Appendix H
Containment System Evaluation

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H.1 CONTAINMENT SYSTEM DESCRIPTION

The total containment consists of two systems:

1. The Primary Containment System (see Chapter 5) consists of a steel structure and its associated Engineered Safety Features (ESF) Systems. This system, also referred to as the Reactor Containment Vessel, is low-leakage steel shell, including all its penetrations, designed to confine the radioactive materials that could be released by accidental loss of integrity of the Reactor Coolant System (RCS) boundary. ESF Systems directly associated with the Primary Containment System include the Containment Vessel Internal Spray (Section 6.4), Containment Air Cooling (Section 6.3), and Containment Isolation System (Section 5.3).
2. The Secondary Containment System consists of the Shield Building (Section 5.2), its associated ESF systems, and a Special Ventilation Zone (Section 9.6.5) in the Auxiliary Building. The Shield Building is a medium-leakage concrete structure surrounding the Reactor Containment Vessel and designed to provide:
   - Biological shielding for Design Basis Accident (DBA) conditions;
   - Biological shielding for parts of the RCS during operation;
   - Protection of the Reactor Containment Vessel from low temperatures and other adverse atmospheric conditions, and external missiles;
   - A means for collection and filtration of fission-product leakage from the Reactor Containment Vessel following the DBA. The Shield Building Ventilation System (SBVS) is the ESF used for this function.

The Special Ventilation Zone of the Auxiliary Building confines leakage that could conceivably bypass the Shield Building annulus.

H.2 LEAK PATHS

In this section the objective is to show that the probability for leakage from the primary containment to the Auxiliary Building is small as compared with the probability for leakage to the Shield Building annulus. In order to demonstrate that the leakage through the Containment System does not impose a burden on the Auxiliary Building Ventilation System, the probable paths of leakage were re-examined.

The list of penetrations was arranged into eight groups to permit a detailed examination of the transport path of potential leakage from each group.

1. Group I

   All the leakage through seats from these penetrations goes to the Waste Disposal System, which is a closed minimal leakage system normally maintained in good leak-tight condition because it is continuously handling radioactivity. Leakage from this group of penetrations does not get into the Auxiliary Building except by leakage through valve packing, which is minimal, because of the type of valve used for this service.

2. Group II

   The leakage through seats from this group ultimately enters the volume control tank, which is designed to withstand 75 psig and operates normally as a gas-tight system. The volume control tank would normally remain in a pressurized condition following a loss-of-coolant accident (LOCA) and could be vented to the Waste Gas System or back to containment, if necessary. Instrument lines are included in this group although they, as self-closed lines, do not vent to the volume control tank.

3. Group III

   The leakage through this group of penetrations is sealed by pressure, which is normally higher than containment pressure.

4. Group IV

   The leakage through the seats of this group will enter the Shield Building annulus by special design of the isolation system.

   With respect to the Containment Purge and Ventilation System: Under accident conditions the two isolation valves inside and outside the Reactor Containment Vessel and the isolation valves outside the Shield Building will be closed, as indicated in Figure 5.3-1. Any potential leakage through seats will enter the Shield Building annulus through the opening that is provided in the line between the second isolation valve and the isolation valve outside the building.

5. Group V

   Leakage through seats from this group of items is stopped by a water seal.

   a. With respect to the fuel transfer tube: This tube is closed by a blind flange with a testable double gasket located on the containment side of the tube. This gasket provides containment integrity. A gate valve is also provided outside containment to isolate the refueling cavity from the spent fuel pool.

Although not required for containment integrity, when the canal is flooded there is approximately 38 feet of water, which would also act as an additional barrier. In the flooded condition there would be no potential for leakage when containment pressure is less than approximately 16 psig. Containment pressure would be reduced to this level within one hour after a LOCA. Any leakage occurring during the peak pressure would pass through the water resulting in iodine being scrubbed from the leakage prior to its release to the Auxiliary Building.

b. With respect to Main Steam, Feedwater and Steam Generator Blowdown Systems: A pressurized water seal in the secondary side of the steam generators will be maintained by the auxiliary feedwater pumps so that these isolation systems will not leak following a LOCA.

c. With respect to the Component Cooling System: These isolation valves are covered by a water seal established by the level of water in the Component Cooling System surge tank or by the discharge head of the component cooling pump.

6. Group VI

Leakage through seats of this group of items could bypass the Shield Building annulus and enter the Auxiliary Building.

Any leakage from this group is expected to be very small since the valves are small and are normally maintained in a leak-tight condition.

The transport path of any potential leakage will be through the Sampling System and the sampling room.

7. Group VII

These systems are required to operate following a LOCA. The seals and packing of the equipment associated with those systems recirculating containment water comply with the low-leakage requirements defined in Section 6.2.3. Leakage through the seals and packing will enter the Auxiliary Building Zone SV. The radiological consequences from this leakage are discussed in Section 6.2.5.

8. Group VIII

   Leakage through seat is into the Shield Building.

   Table 5.2-3 includes all containment penetrations. A further breakdown was made of the above information identifying the potential leak paths and where they terminate. Table H.2-1 lists the potential leakage paths to the Shield Building from Containment; Table H.2-2 lists the through-line leakage that bypasses the Shield Building but terminates in the Auxiliary Building Special Ventilation Zone (ABSVZ); Table H.2-3 lists the through-line leakage that bypasses both the Shield Building and the ABSVZ. The potential bypass leakage based on a comparison of nominal seal or seat diameters can be obtained from Table H.2-2 and Table H.2-3. The total from these tables represents only 8 percent of the total, which is lower than the fractions used in the LOCA dose calculations. And since part of this leakage would be treated by the Auxiliary Building Special Ventilation System (ABSVS), the effect on dose will be minimal. The sensitivity of the bypass dose is shown in Section H.4.

Leak Path Testing

Since the offsite dose consequence of where containment leakage is treated is of significance in this dual containment concept, provisions are made to determine, by test, how much containment leakage could bypass the annulus through various paths.

The Type B and C tests (10 CFR 50, Appendix J terminology) identify leakage through individual leakage paths. Vents, drains, and isolation valving are provided to allow testing of the potential leakage paths past valve seats, resilient seals and double wall expansion bellows. Valves are tested by individually pressurizing or by pressurizing between valves and the leakage computed by Appendix J test methods. The volume between double seals or bellows is pressurized, and the leakage detected, or the leakage rate computed by Appendix J test methods.

Table H.2-1 is considered historical and should not be revised or updated. This information was used as input in the evaluation in Section H-4, sensitivity of the bypass dose.

Table H.2-1
Leakage from Containment Vessel to Shield Building Annulus

Penetration	Type of Seal	Fluid on Outside of Seal	Diameter of Seal-In.	Group
1. Equipment Hatch	R.G.	G	252	VIII
2. Personnel Air Lock	R.G.	G	84	VIII
3. Emergency Air Lock	R.G.	G	30	VIII
4. Ventilation Valves	R.G.	G	72	IV
5. Containment Vessel Pressure Test	R.G.	G	10	IV
6. Vacuum Breakers	R.G.	G	40	VIII
7. Electrical	–	G	576	–
			1064	

Note: R.G. = Resilient Gasket
G = Gas

Table H.2-2 is considered historical and should not be revised or updated. This information was used as input in the evaluation in Section H-4, sensitivity of the bypass dose.

Table H.2-2
Through-Line Leakage That Bypasses Annulus and Terminates in ABSVZ

	Penetration Title - No.	Leak Path Source: Inside Containment	Leak Path Source: Outside Containment	Type of Seat In. Diameter	Testable (see Note)
Group I	RC Drain Tank Gas Sample - 21		MG(R)503, 504 RSV-T+RSV-T	MMS - 0.375	Yes
	Press Rlf. Tank Gas Sample - 1		MG(R)512, 513 RSV-T+RSV-T	MMS - 0.375	Yes
	RC Drain Tank Pumps Disch. - 5		RC507, RC508 RSV-T+RSV-T	RG - 3.00	Yes
	Cont. Sump “A” Disch. - 26		MD(R)134, 135 RSV-T+RSV-T	RG - 3.00	Yes
Group VI	Press. Steam Sample Line - 15	RC402 RSV	CV-31267 RSV-T	MMS - 0.375	Yes
	Press. Liquid Sample Line - 15	RC412 RSV	CV-31268 RSV-T	MMS - 0.375	Yes
	Hot Leg Loop B Sample Line - 15	RC422 RSV	CV-31269 RSV-T	MMS - 0.375	Yes
	SI Accum. Test Line - 35	SI201A, B SI202A, B RSV	SI 204 MV	MMS - 0.750	Yes
	Cont. Air Sample Line - 22	AS33 CHK	AS32 RSV	RG - 1.00	Yes
	Cont. Air Sample Line - 23		AS1, AS2 RSV, RSV	RG - 1.00	Yes
				Total MMS = 2.625 in RG = 8.00 in	

Note: In addition to an integrated leakage test of the entire containment, additional tests will be performed to identify leakage through individual leakage paths. Vents, drains, and isolation valves are provided to allow testing of the potential leakage paths past valve seats and resilient seals.
Valves will be tested by individually pressurizing or by pressurizing between valves and the leakage computed.

Table H.2-3 is considered historical and should not be revised or updated. This information was used as input in the evaluation in Section H-4, sensitivity of the bypass dose.

