ =

$$\begin{bmatrix} +\lambda_d & -L_{21} & -L_{31} & 0 \\ 0 & +(\lambda_d+\lambda_s+L_{21}+L_{23}) & -L_{32} & 0 \\ 0 & -L_{23} & +(\lambda_d+L_{31}+L_{32}) & 0 \\ 0 & -\frac{\chi}{Q}(L_u+(1-f_L)L_f)L_{21} & -\frac{\chi}{Q}(L_u+(1-f_L)L_f)L_{31} & +(L_f+L_u+f_R R_c+\lambda_d) \end{bmatrix}$$

After solving for A(t), the integrated activity in each node can then be calculated.

From the integrated activity, the offsite doses and the doses to the operators in the control room can be calculated using the dose models given in sections 15B.3 and 15B.4.

15B.6.3 THE MODEL FOR RECIRCULATION LOOP LEAKAGE

The model for LOCA leakage in recirculation loops outside containment is shown in figure 15.B-2. The activity released due to the operational leakage of the engineered safety feature (ESF) components during the recirculation mode of the postulated LOCA is calculated from the following equations:

$$\frac{dA_1}{dt} + \lambda_d A_1 - (1-f)L_{21}\, A_2 = 0 \qquad (8a)$$

$$\frac{dA_2}{dt} + (+\lambda_d+L_{21})\, A_2 = S_2 \qquad (8b)$$

$$Q = \int_{t_o}^{t_1} (1-f)\, L_{21}\, A_2\, dt \qquad (9)$$

where:

A_1 = the activity in the environment, (Ci)

A_2 = the activity in the ESF component rooms, (Ci)

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λ_d = decay constant, (s^{-1})

L_{21} = filtered leak rate to the environment, (ESF room vol/s)

f = filter efficiency of the filters on the ESF room purge units.

$$S_2 = P \cdot \frac{A_o T_s}{V_s}$$

A_o = activity in the recirculation water, (Ci)

P = iodine partition factor

T_s = twice the maximum operational leak rate, (cm^3/s)

V_s = total volume of recirculation water, (cm^3)

Q = activity released to the environment, (Ci)

The coefficient matrix is:

$$\bar{C} = \begin{bmatrix} \lambda_d & -(1-f)L_{21} \\ 0 & (\lambda_d + L_{21}) \end{bmatrix}$$

The source vector is

$$\bar{S} = \begin{bmatrix} 0 \\ S_2 \end{bmatrix}$$

15B.6.4 THE MODEL FOR THE FUEL HANDLING ACCIDENT IN THE FUEL BUILDING WITH ESF SAFEGUARDS ACTUATION

The model for the release of activity from the fuel building during a postulated fuel handling accident is shown in figure 15B-3. The activity released to the environment is estimated from the following equations:

$$\frac{dA_1}{dt} + \lambda_d A_1 - (1-f)L_{21}A_2 = 0 \qquad (10a)$$

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$$\frac{dA_2}{dt} + (\lambda_d + L_{21})A_2 = 0 \qquad (10b)$$

$$Q = \int_{t_o}^{t_1} L_{21}A_2 dt \qquad (11)$$

where:

A_1 = activity in the environment, (Ci)

A_2 = activity in the fuel building atmosphere, (Ci)

λ_d = decay constant, (s^{-1})

L_{21} = purge rate to the environment, (s^{-1})

f = filter efficiency of the filters on the ventilation unit

Q = activity released to the environment, (Ci)

The resultant coefficient matrix is:

$$\overline{C} = \begin{bmatrix} \lambda_d & -(1-f)L_{21} \\ 0 & (\lambda_d + L_{21}) \end{bmatrix}$$

15B.6.5 OTHER ACCIDENT MODELS

Other accidents can be conservatively modeled as simulated instantaneous releases to the environment. This is simulated as a large transfer rate to the environment. The model is shown in figure 15B-3. The system of differential equations is:

$$\frac{dA_1}{dt} + \lambda_d A_1 - L_{21}A_2 = 0 \qquad (12a)$$

$$\frac{dA_2}{dt} + (\lambda_d + L_{21})\ A_2 = 0 \qquad (12b)$$

$$Q = \int_{t_o}^{t_1} L_{21}\ A_2\ dt \qquad (13)$$

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where:

A_1 = activity in the environment, (Ci)

A_2 = activity to be released to the environment, (Ci)

λ_d = decay constant, (s^{-1})

L_{21} = very large transfer rate to the environment, (s^{-1})

Q = activity released to the environment, (Ci)

The resultant coefficient matrix is:

$$\overline{C} = \begin{bmatrix} \lambda_d & -L_{21} \\ 0 & (\lambda_d + L_{21}) \end{bmatrix}$$

15B.7 REFERENCES

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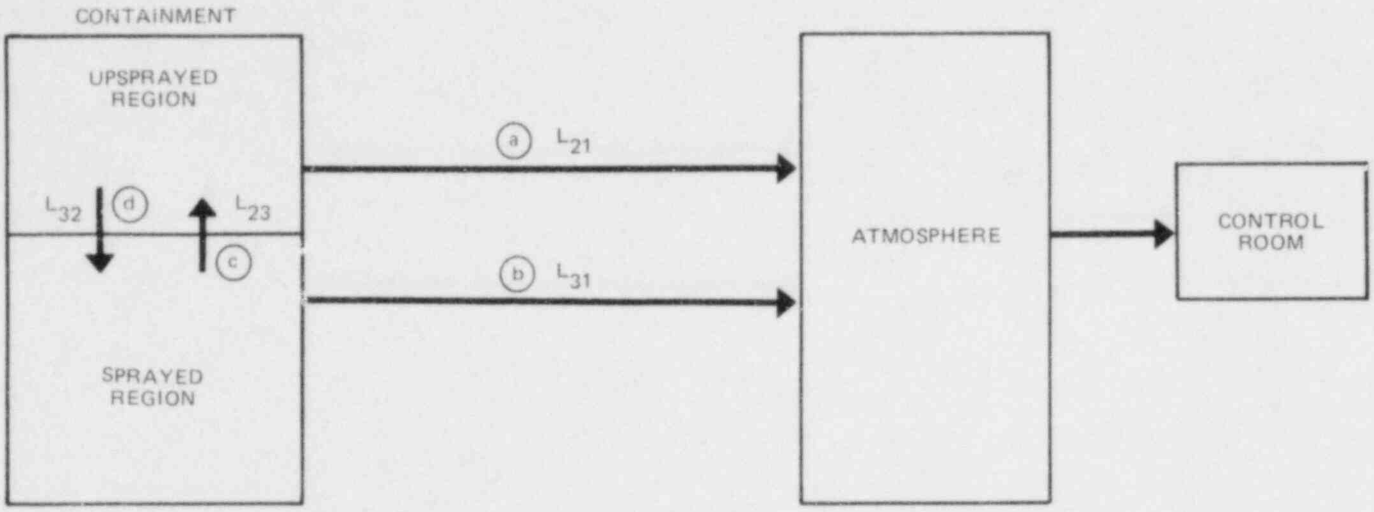

(a) DIRECT UNFILTERED LEAKAGE FRACTION FROM UNSPRAYED REGION

(b) DIRECT UNFILTERED LEAKAGE FRACTION FROM SPRAYED REGION

(c) TRANSFER RATE FROM SPRAYED REGION TO UNSPRAYED REGION

(d) TRANSFER RATE FROM UNSPRAYED REGION TO SPRAYED REGION

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CONTAINMENT LEAKAGE
DOSE MODEL

