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SUBJECT: Forwards 820121 meeting handouts & associated changes re control room design.Changes will be incorporated into FSAR Amend 29.

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MANAGER OF NUCLEAR ENGINEERING,
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Director, Office of Nuclear Reactor Regulation
Attention: Mr. Frank Miraglia, Branch Chief
Licensing Branch No. 3
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Gentlemen:

Subject: Docket Nos. 50-361 and 50-362
San Onofre Nuclear Generating Station
Units 2 and 3

Based on the results of three control room air tests conducted during the past three months to demonstrate that San Onofre Units 2 and 3 meet the NRC acceptance criterion of a one-eighth inch water guage pressure (Reference: NRC Question 312.18), it is necessary to make minor changes to the control room design. These changes and the associated changes in control room dose and toxic gas analyses were the subject of a meeting between the NRC and SCE on January 21, 1982. The purpose of this letter is to transmit formally seven copies (NRC Mail Code B028) of the handouts used in that meeting and the associated changes to the San Onofre Units 2 and 3 FSAR. These FSAR changes will be incorporated in FSAR Amendment 29.

The schedule for completion of the subject design changes (installation of (1) larger emergency ventilation system fan motors and (2) low leakage dampers on the normal ventilation system ducts) is August 1, 1982. This six month period is necessary to permit (1) procurement of safety grade fan motors, (2) procurement of low leakage dampers, (3) seismic qualification of the dampers and (4) installation. Therefore, SCE requests that the NRC apply an acceptance criterion of "a slight positive pressure" to the control room during the interim period between fuel loading and August 1, 1982. As was discussed during the January 21, 1982 meeting, the dose and toxic gas analyses for both the existing design and the design change which will be completed by August 1, 1982 demonstrate acceptable results.

If you have any questions concerning this matter, please contact me.

Very truly yours,

K P Baskin

cc: H. Rood (with one attachment, deliver to addressee only)

B028
S 1/1

MEETING WITH NRC

SAN ONOFRE UNITS 2&3

CONTROL ROOM PRESSURIZATION TEST

JANUARY 21, 1982

I.	INTRODUCTION AND ORIGINAL DESIGN BASIS	M. MEDFORD
II.	CONTROL ROOM TOXIC GAS EVALUATION	B. DUNCIL
III.	CONTROL ROOM RADIOLOGICAL EVALUATION	A. WEHRENBERG
IV.	CONCLUSION	M. MEDFORD

CONTROL ROOM INLEAKAGE REEVALUATION

FOR TOXIC GASES

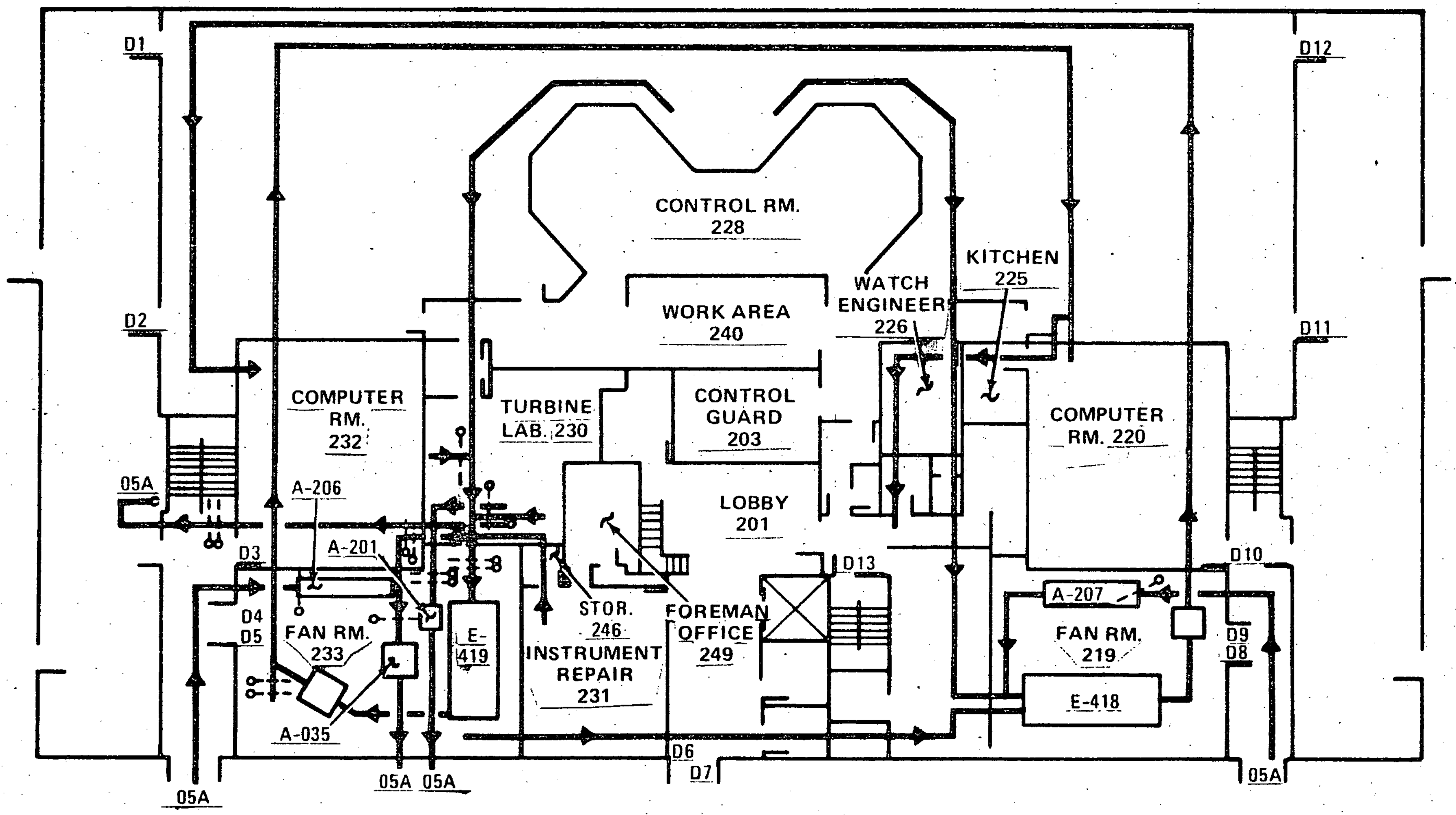
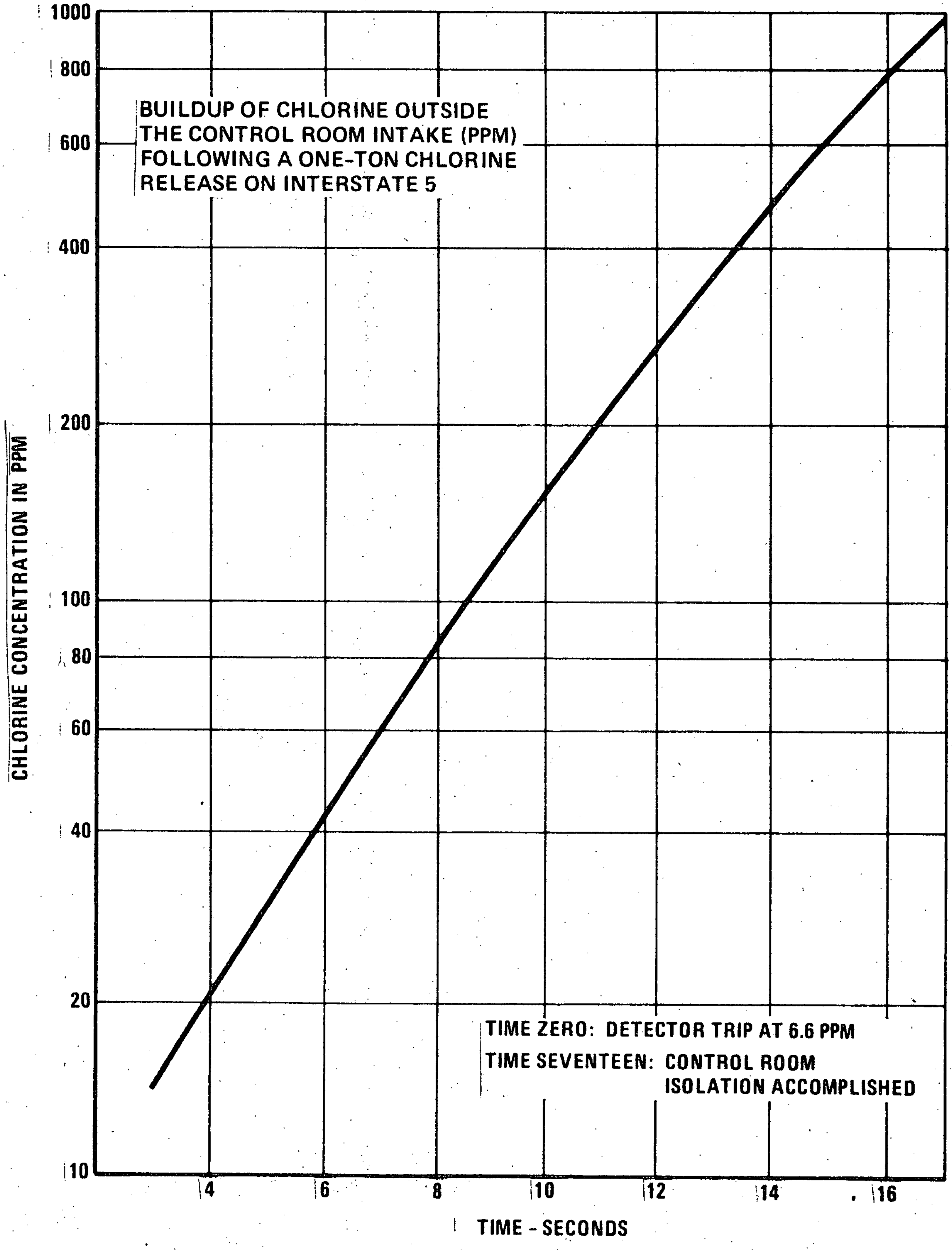