Table H.2-3
Through-Line Leakage That Bypasses Both Annulus and ABSVZ

		Leak Path Source			
	Penetration Title - No.	Inside Containment	Outside Containment	Type of Seat, In. Diameter	Testable (see Note)
Group I	Primary System Vent Header - 4		MG(R)509, 510 RSV-T+RSV-T	RG - 1.00	Yes
	Instrumentation - 3 (2 lines)	–	MV	MMS - 0.375	Yes
	Instrumentation - 27N (3 lines)	–	MV	MMS - 0.375	Yes
Group II	Instrumentation - 27NE (2 lines)	–	MV	MMS - 0.375	Yes
	Instrumentation - 36N (3 lines)	–	MV	MMS - 0.375	Yes
	Station Air - 19	SA472 MV	SA471 MV	MMS - 2.00	Yes
	Service Water - 24	SW6011, 6012 CHK, MV	SW6010 MV	MMS - 2.00	Yes
Group III	N_2 Supply to Press Rlf. Tank - 2	NG304 CHK	NG303, NG302 MV, RSV-T	RG - 0.750	Yes
	Instrument Air - 20	IA103 CHK	IA102, CV-31309 CHK, RSV	MMS-1.00	Yes
	Fuel Transfer Tube - 18	FLG	FPC1-1 MV	RG - 20.00	Yes
Group V	Press. Rlf. Tank MU Water Line - 45	MU1011, 1012 CHK+RSV	MU1010-1 RSV-T	MMS - 2.00	Yes
Group VI	N_2 Supply to Accum. - 31	NG107-1 RSV	NG107 RSV-T	MMS - 1.00	Yes

Table H.2-3 is considered historical and should not be revised or updated. This information was used as input in the evaluation in Section H-4, sensitivity of the bypass dose.

Table H.2-3
Through-Line Leakage That Bypasses Both Annulus and ABSVZ

	Leak Path Source			
Penetration Title - No.	Inside Containment	Outside Containment	Type of Seat, In. Diameter	Testable (see Note)
			Total MMS = 11.75 In. RG = 21.75 In.	

Note: In addition to an integrated leakage test of the entire containment, additional tests will be performed to identify leakage through individual leakage paths. Vents, drains, and isolation valves are provided to allow testing of the potential leakage paths past valve seats and resilient seals.

Valves will be tested by individually pressurizing or by pressurizing between valves and the leakage computed.

Nomenclature for Tables H.2-2 and H.2-3

MMS - metal-to-metal disc and seat

RG - resilient gasket

RSV - remotely operated stop valve

RSV-T - remotely operated stop valve, trips on S signal

CHK - check valve

MV - manual valve

H.3 SHIELD BUILDING VENTILATION SYSTEM ANALYSIS

The objective of this section is to show that the performance of the modified SBVS described in Section 5.5 can be predicted with the use of the computer program (New Shield Building Ventilation System (NSBVS) (Reference 2.) and parameters well defined from published experimental data. This section also provides the description of the NSBVS analytical model in which the acceptance criteria (II) (1) of Standard Review Plan 6.2.3 are incorporated.

H.3.1 Reactor Containment Vessel Shell Temperature Evaluation

The freestanding Containment Vessel was designed to accommodate the maximum internal pressure that would result from a DBA.

The Containment Vessel design providing the capability for absorbing energy additions without exceeding the containment design pressure following DBAs is discussed in detail in Chapter 14.

The heat transfer coefficient of the Reactor Containment Vessel internal surface was based on the work of Tagami (Reference 1.). From this work it was determined that the value of the heat transfer coefficient increases parabolically to a peak value at the end of blowdown and then decreases exponentially to a stagnant heat transfer coefficient which is a function of steam-to-air weight ratio.

The shell temperature evaluation (which provides the input for the SBVS analysis) used a higher heat transfer coefficient than that of Tagami (25 percent higher). This results in a conservatively higher shell temperature, as shown in Figure H.3-1. This transient is then used for the SBVS analysis, which incorporates additional conservatism.

H.3.2 Shield Building Ventilation System Analysis

The safety analysis is based on conservatively chosen assumptions regarding the sequence of events relating to activity release, attainment of vacuum in the Shield Building annulus, the effectiveness of filtering, the leak rate of the Containment Vessel as a function of time, and the mixing factor of fission products within the annulus volume.

The initial conditions in the Shield Building annulus are given in Table H.3-1.

H.3.3 Shield Building Ventilation System - Mathematical Modes

The basic input for this model is the Containment Vessel pressure temperature transient. The mathematical model involves the following three transient phenomena, which interact with each other:

1. Convective heat transfer from the steel shell to the air in the annulus, and from the air to the concrete wall of the Shield Building, and radiant heat transfer from the steel shell to concrete.

2. Pressurization of the air in the annulus corresponding to the air temperature and air mass remaining in the annulus.
3. The flow of air through the network of ducts, fans, dampers and the charcoal filter system, along with the inleakage of air through the walls of the Shield Building (see Figure H.3-2 and Figure H.3-3).

H.3.4 Calculational Detail

1. Initialization of Annulus Conditions

   The initial steady state air mass in the annulus ($M_{a,o}$) is calculated from:

$$M_{a,o} = 2.7017 \frac{P_{a,o} V_o}{T_{a,o}}, lbm \qquad \text{(H.3-1)}$$

where:

$P_{a,o}$ = initial steady state annulus pressure, psia

$T_{a,o}$ = initial steady state annulus temperature, °R

V_o = initial annulus free volume, ft^3

The initial energy ($U_{a,o}$) associated with the air is:

$$U_{a,o} = M_{a,o} c_v T_{a,o}, Btu \qquad \text{(H.3-2)}$$

where:

c_v = specific heat of air at constant volume, Btu/lbm °F

2. Mass and Energy Balance

   NSBVS problem execution consists of a series of stepwise time advancements of user-designated time step sizes. The annulus air conditions at the beginning of a time step is known and the conditions at the end of the time step is calculated.

   The annulus volume decrease due to DBA LOCA containment pressure increase is considered instantaneous and that due to containment vessel thermal expansion is time dependent based on its temperature increase shown in USAR Figure H.3-1.

The annulus air (M_a) at the end of a time step is determined from:

$$M_a = M_{a,o} + (\dot{m}_i - \dot{m}_f)\Delta\theta,\ lbm \tag{H.3-3}$$

where:

$\dot{m}_i$ = time dependent in-leakage rate, lbm/min

$\dot{m}_f$ = annulus air discharged to the surroundings through fan, lbm/min

$\Delta\theta$ = time step size, min

The annulus air internal energy U_a the end of the time step is determined from:

$$U_a = U_{a,o} + \left(\dot{m}_i \times c_\rho \times T_\infty - \dot{m}_f \times c_\rho \times T_{a,o} + \frac{\dot{q}}{60}\right)\Delta\theta\ Btu \tag{H.3-4}$$

where:

c_ρ = specific heat of air at constant pressure, Btu/lbm °F

T_∞ = surrounding air temperature, °R

$\dot{q}$ = convective heat load to the annulus air, Btu/hr

The annulus air temperature (t_a) at the end of the time step is calculated from:

$$t_a = \frac{U_a}{M_a c_{v,a}} - 460,\ °F \tag{H.3-5}$$

And the annulus air density (ρ_a) and pressure (P_a) are:

$$\rho_a = \frac{M_a}{V},\ lbm/ft^3 \tag{H.3-6}$$

$$P_a = 0.3701 \times \rho_a(t_a + 460),\ psia \tag{H.3-7}$$

where:

V = annulus volume corrected to account for the containment pressure increase and vessel thermal expansion, ft^3

3. Heat Transfer Coefficients

The heat transfer rate from the shell to the air was evaluated with consideration for both natural convection heat transfer and heat transfer by radiation. The convective heat transfer was evaluated using the equation for natural convective heat transfer recommended by many investigators.

$$N_{Nu} = c[N_{Gr}N_{Pr}]^n \tag{H.3-8}$$

where, in the turbulent region,

c = 0.14	N_{Gr} = Grashof Number
n = 1/3	N_{Nu} = Nusselt Number
	N_{Pr} = Prandtl Number

Appropriate substitution of the physical parameters produced the following heat transfer equations:

For vertical walls (external surface)

$$h_c = 0.196(t)^{1/3} \tag{H.3-9}$$

For the Shield Building dome (internal surface)

$$h_c = 0.224(t)^{1/3} \tag{H.3-10}$$

For the Containment Vessel hemispherical head (external surface)

$$h_c = 0.205(t)^{1/3} \tag{H.3-11}$$

The above natural convection heat transfer coefficients are temperature (therefore time) dependent variables in the computer model.

The radiant heat transfer coefficient (h_r) with the consideration of shape factor was calculated from:

$$h_r = \frac{0.1713\left[\left(\frac{T_c}{100}\right)^4 - \left(\frac{T_{SB}}{100}\right)^4\right]}{\left[\frac{1}{\varepsilon_c} + \frac{A_c}{A_{SB}}\left(\frac{1}{\varepsilon_{SB}} - 1\right)\right](T_c - T_{SB})} \tag{H.3-12}$$

where:

T_c = reactor containment vessel outside surface temperature, °R

T_{SB} = shield building inside surface temperature, °R

ε_c, ε_{SB} = emissivity of the containment vessel and of the shield building at low temperature

A_c, A_{SB} = surface area of the containment vessel and of the shield building, ft

Due to the low temperatures involved in the analysis, the radiation contribution is very small in the total heat transfer interactions. Nevertheless, its effect is included in all of the transient analyses.