Figure 15B-1

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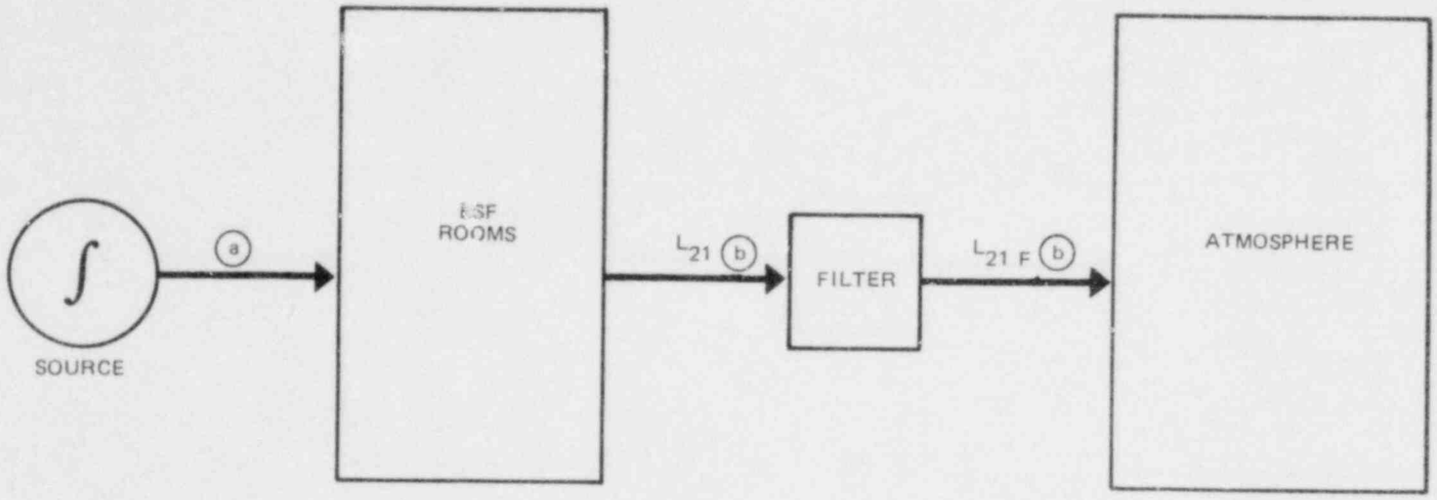

(a) RECIRCULATION OF SUMP WATER TO ESF COMPONENTS

(b) DIRECT FILTERED LEAKAGE FRACTION FROM ESF ROOM

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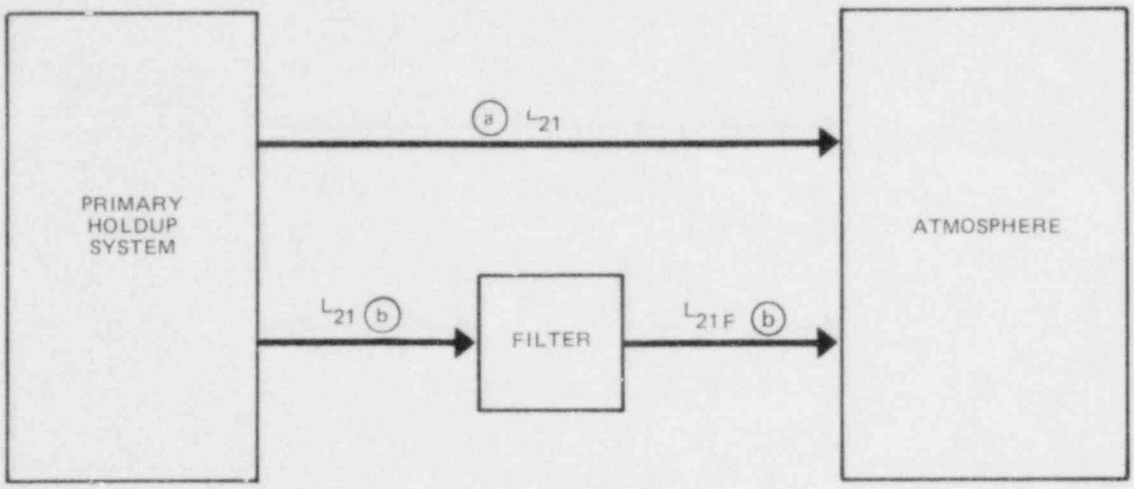
ESF ROOM LEAKAGE
DOSE MODELS

Figure 15B-2



(a) DIRECT UNFILTERED LEAKAGE FRACTION FROM PRIMARY HOLD-UP SYSTEM

(b) DIRECT FILTERED LEAKAGE FRACTION FROM PRIMARY HOLDUP SYSTEM

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OTHER ACCIDENT
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Figure 15B-3