FIGURE 1 – CONTROL ROOM ENVELOPE 30'-0" ELEVATION

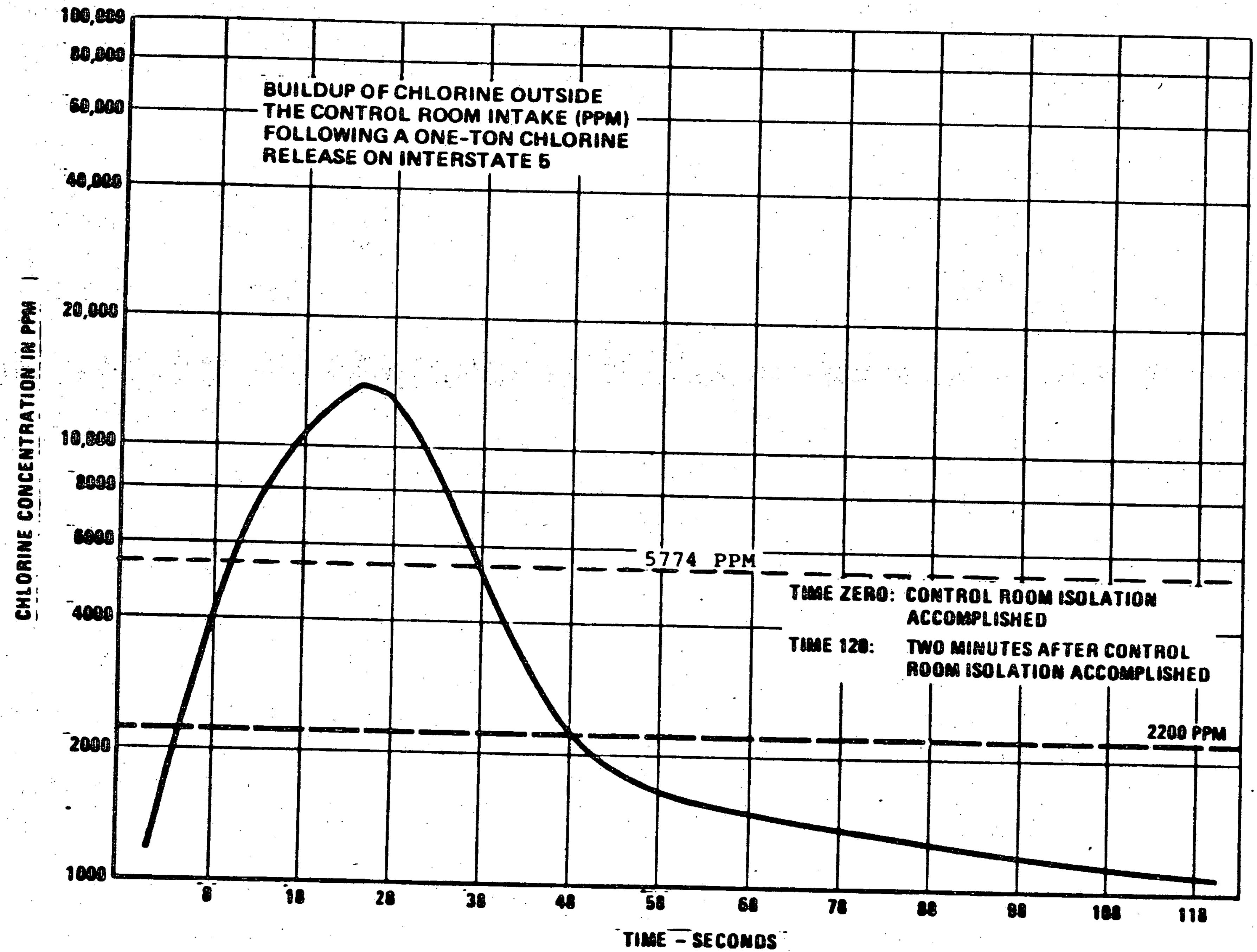
CONTROL ROOM LEAKAGE RATES

FSAR TABLE 6.4-1

Leak Path	Original In-Leakage Rate at 1/8-Inch Wg, Ft^3/min	Revised In-Leakage Rate at 1/8-Inch Wg, Ft^3/min	Effective In-Leakage Rate at 1/8-Inch Wg, Ft^3/min
Plaster Walls	9.4	1590	379.2
Duct-Piping and Electrical Penetrations	0.33		
Dampers	250.7	323.0	89.93
Elevator Shaft	380.0	10.8	2.5
Doors	315.0	68.0	41.4
No Airlock	10.0	10.0	10.0
TOTAL	965.43	2000	523



BUILDUP OF CHLORINE OUTSIDE THE CONTROL ROOM INTAKE (PPM) FOLLOWING A ONE-TON CHLORINE RELEASE ON INTERSTATE 5
TIME ZERO: DETECTOR TRIP AT 6.6 PPM
TIME SEVENTEEN: CONTROL ROOM ISOLATION ACCOMPLISHED
CHLORINE CONCENTRATION IN PPM
1000
800
600
400
200
100
80
60
40
20
10
4
6
8
10
12
14
16
TIME - SECONDS



BUILDUP OF CHLORINE OUTSIDE THE CONTROL ROOM INTAKE (PPM) FOLLOWING A ONE-TON CHLORINE RELEASE ON INTERSTATE 5
CHLORINE CONCENTRATION IN PPM
100,000
80,000
60,000
40,000
20,000
10,000
8000
6000
4000
2000
1000
5774 PPM
2200 PPM
TIME ZERO: CONTROL ROOM ISOLATION ACCOMPLISHED
TIME 120: TWO MINUTES AFTER CONTROL ROOM ISOLATION ACCOMPLISHED
0
10
20
30
40
50
60
70
80
90
100
110
TIME – SECONDS

OVERALL SUMMARY OF LEAKAGES INTO THE CONTROL ROOM ENVELOPE (A)						
	LEAKAGE IN 1 MINUTE			LEAKAGE IN 2 MINUTES		
LEAK SOURCES	FT^3	DILUTION RATIO	EQUIVALENT FT^3 AT 5744 PPM	FT^3	DILUTION RATIO	EQUIVALENT FT^3 AT 5744 PPM
DAMPERS FV-9769 FV-9779	215	11.3	19.03	430	5.65	76.11
DAMPER FV-9742	19.20	20.88	0.92	38.4	10.44	3.68
DAMPER FV-9762	19.20	22.50	0.85	38.4	11.25	3.41
DAMPER FV-9711 FV-9712	70	41.62	1.68	140	20.81	6.73
TOTAL	323		22.48	646.8		89.93
DOORS D-1, D-2 D-11, D-12	17.8	46.51	0.38	35.6	23.26	1.53
DOORS D-4, D-5 D-8, D-9	13.2	18.02	0.73	26.4	9.01	2.93
DOORS D-6, D-7	16.0	1.0	16.0	32.0	1.0	32.0
DOORS D-13, D-14 D-15	21.0	16.88	1.24	42.0	8.44	4.98
TOTAL	68.0		18.35	136.0		41.44
ELEVATOR	10.8	17.38	0.62	21.6	8.69	2.49
WALLS, PENETRATIONS NO AIR LOCK	1600	16.88	94.79	3200	8.44	379.2
		RG 1.78	+ 10.0		RG 1.78	+ 10.0
TOTAL	2002.2		146.24	4004.4		523.1

OVERALL SUMMARY OF LEAKAGES INTO THE CONTROL ROOM ENVELOPE (B)						
	LEAKAGE IN 1 MINUTE			LEAKAGE IN 2 MINUTES		
LEAK SOURCES	FT^3	DILUTION RATIO	EQUIVALENT FT^3 AT 5744 PPM	FT^3	DILUTION RATIO	EQUIVALENT FT^3 AT 5744 PPM
DAMPER FV-9742	19.20	20.88	0.92	38.4	10.44	3.68
DAMPER FV-9762	19.20	22.50	0.85	38.4	11.25	3.41
TOTAL	38.4		1.77	76.8		7.10
DOORS D-1, D-2 D-11, D-12	17.8	46.51	0.38	35.6	23.26	1.53
DOORS D-4, D-5 D-8, D-9	13.2	18.02	0.73	26.4	9.01	2.93
DOORS D-6, D-7	16.0	1.0	16.0	32.0	1.0	32.0
DOORS D-13, D-14 D-15	21.0	16.88	1.24	42.0	8.44	4.98
TOTAL	68.0		18.35	136.0		41.44
ELEVATOR	10.8	17.38	0.62	21.6	8.69	2.49
WALLS, PENETRATIONS NO AIR LOCK	1600	16.88	94.79	3200	8.44	379.2
		RG 1.78	+ 10.0		RG 1.78	+ 10.0
TOTAL	1717.2		125.53	3434.4		440.3

DILUTION RATIO METHODS

V_D = VOLUME (NET) DUCT, STAIRWELL FT^3

J = VOLUME FLOW RATE (IN-LEAKAGE) CFM

t = TIME MINUTES

P = PPM CHLORINE CONCENTRATION OF OUTSIDE AIR

I_P = PPM CHLORINE CONCENTRATION AT THE TIME OF ISOLATION IN THE CONTROL ROOM ENVELOPE. CALCULATED BY TOXGAS AND VERIFIED INDEPENDENTLY TO BE I_P = .9 PPM.