4. Heat Addition to the Annulus Air

The simultaneous heat addition (q) from the surfaces of the steel and shield building walls to the annulus air is calculated from:

$$\dot{q} = h_{c,w}A_{c,w}(t_{c,w} - t_a) + h_{c,d}A_{c,d}(t_{c,d} - t_a) + h_{SB,w}A_{SB,w}(t_{SB,w} - t_a) + h_{SB,d}A_{SB,d}(t_{SB,d} - t_a),\ Btu/hr \qquad \text{(H.3-13)}$$

where:

h = convective heat transfer coefficient described in 3. above, Btu/hr-ft^2-°F

A = heat transfer area, ft^2

t = temperature, °F

subscripts: c = containment shell

SB = shield building

w = vertical wall portion

d = dome portion

a = annulus

5. Air In-leakage through the Shield Building Walls

The modified design basis in-leakage rate shown in Figure 5.2-14 was coded in the computer program NSBVS as:

$$\dot{m}_i = (a_1 - a_2 \times P_a)\frac{\rho_\infty^{1/2}}{\rho_s},\ lbm/min \qquad \text{(H.3-14)}$$

0" WC > P_a > - 0.5" WC

and

$$\dot{m}_i = (b_1 - b_2 \times P_a)\frac{\rho_\infty^{1/2}}{\rho_s},\ lbm/min \qquad \text{(H.3-15)}$$

$P_a < 0.5"$ WC

where:

a_1, a_2, b_1, b_2 are the constants correlated from Figure 5.2-14

$a_1 = 152654$

$a_2 = 10384.65$

$b_1 = 12384.78$

$b_2 = 830.767$

ρ_∞, ρ_s = air density corresponding to the surrounding air temperature T_∞ and T_o the standard air temperature at 70°F, lbm/ft^3

6. Flow of Air through the Shield Building Ventilation System

The SBVS flow resistance and fan flow characteristics were correlated from the SBVS Test Procedure 24-1 test results, and corrected to reflect the post LOCA annulus temperature and pressure. Since analysis results have indicated that the post LOCA annulus pressure is between +3.6 inch WC and –1.0 inch WC and annulus temperature below 170°F, the relationship between the fan discharge flow and the annulus pressure can be established with a linear equation shown below.

$$\dot{m}_f = \rho_a(c_1 P_a - c_2),\ lbm/min \qquad \text{(H.3-16)}$$

where c_1 and c_2 are the constants derived from the flow resistance and fan characteristic curve,

$c_1 = 2505.7$

$c_2 = 32135.34$

P_a is the annulus air pressure in psia and ρ_a is the corresponding air density in lbm/ft^3.

H.3.5 Computational Results

The computational results for the design basis case are shown in Figure H.3-4, Figure H.3-5 and Figure H.3-6. The following are the four phases of computations for the entire transient following the DBA LOCA.

1. The post DBA LOCA containment pressure reaches its peak value in approximately 20 seconds and results in decreasing the annulus volume by 2450 ft^3 because of shell expansion. It is conservatively assumed that this displacement is instantaneous and, as a result, the annulus pressure increases to 14.797 psia or 2.684 inches WC.
2. Following the instantaneous compression of the annulus air, the annulus pressure continues to increase from 2.684 inches WC to a maximum of 3.6 inches WC at 0.6 minutes (fan starting time). This is due to the combined effects of containment shell thermal expansion and heat contribution from containment shell to the annulus air. It was assumed that the initial air mass in the annulus remains unchanged up to fan start.
3. When the discharge fan is energized at 0.6 minutes following the accident, the annulus air internal energy at the end of a time step is computed from Equation H.3-4 where the energy addition due to convective heat transferred (Equation H.3-13) and energy subtraction due to fan discharge (Equation H.3-16) are first calculated. With internal energy known the annulus air temperature and pressure can be calculated from Equation H.3-5 and Equation H.3-6. The calculations are repetitive until the annulus pressure reaches the end of drawdown point at –1.0 inch WC. At –1.0 inch WC the recirculation shut-off damper will open and the control dampers will receive permission to modulate. With one SBVS operating, the annulus pressure reaches –1.0 inch WC in 8.9 minutes after the DBA. No in-leakage or out-leakage is assumed while the annulus is above atmospheric pressure and the in-leakage is calculated using Equation H.3-14 or Equation H.3-15 when the annulus is sub-atmospheric. It is of particular interest to note that the duration for which the annulus is above atmospheric pressure is 3.2 minutes.
4. When the annulus pressure is at the set pressure of the controller (also –1.0 inch WC), the control dampers will then be automatically positioned so as to maintain this annulus set pressure by allowing a portion of the fan discharge to be exhausted to the atmosphere. The NSBVS code output does indicate the flow to the atmosphere in cfm. For the design basis case, the discharge flow to the atmosphere is 4293 cfm at the beginning of the modulation and decreases to 2892 cfm in 22 minutes after the DBA.

H.3.6 Parameter Study

Further analysis beyond the design basis was directed to the investigation of the sensitivity of the performance of the system with respect to the in-leakage air temperature and in-leakage rate.

With the in-leakage air at 104°F, the annulus pressure and temperature transient curves are very close to those with the design basis case using 70°F surrounding air.

With 70 percent of the design basis in-leakage rate, the annulus pressure reaches –1.0 inch WC in 6.9 minutes. Since this in-leakage rate is approximately equal to the actually measured in-leakage rate, a 6.9 minute duration for recirculation to start is more realistic as compared with the 8.9 minutes for the design basis case. The computational results for this case are shown in Figure H.3-7 and Figure H.3-8.

H.3.7 Conclusions

It is concluded from these analyses that the SBVS, as modified, is capable of performing its intended function over a credible range of system parameters.

H.3 REFERENCES

1. Tagama, Tasaki, “Interim Report on Safety Assessments and Facilities Establishment Project in Japan for Period Ending June 1965 (No. 1)”
2. Fluor Engineers, Inc., Power Division, Calculation No. 611.1170.M1, Revision 0, September 2, 1988, “Annulus Pressure Transient Following a LOCA (use of the New Shield Building Ventilation System Computer Program (NSBVS))”

Table H.3-1
Calculation Bases for Shield Building Post-DBA Pressure and Temperature Transient

	Input		Remark
Assumption	Failure of both trains of SBVS		Incredible
	Annulus pressure at the beginning of fan start at 0.6 min	14.83 psia	Includes 0.097 psia due to shell expansion
Initial Conditions	Ambient pressure	14.7 psia	
	Ambient temperature	120°F	
	Annulus temperature	120°F	
	Concrete temperature	120°F	
Properties	Concrete density	144 lb/ft^3	
	Concrete heat capacity	0.2 Btu/lb°F	
	Concrete conductivity	1.0 Btu/hr-ft°F	

Table H.3-2
Summary of Parameter Study

Figure	No. of SBVS	Heat Transfer Coefficient (See Note 1 Below)	Shield Bldg. Leak Rate	Parameter Shown on Figure
H.3-1	NA	25% over Tagami (See Note 2)	NA	Reactor Containment Vessel Dome and Cylindrical Wall Outside Surface Temperature
H.3-2 & H.3-3	NA	NA	NA	Flow Paths for the SBVS
H.3-4	1	Normal and + 300%	Normal	Annulus Air Temperature
H.3-5 & H.3-6	2	Normal	Normal	Pressure and Flow
H.3-7 & H.3-8	1	-33%	Normal	Pressure and Flow
H.3-9 & H.3-10	1	+25%	Normal	Pressure and Flow
H.3-11 & H.3-12	1	Normal	Variable 10% to 100%	Pressure and Flow
	1	Normal	Normal	Pressure and Flow Assuming Concrete as an Adiabatic
H3.-13 & H.3-14	1	Normal	Normal	Wall

Note 1: Heat Transfer Coefficient variation was made on the external surface of the Reactor Containment Vessel and involves varying the natural convection heat transfer coefficient from the steel shell to air in the annulus.

Note 2: The temperature of the Reactor Containment Vessel shell is obtained from the containment vessel pressure-temperature transient using a heat transfer coefficient to the containment internal surface that is 25 percent higher than that obtained from Tagami's work. This temperature is then used for all transient studies.

Figure H.3-1 Containment Dome and Cylindrical Wall Outside Surface Temperature Transient

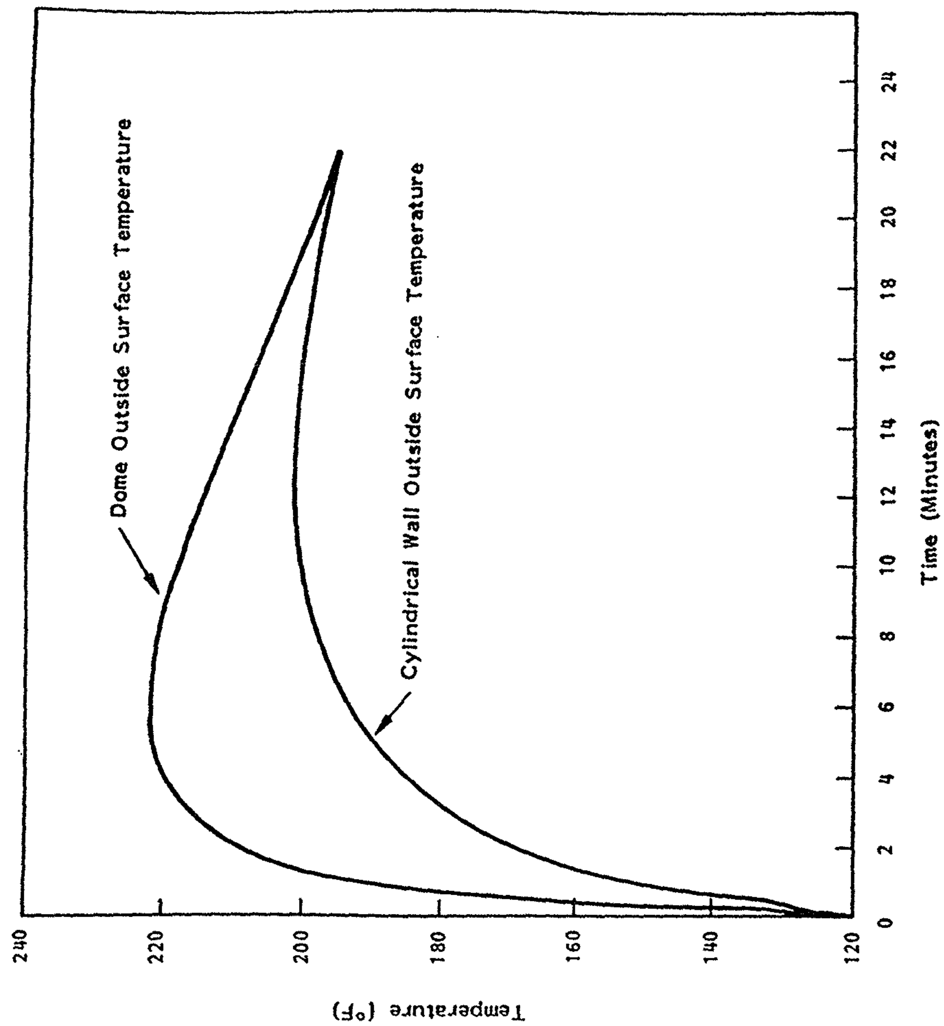


Figure H.3-2 Configuration Without Recirculation

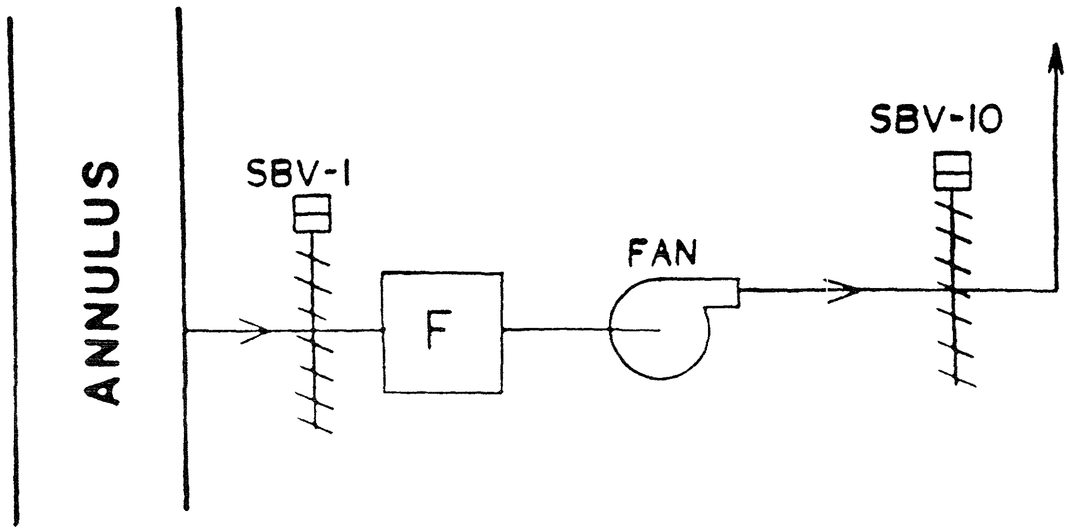


Figure H.3-3 Configuration With Recirculation

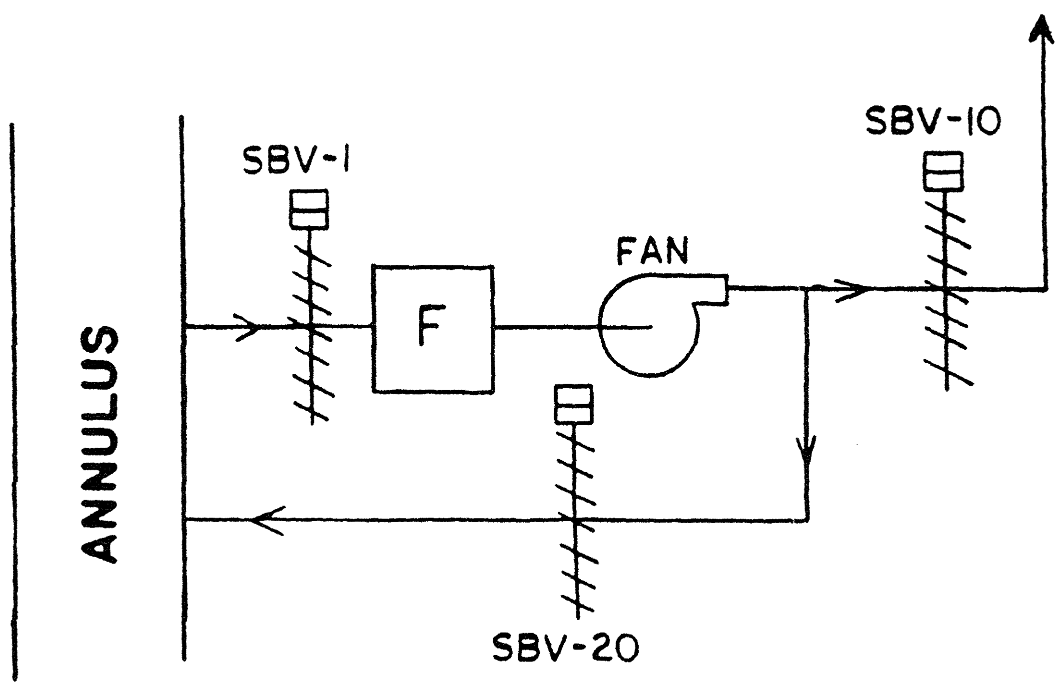


Figure H.3-4 Annulus Air Temperature

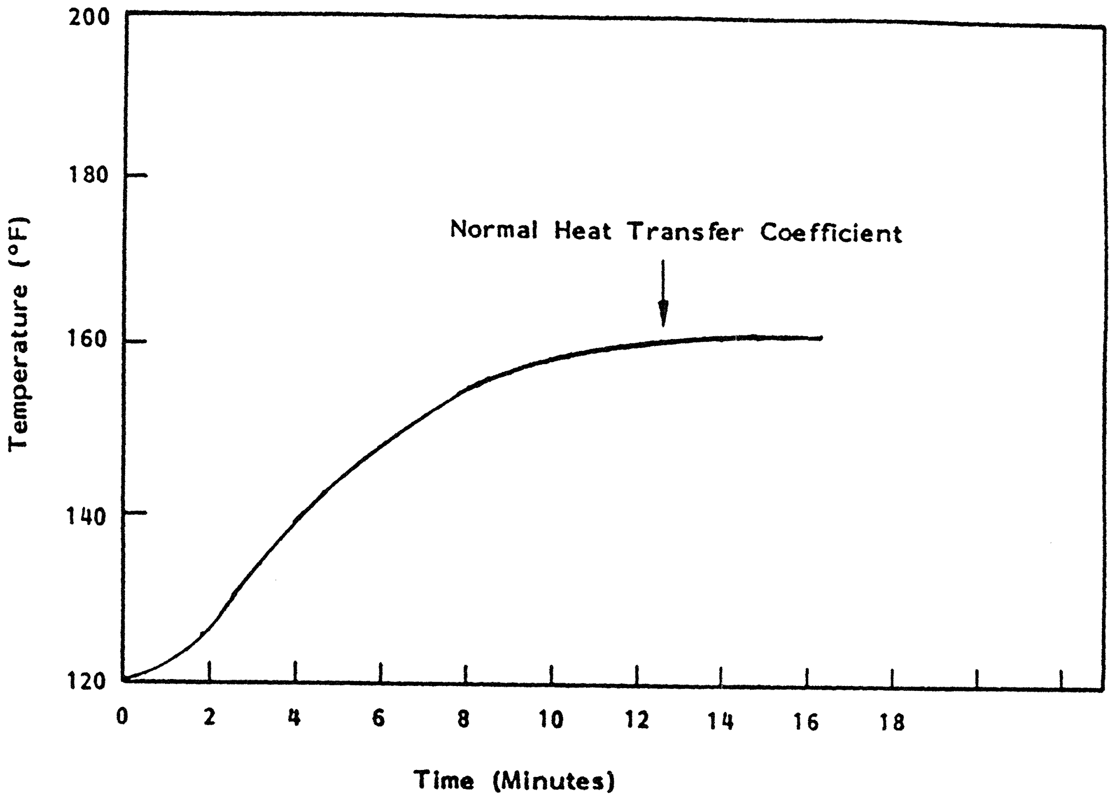


Figure H.3-5 Annulus Pressure - One SBVS Operating

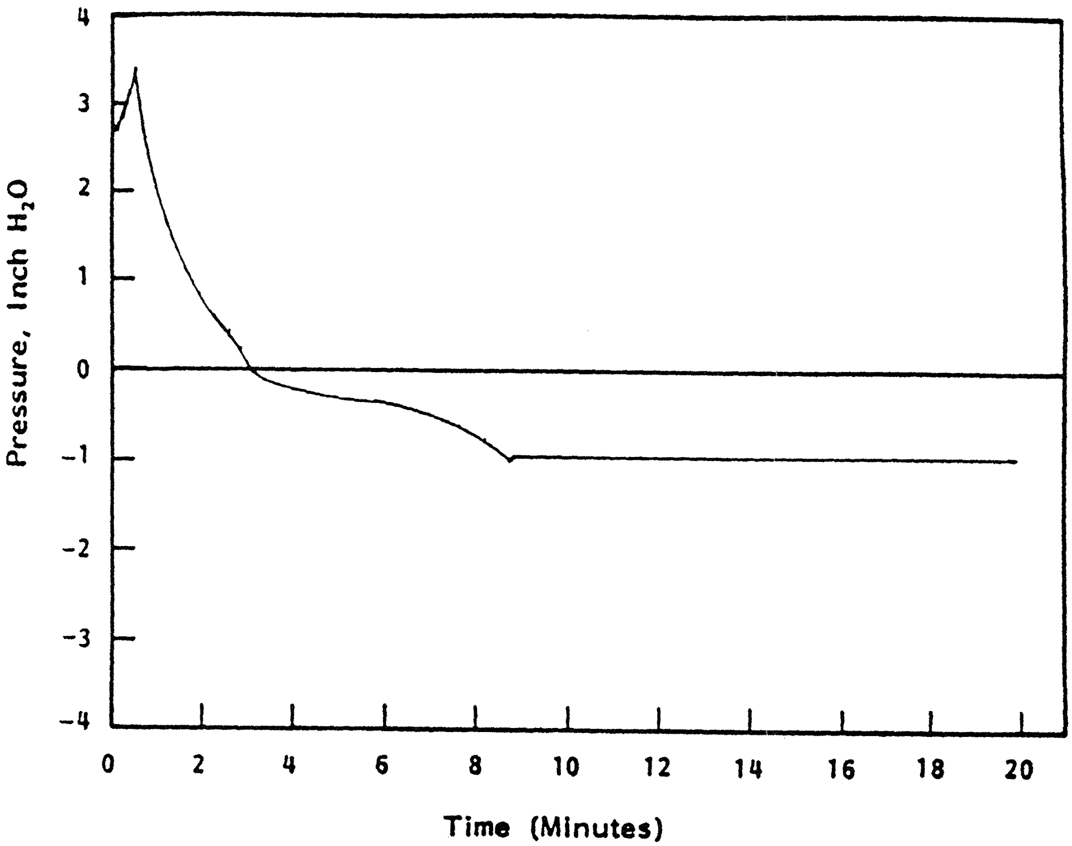


Figure H.3-6 Flow Out of SBVS - One SBVS Operating

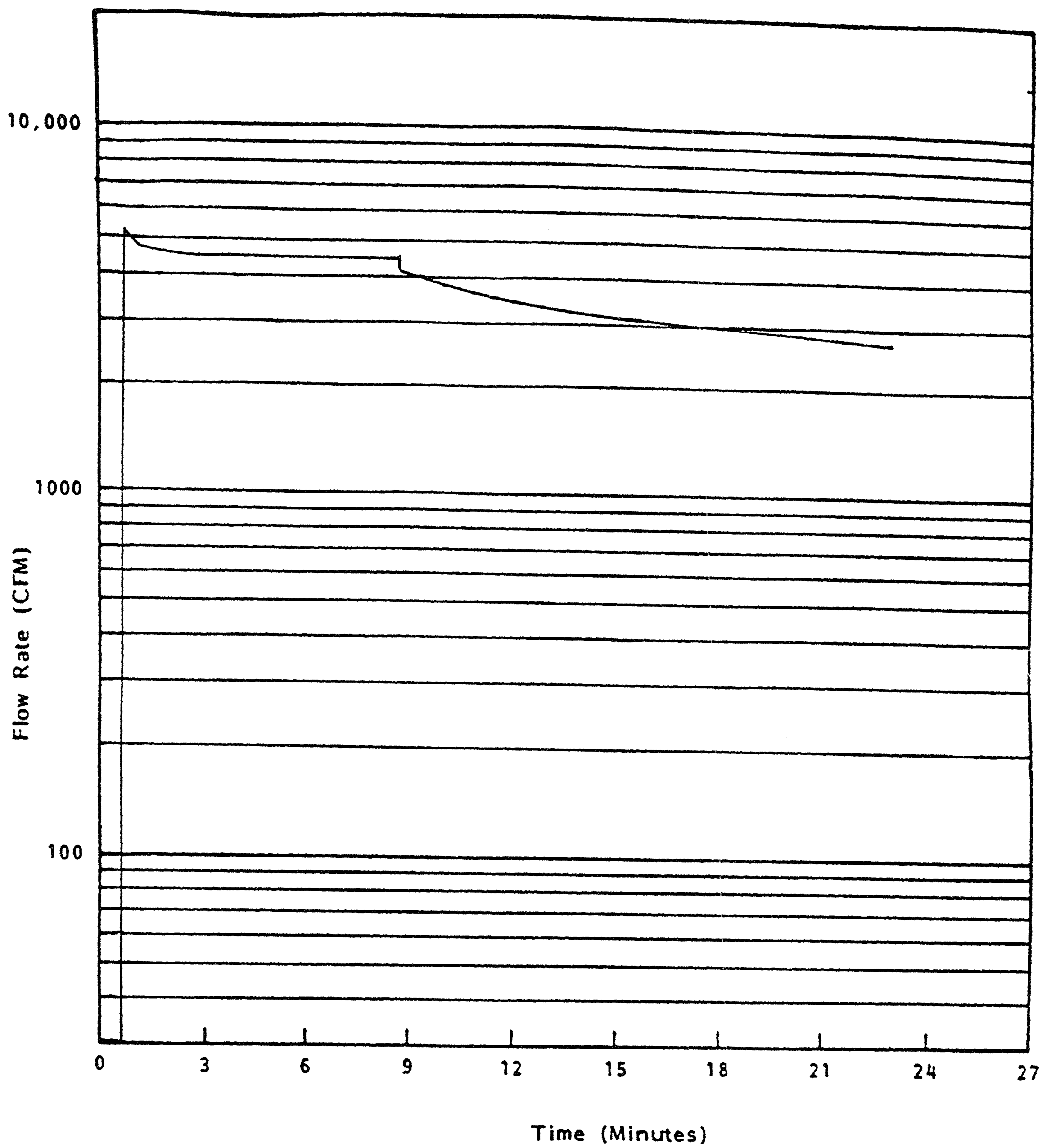


Figure H.3-7 Annulus Pressure - 70% Design Basis Inleakage

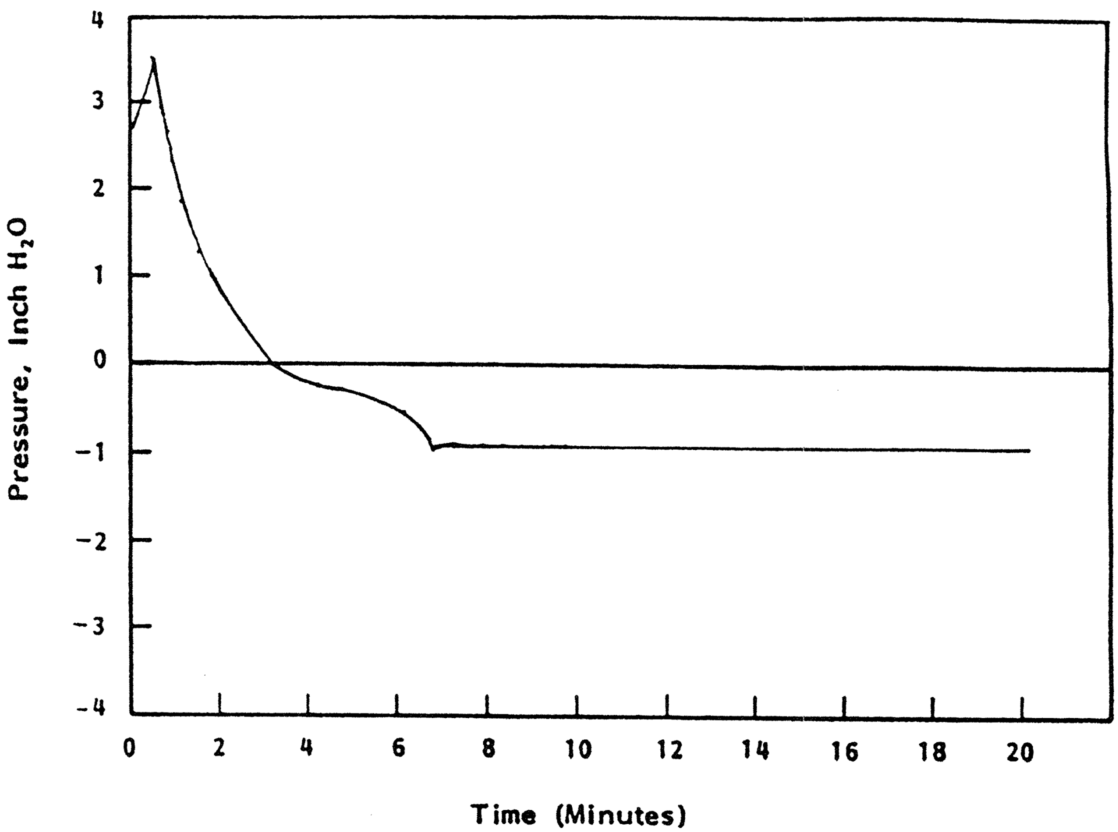
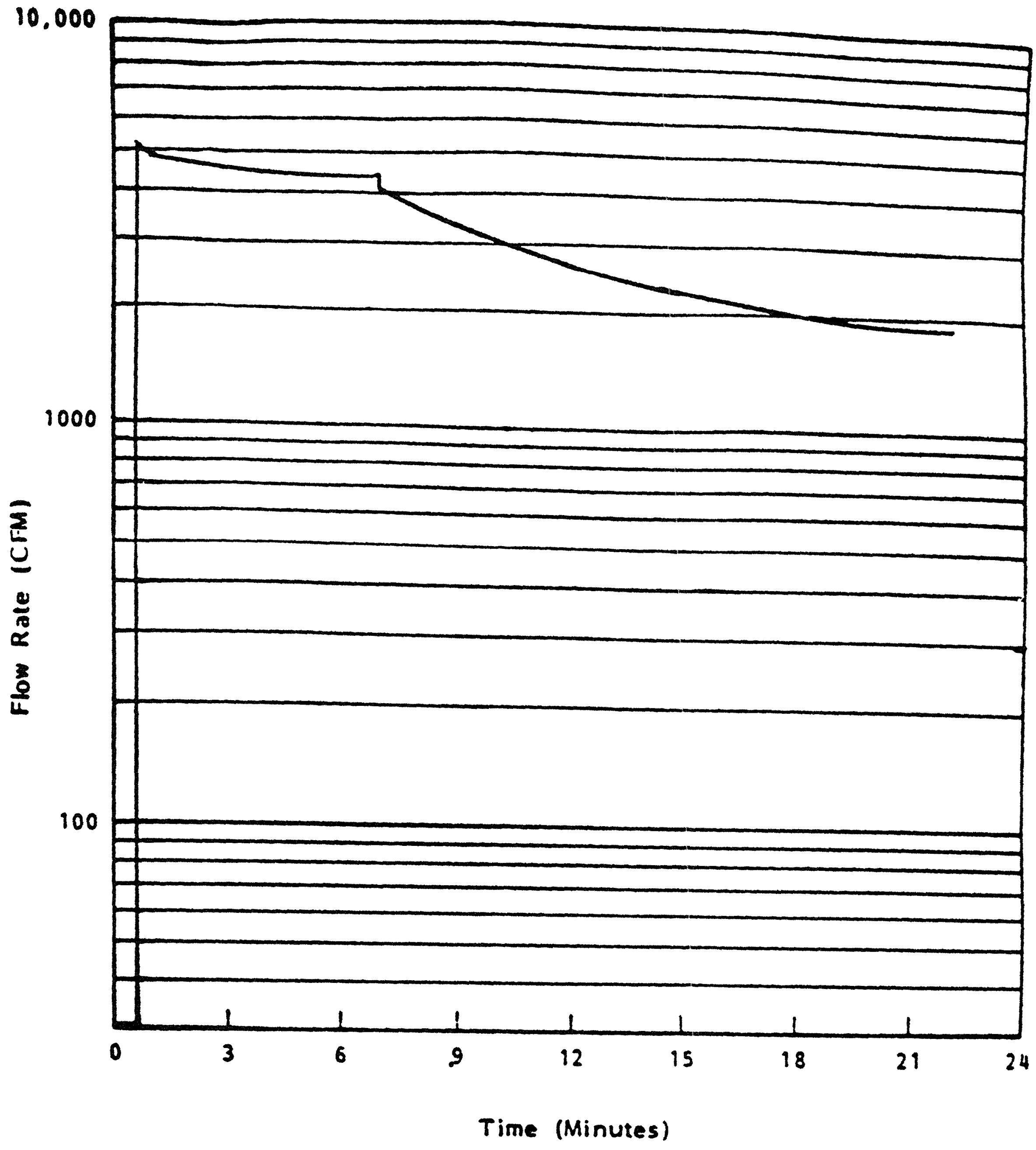


Figure H.3-8 Flow Out of SBVS - 70% Design Basis In-Leakage



H.4 EVALUATION OF DOSES AND DOSE REDUCTION FACTORS

NOTE: The information presented in this section was developed in response to AEC Question No. 14.9, regarding KNPP's dual containment design. References in this section pertain to those found in the FSAR.

The objectives of this section are:

1. To compare in detail the results of dose calculations for the reference basis and for specific bases of evaluation suggested by the Commission.
2. To demonstrate the factors of dose reduction implicit in the dose calculations for the dual containment and the effects of mixing assumptions on these factors, and to assess the significance of these assumptions with regard to the total calculated dose.
3. To present analysis of mixing effects to justify design assumptions, and to define the relevance and feasibility of possible mixing tests.
4. To propose certain minimum factors of dose reduction for purposes of evaluation.

H.4.1 Comparison of Dose Calculations