C_1 = PPM CHLORINE CONCENTRATION AT 1 MINUTE (FROM EACH LEAKAGE PATH)

C_2 = PPM CHLORINE CONCENTRATION AT 2 MINUTES (FROM EACH LEAKAGE PATH)

$$C = \frac{(t \times J \times P) + (V_D - t \times J) \times I_P}{V_D}$$

AVERAGE CONCENTRATION OF CHLORINE FOR 1 MINUTE

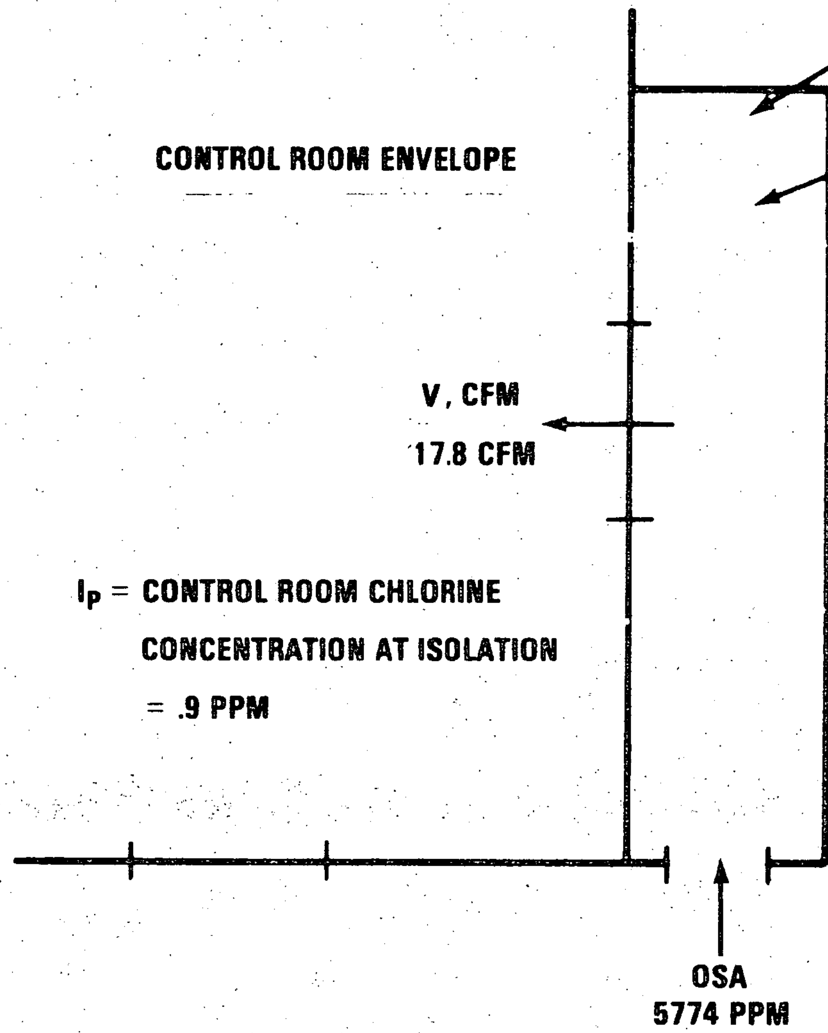
$$= \frac{I_P + C}{2} = A_C$$

DILUTION RATIO FOR 1 MINUTE

$$DR = \frac{P}{A_C}$$

EQUIVALENT CUBIC FEET IN-LEAKAGE OF OUTSIDE AIR

$$= \frac{J}{DR}$$



CHLORINE CONCENTRATION

AT 2 MINUTES

$$= \frac{\{(2 \text{ MIN} * 17.8 \text{ CFM} * 5774 \text{ PPM}) + [415.4 \text{ FT}^3 - (2 \text{ MIN} * 17.8 \text{ CFM})] * .9 \text{ PPM}\}}{415.4 \text{ FT}^3}$$

= 495.7 PPM

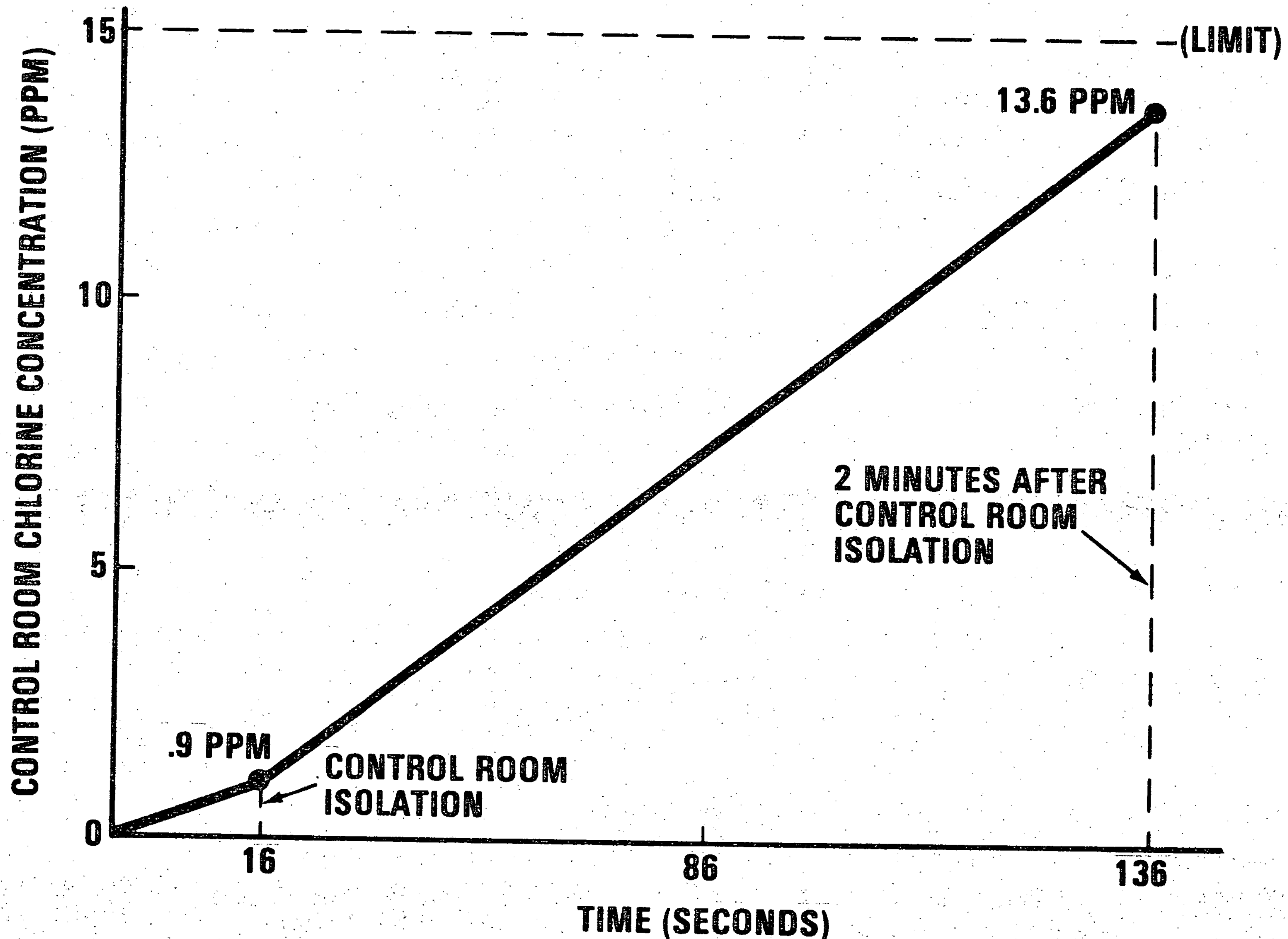
AVERAGE CHLORINE CONCENTRATION FOR 2 MINUTES $= \dfrac{9 \text{ PPM} + 495.7 \text{ PPM}}{2}$