A detailed comparison of the results of thyroid and whole-body dose calculations is presented in Table H.4-1 and Table H.4-2 for the case of total containment leakage rate normalized to an initial 1% per day, followed by 0.5% per day beyond 24 hours.

The first column in each table corresponds to the reference case described in Chapter 14, based on 95% filter efficiency and full mixing in half the annulus volume. An additional dose is assumed to result from 10% bypass of the Shield Building through the filters of the Special Ventilation Zone of the Auxiliary Building, plus 1% unfiltered bypass directly to the atmosphere. These bypass leakage values are regarded as conservative upper limits, and no credit is taken for mixing in the Auxiliary Building volume, although substantial reduction in this component of the 2-hour dose would be expected as a result of the mixing holdup and deferred release of activity.

Column 2 in both tables is the same reference case adjusted for 90% filter efficiency.

Column 3 is the AEC suggested basis of evaluation wherein 70% of the containment leakage is arbitrarily assumed to be transported directly through the filters of either the Shield Building or the Special Ventilation Zone. In this case, it is again assumed that 10% filtered release and 1% unfiltered release bypass the Shield Building, and that 59%, the remainder of the suggested 70%, is transported directly to the filters of the Shield Building. The remaining 30% is assumed to have available half the annulus capacitance, as in the second column.

The 59% component is assumed to experience only direct filter reduction for the first 20 minutes but the effects of recirculation are included beyond this time, still with no mixing or dilution on the first pass to the filter. As will be shown subsequently, the large advantage factors associated with recirculation are, at least for thyroid doses, largely independent of mixing in the first or subsequent passes, so there is no reason to neglect this advantage under the suggested basis of evaluation.

The last column in each table corresponds to an equivalent single containment with all halogens released through a 90% filter, except during the first 4.5 minutes associated with positive annulus pressure, during which time it is assumed that all leakage bypasses the filter. This column represents the theoretical dose potential which, as the comparison demonstrates, can be greatly reduced by the effectiveness of the dual containment.

To show the potential capability of the dual containment concept, the initial dose analysis presented in Section 14.3.5 used a containment vessel leak rate of 2.5% per day. The analysis, presented in this Appendix was based on a normalized 1% per day leak rate to provide a convenient means for examining the dual containment system for different leak rates and bypass leakage fractions.

It has been recognized that the quality of Containment Vessel and penetration seals used in the construction of this containment can permit readily meeting a 0.5% leakage rate. Further, since the issuance of Appendix J, there is no benefit in terms of extended time intervals between Containment Vessel integrated test periods for a system with substantial margin between actual leakage rate and allowable leakage rate. Our Technical Specifications use the 0.5% per day allowable leakage.

H.4.2 Simplified Analysis of Dose Reduction Factors Associated With Dual Containment

For purposes of recognizing and evaluating specific reduction factors that are implicit in the calculation of the dual containment performance, it is useful to consider simplified analyses that neglect decay and containment depletion, and which also neglect certain aspects of mixing and dilution where this can demonstrate the significance of the assumptions applied with regard to mixing.