= 248.3

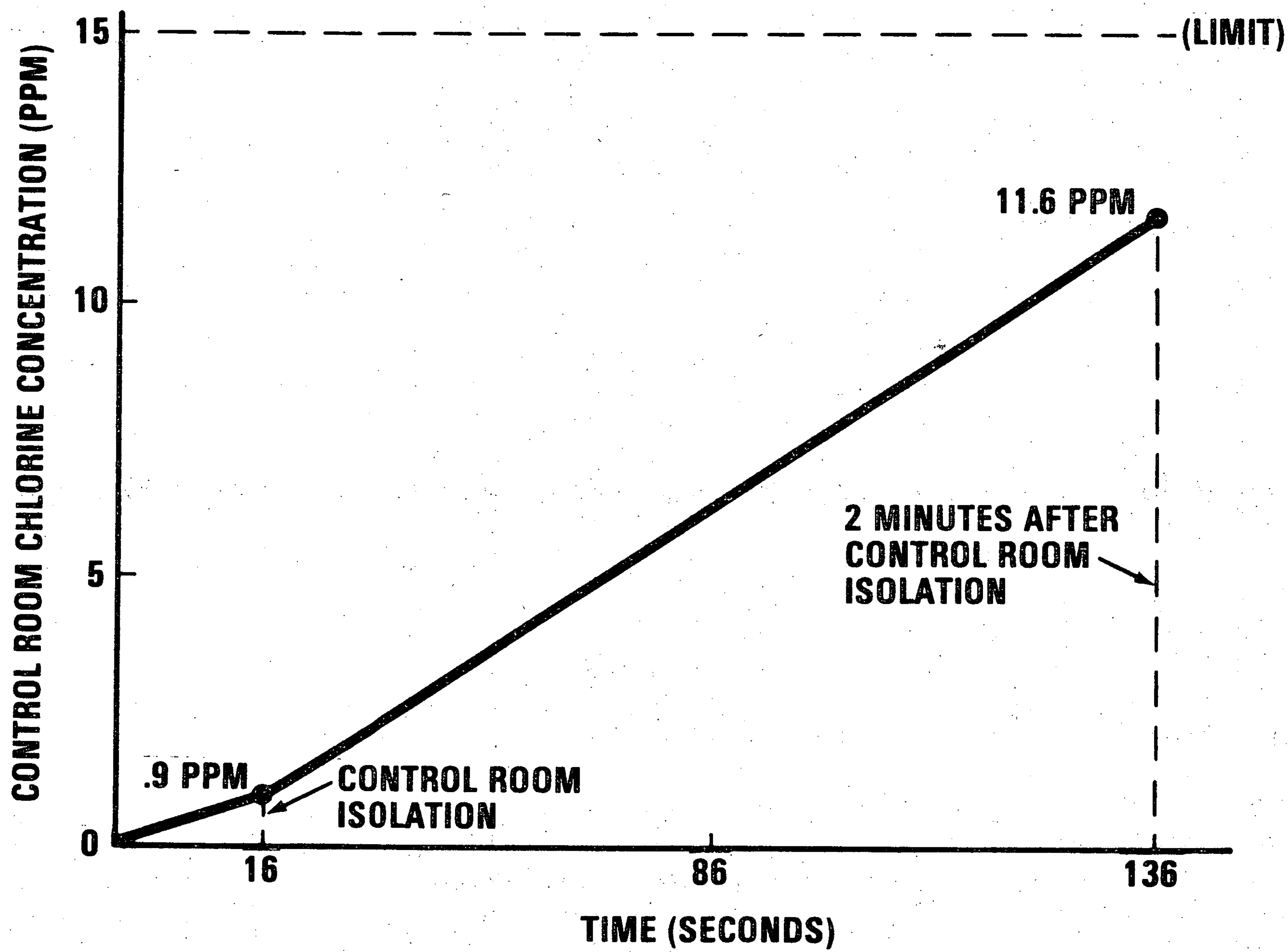
DILUTION RATIO $= \dfrac{5774 \text{ PPM}}{248.3}$

= 23.26

TYPICAL DILUTION RATIO CALCULATION



15
10
5
0
(LIMIT)
13.6 PPM
.9 PPM
CONTROL ROOM ISOLATION
2 MINUTES AFTER CONTROL ROOM ISOLATION
CONTROL ROOM CHLORINE CONCENTRATION (PPM)
16
86
136
TIME (SECONDS)


CONTROL ROOM CHLORINE CONCENTRATION (PPM)
15
10
5
0
(LIMIT)
11.6 PPM
2 MINUTES AFTER CONTROL ROOM ISOLATION
.9 PPM
CONTROL ROOM ISOLATION
16
86
136
TIME (SECONDS)

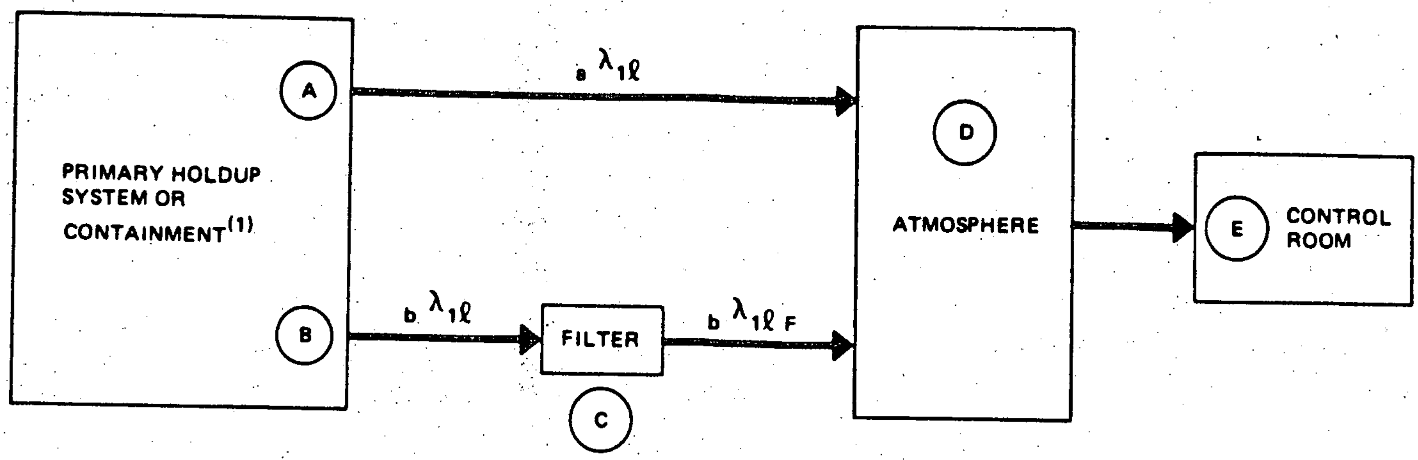
CONTROL ROOM RADIOLOGICAL EVALUATION

I. RELEASE AND EXPOSURE PATHWAYS MODEL

II. ACTIVITY EQUATIONS AND SOLUTIONS

III. INPUT PARAMETERS

IV. RESULTS AND CONCLUSIONS



a = DIRECT UNFILTERED LEAKAGE FRACTION

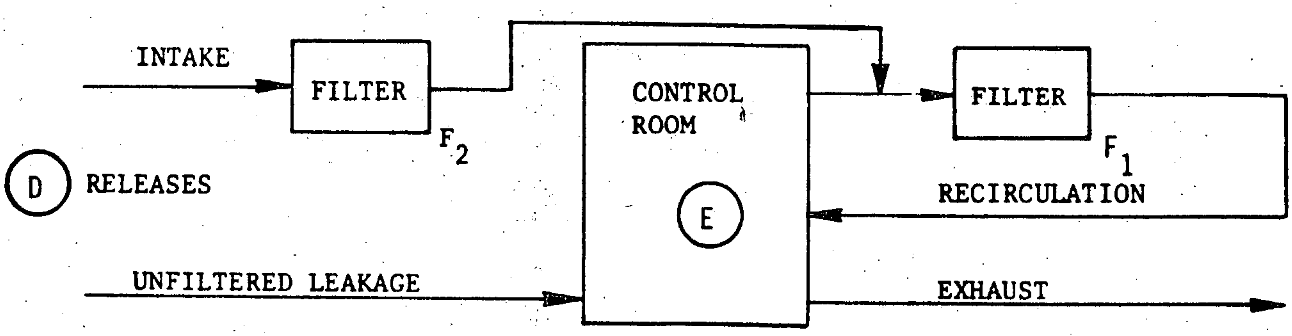
b = DIRECT FILTERED LEAKAGE FRACTION

F_1 = PRIMARY FILTER NONREMOVAL EFFICIENCY

$\lambda_{1\ell}$ = LEAKAGE REMOVAL CONSTANT FROM PRIMARY

NOTES:

1. THE PRIMARY HOLDUP SYSTEM MAY CONTAIN INTERNAL CLEANUP SYSTEMS. FOR EXAMPLE, IN THE LOCA CASE, THE CLEANUP SYSTEM WILL BE THE CONTAINMENT SPRAY SYSTEM DESCRIBED IN SUBSECTION 6.5.2.
2. UNFILTERED RELEASE PATHWAYS ARE A-D-E AND D-D-E.
3. FILTERED RELEASE PATHWAY IS B-C-D-E.