The relevant factors are conveniently considered in terms of the dose intervals identified in Table H.4-1 and Table H.4-2 for thyroid and whole-body doses. The factors considered are the reductions applicable to the potential doses for each interval as listed in the last column of each table.

a. Initial Unfiltered Dose from Shield Building Outleakage

The reference calculation for the assumed initial 4.5 minute period of positive pressure period assumes that mixing occurs, with half the capacitance of the annulus volume available. The equations for the annulus activity, A_2, and the activity released to the environment during this period, A_3, can be simplified by neglecting decay and containment depletion, or by expanding the exponential functions in the expressions on Section 14.3.9 subsection titled, “Analysis of Venting Through Shield Building Annulus,” and retaining only the first terms of the expansion.

$$A_2 = L_1 A_{10} t$$

$$A_3 = L_{D_o} \int^t A_2 dt = L_D L_1 A_{10} \frac{t^2}{2} = L_1 A_{10} t \times \frac{L_D t}{2}$$

The first term in A_3 is the leakage into the annulus during the assumed 4.5 minutes which, for L_1 = 0.0089/day (0.01/day total leakage), represents a potential thyroid dose of 63 rem. This dose potential varies with time at positive pressure, while the calculated attenuated dose varies as time squared.

The Shield Building attenuation is given by the second term, where a reduction in volumetric capacitance can be applied to L_D, the fractional leakage rate of the Shield Building, in the form of a participation factor, f. The reciprocal of the reduction is then:

$$\frac{2f}{L_D t} = \frac{2 \times f}{1.20/day \times (4.5/1440)\ days} = 532f$$

For f = 0.5, the reduction would be 266, resulting in an unfiltered dose of 63/266 = 0.24 rem.

Determination of the effect of very low participation factors requires that the exponential terms be better approximated or used directly. The dose reduction with removal only by outleakage is:

$$\left[1 - \frac{1 - e^{-x}}{x}\right] = \left[\frac{x}{2!} - \frac{x^2}{3!} + \dots\right] \text{ where } x = L_D t/f$$

With simultaneous removal of activity by filtered stack discharge, $L_2 f$, as well as by unfiltered outleakage (as in the reference calculation beyond 36 seconds), the reduction applicable to the unfiltered dose would, instead, be:

$$\frac{L_D}{L_2 + L_D}\left[1 - \frac{1 - e^{-x}}{x}\right] \text{where } x = \frac{L_2 + L_D}{f} t$$

The 4.5-minute dose reduction factors in each case would vary as follows with participation factors, where L_2 is taken as 23.1/day (6000 cfm) and L_D=1.2/day.

	Reduction in Unfiltered Dose	
f	Without Competing Stack Release	With 6000 cfm Stack Release
1	534	545
0.5	267	278
0.1	54	64
0.05	27	30
0.01	6	22
0	1	19

Past evaluation of a similar Shield Building for the Sequoyah plant (Reference 1.) has resulted in recognition of a reduction factor of 10 applied to thyroid dose during the period of positive pressure, with indication that further credit might result if appropriate tests were performed.

According to the above table, a factor of ten reduction in thyroid dose would correspond to a participation factor of only 0.018, or would be less than the minimum reduction where competitive removal by filtered stack release is considered. Conversely, it may be concluded that full mixing in only one-fiftieth of the annulus volume (for example, in a vertical pie-shaped slice that is one-fifteenth of the circumference) should accomplish at least a tenfold reduction in thyroid dose.

The unfiltered outleakage component is unimportant with regard to whole-body dose during this interval because the whole-body dose is then essentially all due to the greater volume of stack release. The reduction factors applicable to the total whole body dose would be those in the first column above, but it is more convenient to consider a factor applicable over the larger interval of 0 to 20 minutes, as in the next section.

b. Filtered Release from 0 to 20 Minutes

The reference calculation of filtered Shield Building release from time 0 to 20 minutes is based on a stepwise reduction of exhaust flow from the annulus, as described in Table 14.3-7. All flow is directly out the filter, with no recirculation assumed and a participation factor of 0.5.

With decay and containment depletion neglected, the reduction factor is identical for thyroid and whole-body doses. Repeated application of the simplified equations through these flow changes results in the following variation of reduction factor with participation factor.

f	Reduction Factor
1	26
0.5	13
0.1	3.5

Somewhat less reduction actually applies directly to the dose potential during this period in that a portion of the 20-minute annulus inventory will later be released during the 20-minute to 2-hour period.

The effect of noble gas decay significantly increases the whole-body dose reduction factor associated with the larger participation factors; a reduction of 60 obtains an f = 0.5, as may be noted from Table H.4-2.

c. Filtered Release During Recirculation Phase

The most significant reduction factor is that associated with the 20-minute to 2-hour interval when recirculation is assumed to be established and when the effectiveness of mixing is least questionable.

Thyroid Dose

Direct release of 0.0089/day leakage (0.01/day total) during this period would result in 134 rem thyroid dose with a 90% filter. The reference calculation assumes mixing with effectively half the annulus capacitance available, which reduces the dose by a factor of about 32 and results in a thyroid dose of 4.2 rem for the 90% filter.[1]

The source of this thyroid dose reduction factor can be understood more readily by neglecting decay, source depletion and initial inventory, and by solving directly for a reduction factor under various assumptions. Table H.4-2 compares the effects of different assumptions, using these simplifications and somewhat simpler terminology than is used in Chapter 14. The last column on this chart presents the expression for the reduction factor relative to the case of direct filtered release, and gives numerical values for the case of 0.5 participation factor.

The case for the "actual flow pattern" in Table H.4-3 corresponds to the reference calculation. The thyroid dose reduction factor is the recirculation ratio, R, or its reciprocal 20, times a capacitance factor associated with 100 minutes of recirculation flow, for a total reduction of 32. Reduced mixing, or lower participation factor, affects only the capacitance term in this case, so a reduction factor of at least $20 \times 0.915 = 18.3$ is applicable.

1. The reference calculation for this time interval includes also the effects of partial release of the initial 20-minute inventory in the annulus, which causes typically 20 to 30% of the dose from the fresh component. This deferred component should be charged to the previous period and must be neglected in defining a reduction factor applicable to the containment leakage that occurs during the recirculation period.

This same result permits direct calculation of a reduction factor applicable to the suggested composite halogen source (90% particulates and inorganics removable with 90% efficiency plus 10% organics removable with only 70% efficiency). The resulting reduction factor varies from 30 at a participation factor of 0.5 to 17 at lower participation factors.

A second way in which adverse mixing effects can be allowed for in the calculation is to neglect mixing of containment leakage until it has once passed the filter and begun to recirculate, as represented by the next case in Table H.4-3. This effect still results in a reduction factor of about 20. Neglect of the capacitance term in this case (or the assumption of very low participation factor) is equivalent to cascading the recirculated component through the filter such that a fraction (1-n)R escapes on first pass, a fraction (1-n) (1-R) times as much escapes on second pass, $(1\text{-}n)^2$ $(1\text{-}R)^2$ as much on third pass, etc., for a total release rate of (1-n)R/[1-(1-n)(1-R)]. The resulting shield building attenuation factor would then be 18 for a 90% filter and 19 for a 95% filter.

The significant conclusion that can be drawn from comparison of these two cases is that a minimum reduction factor that is approximately equal to the recirculation ratio applies to the thyroid dose, independent of the degree of mixing in either the first or subsequent passes. Over longer periods, as for the 30-day thyroid dose, the same factor also applies.

Based on these considerations, it is believed that a reduction factor of at least 20 is applicable to the thyroid dose during the recirculation period, in addition to the effect of direct discharge through a filter. Such a factor, equal to the ratio of recirculation flow to discharge flow, is equivalent to the recirculation credit that has been recognized for the standby gas treatment system of a boiling water reactor plant (e.g., see Safety Analysis for Shoreham, Docket 50-332, February 20, 1970).

Whole-Body Dose

Table H.4-4 describes similar simplified reduction factors for the dose from noble gases during the 20-minute to 2-hour recirculation period with the effects of decay again neglected.

The effective capacitance of the annulus in these cases is seen to be based on discharge flow rather than recirculation flow, and the 100-minute dose reduction factor is 10 to 19 for a participation factor of 0.5, depending on whether or not first-pass mixing is credited. The effect of reduced participation factor can be directly calculated. For example, with a participation factor of only 0.2, the dose reduction is 8.2 with credit for first-pass mixing and 6.0 without such credit.

Larger reduction factors result when decay is considered. A factor of 26 may be inferred from comparisons of Columns 2 and 4 of Table H.4-2, where Column 2 includes also partial release of the 20-minute inventory and therefore leads to an underestimate of the reduction factor applicable to this time interval.

H.4.3 Significance of Mixing Assumptions in Dose Calculations

Comparison of the magnitude of the dose component for each time interval, with and without Shield Building credit (Columns 2 and 4 of Table H.4-1 and Table H.4-2), shows that the following aspects of Shield Building attenuation are most significant to the total dose.

a. Thyroid dose reduction during the recirculation phase.

b. Thyroid dose reduction during the 4.5-minute period of positive pressure.

c. Whole-body dose reduction during the 20-minute to 2-hour recirculation phase.

The simplified analysis of reduction factors, and of the effects that adverse mixing would have upon these factors, demonstrated that the first item is essentially independent of mixing assumptions for either the first or subsequent passes, because a large reduction factor occurs simply as a consequence of recirculation filtration. Substantiation of mixing would only serve to justify a calculated dose reduction of 30 or more for this component, rather than 20.