SAN ONOFRE
NUCLEAR GENERATING STATION
Units 2 & 3

ACCIDENT RELEASE PATHWAYS

10079-11D-900
18OC6

ACTIVITY IN CONTROL ROOM FROM SINGLE REGION SYSTEM

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

where:

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

F_2 = filter nonremoval fraction on intake

R_{FIN} = filtered intake rate

R_{UIN} = unfiltered intake rate = 0

release(t) = release rate given in equation 4a of section 15B.6.2

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

where:

λ_3 = total removal λ from CR

$\lambda_{3\ell}$ = exhaust from CR

λ_d = isotopic decay constant

λ_r = recirculation removal λ

$$\frac{dA_1}{dt} - L_{21}A_2 = 0$$

$$\frac{dA_2}{dt} + (\lambda_d + \lambda_s + L_{21})\, A_2 = 0$$

$$\frac{dA_3}{dt} - \frac{\chi}{Q}\,(L_u + (1 - f_L)\, L_f)\, L_{21}\, A_2$$

$$+ (L_f + L_u + f_R R_c + \lambda_d)\, A_3 = 0$$

where:

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

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

$A_3(t)$ = activity in the control room, (Ci)

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

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

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

λ_s = the spray removal constant, (s^{-1})

L_u = $\dfrac{T_u \cdot (.3048)^3}{60}$, (m^3/s)

T_u = unfiltered inleakage into the control room, (ft^3/min)

L_f = $\dfrac{T_f(.3048)^3}{60}$, (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 = $\dfrac{T_r}{(V_c)(60)}$, (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

The coefficient matrix is:

$$\bar{C} = \begin{bmatrix} 0 & -L_{21} & 0 \\ 0 & (\lambda_d + \lambda_s + L_{21}) & 0 \\ 0 & -\chi/Q(L_u + (1 - f_L)\, L_f)\, L_{21} & +(L_f + L_u + f_R R_c + \lambda_d) \end{bmatrix}$$

Table 15B-5
CONTROL ROOM EMERGENCY VENTILATION SYSTEM PARAMETERS[a]

Parameter	Assumption
Number of emergency ventilation systems operating	1
Intake rate, standard ft^3/min	1,800 ~~1,000~~
Intake cleanup filter efficiency	
Iodine, elemental, %	99(b)
Iodine, organic, %	99(b)
Iodine, particulate, %	99
Others, %	99
Recirculation rate, standard ft^3/min	34,500
Recirculation cleanup filter efficiency	
Iodine, elemental, %	95
Iodine, organic, %	95
Iodine, particulate, %	99
Others, %	99
Leak rate, standard ft^3/min (out leakage)	1,800 ~~1,000~~
Control room volume, standard ft^3	293,300

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

b. Based on multiple, in series, bed filtration as depicted in section 15B.7.

Table 15.6-17
PARAMETERS USED IN EVALUATING THE RADIOLOGICAL CONSEQUENCES OF A LOSS-OF-COOLANT ACCIDENT

Parameter	Design Basis Assumptions
A Source data	
1. Power level, MWt	3,560
2. Fraction of core activity initially airborne in the containment, %	
a. Noble gas	100
b. Iodine	25
B. Activity release data	
1. Containment leakage rate, Vol %/d	
a. 0 to 24 hours	0.1
b. 1 to 30 days	0.05
2. Fraction of containment leakage that is unfiltered, %	100
3. Credit for containment spray system	
a. Iodine removal constants, hr^{-1}	
(1) Elemental	4.8
(2) Organic	0.0
(3) Particulate	0.22
b. Decontamination factor	
(1) Elemental	100
(2) Particulate	5,000

Table 15.6-18

RADIOLOGICAL CONSEQUENCES OF A POSTULATED LOSS-OF-COOLANT ACCIDENT

Result	Design Basis Assumptions
Control room dose (0 to 30 days), rem	
Radiation external to the control room	
Total-body gamma	
Containment leakage	0.2
Due to recirculation leakage	2×10^{-4}
Due to piping	0.4
Due to HVAC charcoal filter	~~0.24~~ 0.43
Radiation internal to the control room	
Thyroid	
Containment leakage	1.6 ~~1.03~~
Due to recirculation leakage	~~0.24~~ 0.43
Total-body gamma	
Containment leakage	1.5 ~~1.1~~
Due to recirculation leakage	~~7.6×10^{-5}~~ 1.4×10^{-4}
Beta-skin	
Containment leakage	14.1 ~~25.4~~
Due to recirculation leakage	~~1.1×10^{-5}~~ 2.0×10^{-5}

BETA-SKIN DOSE CONVERSION FACTORS

$(REM\text{-}M^3$ / CI-HR)

ISOTOPE	PREVIOUS VALUE[1]	PRESENT VALUE[2]	RATIO
KR 83M	3.06 E1	-	-
KR 85	2.08 E2	1.53 E2	0.74
KR 85M	2.09 E2	1.67 E2	0.80
KR 87	1.10 E3	1.11 E3	1.01
KR 88	3.11 E2	2.70 E2	0.87
KR 89	-	1.15 E3	-
XE 131M	1.18 E2	5.43 E1	0.46
XE 133M	1.57 E2	1.13 E2	0.72
XE 133	1.12 E2	3.49 E1	0.31
XE 135M	7.87 E1	8.11 E1	1.03
XE 135	2.62 E2	2.12 E2	0.81
XE 137	-	1.39 E3	-
XE 138	5.02 E2	4.71 E2	0.94

1 From FSAR Chapter 15B

2 From Regulatory Guide 1.109 Rev. 1

6.4.2.3 Leak Tightness

Tables 6.4-1A and 6.4-1B present the actual control room leakage rates derived from pressurization tests conducted on the San Onofre Units 2 and 3 control room envelope.

Table 6.4-1B presents the actual leakage rates into the control room envelope from the leakage paths depicted in figure 6.4-1A. The dilution ratios are the ratio of the average chlorine concentration in the volumes adjacent to the envelope to the chlorine concentration outside the control building. These ratios account for the dilution of the chlorine in the air volumes adjacent to the control room envelope. The calculated dilution ratios are then applied to the in-leakage rates for the individual flow path to calculate the effective in-leakage of outside air into the control room. The toxic gas hazard was then reevaluated per paragraph 6.4.4.2.2. The results of this evaluation are presented in table 6.4-4.

Table 6.4-1A
CONTROL ROOM OUTLEAKAGE RATES

Leak Path	Outleakage Rate At 1/8-inch WG, Ft^3/min
Plaster Walls Duct-piping and Electrical Penetrations	1311.2
Dampers	
Outleakage	460
Inleakage	(-)285
Elevator Shaft	10.8
Doors	68
No Airlock	10.0
Total	1575

Table 6.4-1B
OVERALL SUMMARY OF LEAKAGES INTO THE CONTROL ROOM ENVELOPE

Leak Sources	Leakage In 1 Minute			Leakage in 2 Minutes		
	Ft^3	Dilution Ratio[a]	Equivalent Ft^3 At 5774 ppm	Ft^3	Dilution Ratio	Equivalent Ft^3 At 5774 ppm
Dampers FV-9769 FV-9779	215	11.3	19.03	430	5.65	76.11
Damper FV-9742	19.20	20.88	0.92	38.4	10.44	3.68
Damper FV-9761	19.20	22.50	0.85	38.4	11.25	3.41
Damper FV-9711 FV-9712	70	41.62	1.68	140	20.81	6.73
TOTAL	323		22.48	646.8		89.93
Doors D-1, D-2 D-11, D-12	17.8	46.51	0.38	35.6	23.26	1.53
Doors D-4, D-5 D-8, D-9	13.2	18.02	0.73	26.4	9.01	2.93
Doors D-6, D-7	16.0	1.0	16.0	32.0	1.0	32.0
Doors D-13, D-14 D-15	21.0	16.88	1.24	42.0	8.44	4.98
TOTAL	68.0		18.35	136.0		41.44
Elevator	10.8	17.38	0.62	21.6	8.69	2.49
Walls, Penetrations	1600	16.88	94.79	3200	8.44	379.2
No Air Lock						
		RG 1.78	+10.0		RG 1.78	+10.0
TOTAL	2002.2		146.24	4004.4		523.1

a. The one-minute and two-minute average chlorine concentrations in volumes adjacent to the control room envelope are compared with the chlorine concentration in the outside air to yield dilution ratios for each individual leakage path.

6.4.2.4 Shielding Design

The design basis loss-of-coolant accident (LOCA) dictates the shielding requirements for the control room. Control room shielding design bases are discussed in paragraph 12.3.2.2.7. Descriptions of the design basis LOCA source terms and control room shielding parameters, and evaluation of design basis accident doses to control room personnel are presented in paragraph 15.6.3.3.5.

Drawings of the control room and its location in the plant, identifying distances, and shield thicknesses with respect to each radiation source discussed in paragraph 15.6.3.3.5 are shown in figures 12.3-3 and 12.3-4.

6.4.3 SYSTEM OPERATIONAL PROCEDURES

6.4.3.1 Normal Mode

Control room HVAC system operation in the normal mode is described in subsection 9.4.2.

6.4.3.2 Emergency Mode

Upon receipt of a control room isolation signal (CRIS), actuated by an SIAS signal or a normal supply air duct high radiation signal, the control room HVAC system is automatically shifted to the emergency mode of operation. Transfer to the emergency mode may also be initiated manually from the control room. 27

Transfer to the emergency mode consists of automatically closing the outside air isolation dampers from the normal supply air handling unit and all exhaust isolation dampers, stopping the control building supply and exhaust fans, activating both train A and train B outside air isolation dampers to the emergency ventilation units, and starting the emergency air conditioning units, opening the outside air isolation damper to the emergency filtration trains, and starting the fans. The emergency ventilation supply train fans discharge into the emergency recirculation type air conditioning units, which are started by the emergency mode transfer. 21 Thus, each emergency ventilation supply train fan draws outside air through HEPA filters and carbon adsorbers, and discharges into the respective emergency recirculation air handling unit. Since there is no control room exhaust, the control room atmosphere exfiltrates to the outside of the control room. The development of the CRIS signal, including the quantity and setpoints of parameters sensed and actuation logic, is discussed in section 7.3. 1-312.15

Table 6.4-4
SUMMARY OF RESULTS
EFFECT OF POSTULATED TOXIC GAS RELEASES ON THE HABITABILITY OF THE SAN ONOFRE UNITS 2 AND 3 CONTROL ROOM

Hazardous Chemical	Postulated Accident	Toxicity Limit For Gas or Vapor (ppm by vol)	Objectives of Reg. Guide 1.78 Met Without Toxic Gas Protection	Effectiveness of Detection and Control Room Isolation as a Mitigating Measure				C=Continuous Release P=Puff release
				Set Point (ppm)	Detector Response Time (sec)	Isolation Time (sec)	χ_{cr} (1) @ 120 sec	Either P or C
Nitrogen	Rupture of 91,800 lb onsite tank	143,000	Yes		(No Protection Required)			
Hydrogen	Rupture of 7,620 scf onsite cylinder	143,000						
Diesel Oil	Rupture of 350 gal fire pump day tank	200						
Hydrazine	Rupture of 55 gal onsite drum	5						
Sulfuric Acid	Rupture of 10,000 gal onsite tank	0.09						
Halon 1301	Discharge of 140 lb cylinder in control room	70,000						
Gasoline	Rupture of 4,500 gal cargo tank I5	780						
Propane	Rupture of 8,485 gal cargo tank I5	1000 (2)	No	133 (3)	30	6	29.3	P
Carbon dioxide	Rupture of 13 ton onsite tank	50,000		5000	30	6	896	P+C
Butane	Rupture of 8,485 gal cargo tank, I5	750 (2)		100 (3)	30	6	29.1	P+C
Chlorine	Rupture of 2000 lb cylinder, I5	15		5	10	6	13.6	P+C
Aqueous ammonia	Rupture of 3000 gal onsite tank	100		50	30	6	7	C

1. χ_{cr} = The toxic gas concentration inside the control room 120 seconds following an alarm from the detector.

2. 1750 mg/m^3 = 1000 ppm propane
   = 750 ppm butane

3. 100 ppm butane setpoint is equivalent to 133 ppm propane setpoint.

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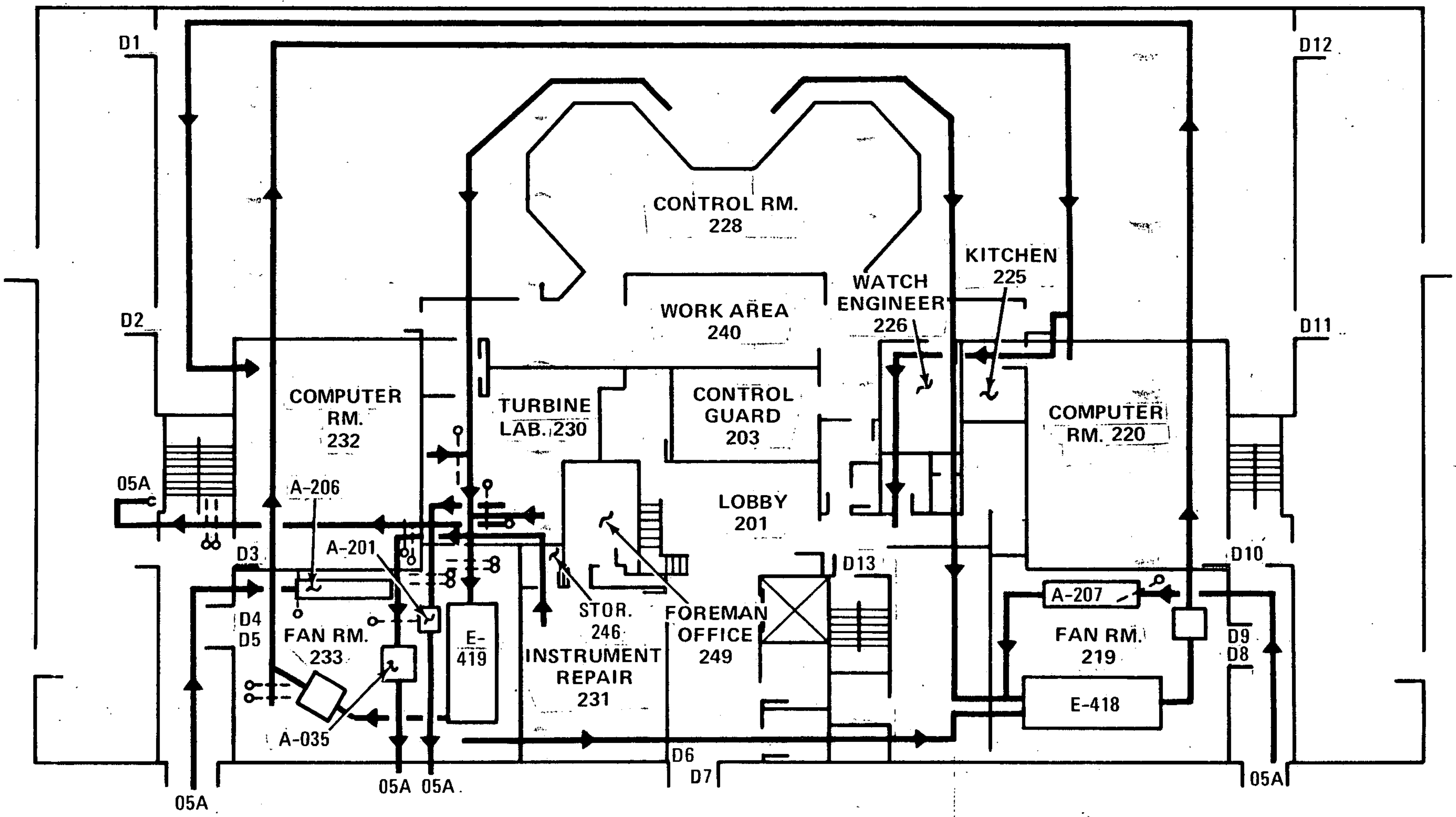


FIGURE 6.4-1A – CONTROL ROOM ENVELOPE 30'-0" ELEVATION

Table 15.6-18
RADIOLOGICAL CONSEQUENCES OF A POSTULATED
LOSS-OF-COOLANT ACCIDENT (Sheet 2 of 2)

Result	Design Basis Assumptions	Realistic Assumptions
Control room dose (0 to 30 days), rem		
Radiation external to the control room		
Total-body gamma		
Containment leakage	0.2	1.36×10^{-9}
Due to recirculation leakage	2×10^{-4}	0
Due to piping	0.4	0
Due to HVAC charcoal filter	0.43	0
Radiation internal to the control room		
Thyroid		
Containment leakage	1.6	4.7×10^{-7}
Due to recirculation leakage	0.43	0
Total-body gamma		
Containment leakage	1.5	1.04×10^{-4}
Due to recirculation leakage	1.4×10^{-4}	0
Beta-skin		
Containment leakage	14.1	2.66×10^{-5}
Due to recirculation leakage	2.0×10^{-5}	0

21

APPENDIX 15B

DOSE MODELS USED TO EVALUATE THE ENVIRONMENTAL CONSEQUENCES OF ACCIDENTS

15B.1 INTRODUCTION

This section identifies the models used to calculate offsite radiological doses that would result from releases of radioactivity due to various postulated accidents.

The postulated accidents are:

A. Steam generator tube rupture (SGTR)

B. Primary sample or instrument line break

C. Inadvertent opening of a steam generator atmospheric dump valve (IOSGADV)

D. Waste gas system failure

E. Radioactive liquid waste system leak or failure

F. Loss-of-coolant accident (LOCA)

G. Steam system piping failures

H. Fuel handling accident (FHA)

I. CEA ejection accident (CEAEA)

15B.2 ASSUMPTIONS

The following assumptions are basic to both the model for the whole body dose due to immersion in a cloud of radioactivity and 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).[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. Isotopic data, including decay constants and decay energies presented in table 15B-1, are taken from references 2 through 6.

15B.2.1 REFERENCES

1. "Report of ICRP Committee II, Permissible Dose for Internal Radiation (1959)," Health Physics, 3, p. 30, 146-153, 1960.

2. Martin, M. J. and Blichert-Toft, P. H., Radioactive Atoms, Auger-Electron, α-, β-, γ-, and X-Ray Data, Nuclear Data Tables A8, 1, 1970.

3. Martin, H. J., "Radioactive Atoms - Supplement 1," ORNL-4923, August 1973.

4. Bowman, W. W. and MacMurdo, K. W., "Radioactive Decay Gammas, Ordered by Energy and Nuclide," Atomic Data and Nuclear Data Tables 13, S9, 1974.

5. Meek, M. E. and Gilbert, R. S., "Summary of Gamma and Beta Energy and Intensity Data," NEDO-12037, January 1970.

6. Lederer, C. M., Hollander, J. M., and Perlman, I., Table of the Isotopes, 6th edition, March 1968.

15B.3 WHOLE BODY GAMMA AND BETA SKIN DOSE

The whole body dose delivered to an offsite receptor is obtained by considering the dose receptor to be immersed in a radioactive cloud that is infinite in all directions above the ground plane; i.e., an infinite hemispherical 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.

The gamma dose due to gamma radiation, equation (1), and the beta dose due to beta radiation, equation (2), for a given time period are given by Regulatory Guide 1.4, Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Pressurized Water Reactors, are as follows:

$$D_{wb} = 0.25 \cdot \chi/Q \cdot \sum_i (Q_i \cdot \bar{E}_i) \qquad (1)$$

$$D_s = 0.23 \cdot \chi/Q \cdot \sum_i (Q_1 \cdot \bar{E}_i) \qquad (2)$$

where:

D_{wb} = whole body dose from gamma radiation (rem)

D_s = skin dose from beta radiation (rem)

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

Q_i = Total activity of isotope i released during time period (Ci-s)

E_i = average gamma or beta decay energy from isotope i (MeV/disintegration)

The isotopic data are given in table 15B-1. The atmospheric dispersion factors used in the analysis of the environmental consequences of accidents are given in chapter 2 of this report.

15B.4 THYROID INHALATION DOSE

The thyroid dose to an offsite receptor for a given time period is obtained from the following expression:[1]

$$D = \chi/Q \cdot B \sum_i (Q_i \cdot DCF_i) \qquad (3)$$

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)

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

DCF_i = dose conversion factor for isotope i (rem/Ci inhaled)

The isotopic data are given in table 15B-1. The atmospheric dispersion factors used in the analysis of the environmental consequences of accidents are given in chapter 2 of this report.

Dose conversion factors for radioactive iodines and breathing rates required for computing thyroid inhalation dose are tabulated in tables 15B-2 and 15B-3, respectively.

15B.4.1 REFERENCES

1. DiNunno, J. J., et al., Calculation of Distance Factors for Power and Test Reactor Sites, TID 14844, March 1962.

Table 15B-1
ISOTOPIC PARAMETERS

Isotope	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
Xe-131m	11.9 D	0.20	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-138	14.17 M	1.183	0.606
H-3	12.3 Y	None	0.006

Table 15B-2
IODINE DOSE CONVERSION FACTORS
FOR OFFSITE RECEPTORS

Isotope	Rem-thyroid/Curie Inhaled
I-131	1.48×10^{6}
I-132	5.35×10^{4}
I-133	4.00×10^{5}
I-134	2.50×10^{4}
I-135	1.25×10^{5}

Table 15B-3
BREATHING RATES

Time After Accident	m^3/s
0 to 8 hours	3.47×10^{-4}
8 to 24 hours	1.75×10^{-4}
1 to 30 days	2.32×10^{-4}

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.

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

D. Direct whole body gamma dose from the radioactivity present in piping. 21

E. Direct whole body gamma dose from emergency HVAC charcoal filters. 26

In calculating the exposure to control room personnel, occupancy factors were obtained from reference 1 as follows: 25

- 0-24 hours: occupancy factor = 1
- 1-4 days: occupancy factor = 0.6
- 4-30 days: occupancy factor = 0.4

The dose model for each of the radiation sources is 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) isotopic concentrations in the containment are calculated. For conservatism, no credit is taken for reduction of the containment activity by means other than radioactive decay. The containment is modeled by an equivalent volume cylindrical source having a diameter of 150 feet and height of 130 feet. The radioactivity present in the containment is assumed to be uniformly distributed in the cylindrical source.

Shielding is provided by the 3-foot 9-inch concrete containment walls, 330 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 could be provided by the penetration 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 cloud. For conservatism it is assumed that this cloud surrounds the control room. Gamma radiation from this cloud 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 concentrations (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). Calculations used to compute χ/Q are presented in subsection 2.3.4. A tabulation of control room χ/Qs is presented in table 15B-4.

Meteorological parameters are given in section 2.3, while the calculated χ/Q values, for those accidents for which control room dose calculations were performed, are presented in table 15B-4.

25 The calculational model for the control room is an equivalent volume hemisphere of radius 52 feet. Credit is taken for 2 feet of concrete shielding provided by the control room walls and ceiling.

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,
25 thyroid inhalation, and beta skin doses. The major parameters of the control room ventilation system are presented in table 15B-5.

Meteorological parameters are given in section 2.3, while the calculated χ/Q values, for these accidents for which control room dose calculations were performed, are presented in table 15B-4.

Table 15B-4
ATMOSPHERIC DISPERSION FACTORS FOR THE SAN ONOFRE SITE

Time Period	χ/Q (s/m^3)					
	Control Room		EAB		LPZ	
	5%	50%	5%	50%	5%	50%
Hourly			2.72×10^{-4}	3.60×10^{-6}		
0-8 hours	3.1×10^{-3}	7.9×10^{-4}			7.72×10^{-6}	9.24×10^{-7}
8.24 hours	1.8×10^{-3}	4.6×10^{-4}			4.74×10^{-6}	6.03×10^{-7}
1-4 days	5.9×10^{-4}	1.5×10^{-4}			3.67×10^{-6}	3.65×10^{-7}
4-30 days	9.6×10^{-5}	2.5×10^{-6}			2.67×10^{-6}	3.28×10^{-7}

Table 15B-5
CONTROL ROOM EMERGENCY VENTILATION SYSTEM PARAMETERS[a]

Parameter	Assumption
Number of emergency ventilation systems operating	1
Intake rate, standard ft^3/min	3,600
Intake cleanup filter efficiency	
Iodine, elemental, %	99(b)
Iodine, organic, %	99(b)
Iodine, particulate, %	99
Others, %	99
Recirculation rate, standard ft^3/min	34,500
Recirculation cleanup filter efficiency	
Iodine, elemental, %	95
Iodine, organic, %	95
Iodine, particulate, %	99
Others, %	99
Leak rate, standard ft^3/min (out leakage)	3,600
Control room volume, standard ft^3	293,300

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

For a more detailed description of this system, refer to subsection 9.4.2.

b. Based on multiple, in series, bed filtration as depicted in section 15B.7. 1.312.17

The technical support center is located within the control room emergency HVAC envelope. The doses to technical support center personnel will be lower than that for the control room due to the concrete floor attenuating the radiation from the HVAC charcoal filter. 26

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:

$$D_{wb} = \frac{(CRVOL)^{0.338}}{1173} \sum_i DCF_{wbi} \frac{(IQ_i)(3600)(CRO)}{(CRVOL)(0.02832)} \quad (1)$$

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

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-6).

The expression $(CRVOL)^{.338}/1173$ is a geometrical correction factor to ratio a finite cloud to infinite cloud (reference 1).

The beta skin dose to control room personnel is calculated assuming a tissue depth of 7 mg/cm^3. The beta skin dose to control room personnel for a given time period is:

$$D_{\beta s} = \frac{CRO}{(CRVOL)(.02832)} \sum_i D_{\beta si} \cdot IQ_i \quad (2)$$

where:

$D_{\beta si}$ = the beta skin dose conversion factor for nuclide i, (rem-m^3/Ci-h). (See table 15B-6 for factor)

and all other parameters are as previously defined.

An inhalation thyroid dose results from the radioactive iodine present in the control room.

The inhalation thyroid dose is given by the following expression:

$$D_{thy} = \frac{(B)(CRO)}{(CRVOL)(.02832)} \sum_i DCF_{thy} \cdot IQ_i \qquad (3)$$

where:

D_{thy} = inhalation thyroid dose (rem)

B = breathing rate for duration of accident ($3.47\text{-}4\ m^3/sec$)

DCF_{thy} = thyroid dose conversion factor for nuclide i, (rem/Ci inhaled) (see table 15B-6)

All other parameters are as previously defined.

D. Direct whole body gamma dose from radioactivity present in piping.

Direct radiation from piping used in the post-accident mode of operation will contribute to the control room whole body gamma dose. 21

Table 15B-6
CONTROL ROOM WHOLE BODY GAMMA, BETA SKIN, AND INHALATION THYROID DOSE CONVERSION FACTORS[a]

Radionuclide	Beta Skin DCF (rem - m^3/Ci - h)	Whole Body Gamma DCF (rem - m^3/Ci - s)	Inhalation Thyroid DCF (rem/Ci)
I-131	1.14E2	8.72E-2	1.49E6
I-132	4.75E2	5.13E-1	1.43E4
I-133	2.65E2	1.55E-1	2.69E5
I-134	3.32E2	5.32E-1	3.73E3
I-135	4.64E2	4.21E-1	5.6E4
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	

a. From Regulatory Guide 1.109

This piping is modeled as a finite length shielded cylinder. Credit is taken for concrete shield floors and walls of the penetration, control and radwaste buildings, as well as the control room shield door. 21

E. Direct whole body gamma dose from radioiodine buildup on control building emergency HVAC filter.

The quantity of iodine entering the filter, following a LOCA, is determined in a manner identical to that described in item C. The dose in the control room is determined by numerical integration of a distributed source model. Filter self-attenuation and dose buildup is modelled. Attenuation by interposed equipment is conservatively neglected. 26

Conservatively, only one emergency HVAC system is assumed to be in operation with a 100% iodine removal efficiency.

15.B.5.1 REFERENCES

1. Murphy, K. G. and Campe, K. M., Dr., "Nuclear Power Plant Control Room Ventilation System Design for Meeting General Design Criterion 19," Proceedings of the 13th AEC Air Cleaning Conference held August 12-15, 1974, CONF. 740-807, Vol. I, pp. 401-430.

15B.6 ACTIVITY RELEASE MODELS

15B.6.1 ACCIDENT RELEASE PATHWAYS

The release pathways for the major accidents are given in table 15B-7 and shown schematically in figure 15B-1. The letters (A-D, D-D, etc.) refer to the labels used in figure 15B-1. The accident and their pathways are as follows.

Table 15B-7
ACCIDENT LEAKAGE PATHWAYS
(Refer to figure 15B-1)

Accident	Pathway	Legend
A. Steam generator tube rupture	Steam dump and → Atm → Control Room Safety Valves	D-D-E
B. Primary sample or instrument line break	Auxiliary building (radwaste → Atm → Control Room area)	A-D-E
C. IOSGADV	Steam dump valve → Atm → Control Room	D-D-E
D. Waste gas system failure	Release pathway identical to B above	A-D-E
E. Radioactive liquid waste system leak or failure	Release pathway identical to B above	A-D-E
F. LOCA		
1. Containment leakage	Primary containment → Atm → Control Room	A-D-E
2. ESF leakage	Safety Equipment building → Atm → Control Room	D-D-E
3. Hydrogen purge	Primary containment → Filter → Atm → Control Room	B-C-D-E
G. Steam system piping failure (main steam line break)	Release pathway identical to A above	D-D-E
H. FHA	Fuel handling building → Filter → Atm → Control Room	B-C-D-E
I. CEAEA		
1. Primary release	Release pathway identical to F.1 above	A-D-E
2. Secondary release	Release pathway identical to A above	D-D-E

15B.6.1.1 Direct Filtered

The accident release pathways for the fuel handling accident (FHA) and LOCA (hydrogen purge releases) involve direct filtered leakage. The release pathway is B-C-D, as shown on figure 15B-1. The applicable equation for calculating activity release for offsite doses is equation (5). Control room internal doses are based on activity release calculated using equation (6).

15B.6.1.2 Direct Unfiltered

6 The accident release pathways for the accidents listed in paragraph 15.B.1, less those accidents described in paragraph 15B.6.1.1, involve direct unfiltered leakage. The release pathway is A-D or D-D, as shown on fig-
6 ure 15B-1. The applicable equation for calculating activity release for offsite doses is equation (5). Control room internal doses are based on activity release calculated using equation (6).

15B.6.2 SINGLE REGION RELEASE MODEL

A single region release model was used for all accident activity release calculations. For the LOCA analysis, a two-region spray model was used, as described in subsection 6.5.2. Effective spray removal coefficients were calculated for the iodine species of interest; and the effective spray removal coefficients were used in the single region release models.

The single region release model is based on two release paths to the environment; (1) direct unfiltered, and/or (2) direct filtered.

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.

$$A_1(t) = A_1(0)e^{-\lambda_1 t} \qquad (1)$$

where:

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

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

λ_1 = total removal constant from primary holdup system

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

where:

λ_d = decay removal constant

$\lambda_{1\ell}$ = primary holdup leak or release rate

λ_r = internal removal constant (i.e., sprays, plateout, etc.)

From this we get the direct release rate to the atmosphere from the primary holdup system.

$$R_u(t) = a\,\lambda_{1\ell}\,A_1(t) \tag{2}$$

where:

a = direct unfiltered fraction of leak

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

and

$$R_f(t) = b\,\lambda_{1\ell}\,F_1\,A_1(t) \tag{3}$$

where:

b = direct filtered fraction of leak

F_1 = filter nonremoval efficiency

$R_f(t)$ = filtered release rate (Ci/sec)

The total release rate is then the sum of the two release pathways.

$$R_t(t) = R_u(t) + R_f(t) \tag{4}$$

or

$$R_t(t) = a\,\lambda_{1\ell}\,A_1(t) + b\,\lambda_{1\ell}\,F_1A_1(t) \tag{4a}$$

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

$$IAR(t) = R_u(t) + R_f(t)$$

This yields

$$IAR(t) = \frac{(a\lambda_{1\ell} + b\lambda_{1\ell}F_1)\,A_1(0)}{\lambda_1}\;1 - e^{-\lambda_1 t} \tag{5}$$ 25

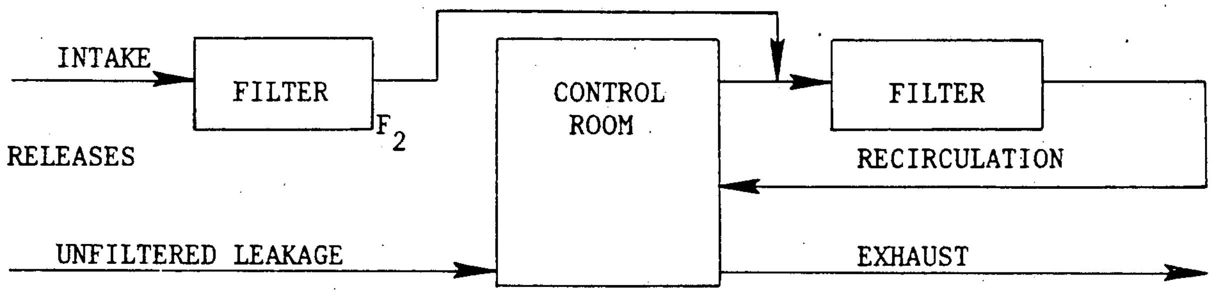
where:

IAR(t) = total integrated activity release at time (t) (Ci)

15B.7 INTEGRATED ACTIVITY IN CONTROL ROOM

The integrated activity in the CR during each time interval is found by multiplying the release by the appropriate χ/Q to give a concentration of the CR intake. This activity is brought into the CR through the filtered intake valves and by unfiltered inleakage and is subjected to the CR ventilation system of recirculation through charcoal filters and exhaust to the atmosphere.

1.312.17



1.312.17 From this, calculate the total integrated activity in the CR during any time interval.

15B.7.1 ACTIVITY RELEASE MODEL FOR CONTROL ROOM

15B.7.1.1 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:

$$\frac{d\bar{A}}{dt} + \bar{C}\,\bar{A} = \bar{S}; \text{ Initial Condition } \bar{A}(t_o) = \bar{A}_o \qquad (6)$$

$$A_1 = \bar{L} \cdot \overline{AI}$$

where:

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

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

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

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)

A_1 = the activity released to the environment over the time period (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.

15B.7.1.2 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:

$$\frac{dA_1}{dt} - L_{21}A_2 = 0 \qquad (7a)$$

$$\frac{dA_2}{dt} + (\lambda_d + \lambda_s + L_{21})\ A_2 = 0 \qquad (7b)$$

$$\frac{dA_3}{dt} - \frac{\chi}{Q}\,(L_u + (1 - f_L)\ L_f)\ L_{21}\ A_2 + (L_f + L_u + f_R R_c + \lambda_d)\ A_3 = 0 \qquad (7c)$$

where:

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

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

$A_3(t)$ = activity in the control room, (Ci)

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

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

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

λ_s = the spray removal constant, (s^{-1})

$L_u = \dfrac{T_u \cdot (.3048)^3}{60}$, (m^3/s)

T_u = unfiltered inleakage into the control room, (ft^3/min)

$L_f = \dfrac{T_f(.3048)^3}{60}$, (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)

$R_c = \dfrac{T_r}{(V_c)(60)}$, (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

The coefficient matrix is:

$$\overline{C} = \begin{bmatrix} 0 & -L_{21} & 0 \\ 0 & (\lambda_d + \lambda_s + L_{21}) & 0 \\ 0 & -\chi/Q(L_u + (1 - f_L)\ L_f)\ L_{21} & +(L_f + L_u + f_R R_c + \lambda_d) \end{bmatrix}$$

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

From the integrated activity, the doses to the operators in the control room can be calculated using the dose models given in section 15B.5.