The significance of mixing therefore applies primarily to the two remaining items, and specifically to the following aspects of these items.

a. Mixing with regard to unfiltered outleakage across the Shield Building annulus during the positive pressure period.

b. First pass mixing enroute to the SBVS inlet as it affects the 20-minute to 2-hour whole-body dose.

c. Recirculation mixing from 20 minutes to 2-hours as it affects the 20-minute to 2-hour whole-body dose.

The second item above is significant only to the extent that substantial mixing is recognized for the third item. As shown by the last case in Table H.4-1 and Table H.4-2, the effect of first pass mixing has little additional effect on the total whole body dose if little mixing credit is associated with the recirculated component.

H.4.4 Mixing Analysis and Possible Mixing Tests

a. Positive Pressure Period

There appears to be no meaningful test that would directly demonstrate the effects of mixing upon the activity that might escape unfiltered across the Shield Building annulus during the initial 4.5-minute period of positive pressure.

Any direct test of transport would involve arbitrarily severe conditions of proximity and character of leaks on either side of the annulus, and it would not include the thermal effects which would most influence the transport and mixing processes during this period of an accident.

Significant to evaluation of large leaks are the actual volumes of air that would leak into or out of the annulus during the period of positive pressure. The expected outleakage can be estimated on the basis of calculated annulus pressure and the maximum design leakage vs pressure:

Case	Positive Pressure Period	Outleakage	Expanded Inleakage**
Normal heat transfer	2.6 min	160* ft^3	56 ft^3
100% greater heat transfer	4.8 min	640* ft^3	103 ft^3
Dose calculation	4.5 min	1400 ft^3	

*Somewhat underestimated because pressure is computed using higher outleakage.

** Normalized to 1%/day initial containment leakage.

If the outleakage volume is regarded as one or more regular volumes adjacent to potential leaks in the outer wall which collapse as they leak out during the positive pressure period, and if no direct transport of the inleakage activity occurred from large leaks on the other side, then the outleakage volumes would not be intersected if they did not initially span the annulus.

Consideration of the volume of a single hemisphere (262 ft^3) that would span the annulus, or other shapes that might reasonably be associated with leakage areas such as the door perimeters, plus consideration of the improbability of having directly opposed inleakage and outleakage sites, leads to a general conclusion that little, if any, direct leakage of activity would be expected on the basis of this model.

A separate model can be applied to the inleakage alone, recognizing that containment pressure could indeed cause part of the leakage from a large leak to be transported rapidly across the annulus. Figure H.4-1 shows the results of calculation of flow distribution from a circular jet corresponding to 1% per day leakage of the contents of the containment, approximately at design conditions (about 9 cfm leakage before expansion, through a single circular hole of 0.218-inch diameter). In this case, average dilution factors are calculated across vertical cross sections of the cone of expansion defined in the figure, and this average dilution is found to be 100 to 1 at the midpoint of the annulus and 200 to 1 at the outer wall. The dispersion characteristics of the mixing jet are supported by experimental measurements. (Reference 2.)

These models are useful in describing the condition of a large leak on one side of the annulus and distributed smaller leaks on the other. The extreme case of large leaks being directly opposed is not considered, because this assumption, compounded with the assumption of full instantaneous availability of fission products, would be unnecessarily conservative.

A more realistic model would consider mixing of inleakage flow with the substantial convective flow that will occur up the inside of the annulus during this period.

It may reasonably be expected that this will result in an overall mixing effect in the annulus similar to that assumed in the reference dose calculations. However, a conservative approach would be to assume that only a portion of the annulus air engaged in the thermal movement and that the containment leakage mixes only with this air volume. For example, a thermal circuit could be postulated to occur up the inner wall and down the outer wall. In this case, the dose reduction could be determined directly on the basis of the participation factor associated with the circulating air volume involved, and the dose reduction factors previously discussed for low participation factor would apply directly.

However, the amount of convective flow, if any, that would occur down the outer wall during this period is questionable in that the general overall process is one of thermal expansion and relief of air out the discharge vent. The disposition of the rising air would be expected to be primarily one of displacement or partial mixing with the 7% of the annulus air that is relieved from the dome area and discharged directly through the filters during the 4.5-minute period. This is regarded as the most useful model for the positive pressure period.

To the extent that this latter model is accurate, no unfiltered leakage would occur, and any dose adjustment would instead be that of adverse mixing applied to the 0 to 4.5-minute or the 0 to 20-minute filtered dose. As previously demonstrated, this component of the dose is not critical to an evaluation of the reduction factors that might be applied to the dual containment.

However difficult it is to conservatively define mixing during this period, it may be noted that a far more difficult problem to prove, and perhaps an easier one to disprove, is the possibility that any measurable unfiltered activity could escape during this period–considering actual time of meltdown and transport and the effects of mixing on both sides of the containment shell, rather than applying the accepted premise of full instantaneous release and mixing within the containment that is part of Safety Guide 4.

b. First Pass to Recirculation Inlet

A review of the locations of the containment penetrations that could leak into the annulus shows that these are all at least 100 feet below the level of the inlet header. Thus, leakage from the expected sources will have a transport path equal to approximately half the height of the annulus before entering the duct leading to the filter and to the discharge and recirculation paths.

The results of analysis described in the next section for the recirculated component should apply generally to first-pass mixing of leakage from containment penetrations at elevations near that of the return header, where mixing of the leakage will be promoted by the nozzle action. As may be noted from Table H.2-1, a major part of the leakage will be from penetrations in this area.

A meaningful test of first-pass mixing might be feasible as part of the possible tests that are discussed for the recirculation period.

c. Recirculation Mixing

The effectiveness of mixing in the dual containment is least questionable with regard to mixing of the recirculated component once recirculation is established. Specific design features provided to ensure mixing during this period include: separation of the suction and inlet system headers at extreme ends of the building; maximum separation of the inlet header from the containment vessel penetrations near the bottom of the vessel, which are the expected sources of leakage; and distribution of return flow through 14 nozzles in the return header which are equally spaced around the lower circumference of the annulus to promote mixing of the containment leakage in the vicinity of the penetrations.

Mixing Analysis

The effectiveness of the nozzle distribution is indicated by the results of calculations described in Figure H.4-2, where centerline values are compared to those of relevant experiments. The nozzles are directed both upward and downward, and the calculation indicates that the expansion cone defined by 10% concentration limits relative to the header concentration would span the 5-foot annulus at a point 10 feet distant from the header.

The calculation demonstrates that substantial mixing will occur in the lower regions of the annulus where leakage is expected, with first-pass leakage being mixed with the return flow and with the volume of air in the lower part of the annulus. Also, velocities from the upward jets are dissipated rapidly with elevation, so channeling of the recirculated air flow should not occur for this reason.

Possible Mixing Tests

Recirculation mixing tests are not regarded as necessary to the evaluation because:

1. reasonable mixing is expected during this period;
2. the results would have significant application only to the 20-minute to 2-hours whole-body dose; and
3. reasonable credit for mixing during this period appears justified on the basis of the previous discussion and analysis.

However, a meaningful cold mixing test applicable to the recirculation phase may be possible because the thermal effects associated with earlier phases of the accident will then have greatly diminished. The containment shell temperature at 20 minutes, for example, is predicted to be 200°F and the annulus air temperature has then risen to 160–180°F. Thus, the temperature differences and the convective effects occurring during a cold test might not differ significantly from those of the 20-minutes to 2-hour accident period.

A possible mixing test would begin at equilibrium recirculation conditions, and a test of recirculation mixing would involve injection of tracer substance into the return leg of the Shield Building Ventilation System, with consequent entry into the annulus through the nozzles of the lower distribution header.

Two types of test might be considered:

- continuous injection
- pulse injection

With continuous injection of a substance that is not removable by filters, the concentration in the annulus and the exhaust flow should accumulate as shown in Table H.4-4 for noble gases without decay.

$$1 - e^{-RP_o t/f} \approx \frac{RP_o t}{f}$$

and the fraction of input discharged in time t should be:

$$1 - \frac{1 - e^{-RPt}}{RPt} = \frac{RPt}{2!} - \frac{(RPt)^2}{3!} + \ldots \approx \frac{RP_o t}{2f}$$

where:

RP_o = discharge flow/total annulus volume

f = participation fraction and other terms are as shown in Table H.4-4

The fact that the Shield Building attenuation without filtration involves an annulus capacitance based on discharge flow rather than recirculation flow thus permits a participation factor to be inferred directly from either the discharge concentration or the time-integrated discharge fraction. The fraction discharged in 100 minutes at 200 cfm discharge, 4000 cfm recirculation, and f = 0.5, for example, is only 0.052, so the accumulation is nearly linear, and both measurements are inversely proportional to an effective participation factor. The integrated discharge is simply 0.026/f units per unit of total input.

A more useful result would be that from pulse injection with subsequent measurement of the transient concentration arriving at the discharge, or at any other point in the ducting beyond the inlet header. In this case, a discrete transport lag will occur in the first pass up the annulus before any tracer arrives, and the measured transient function represents a continuous distribution of all effects of transport delay, mixing, and channeling associated with the different transport paths through the annulus.

In principle, this function could be applied directly to successive passes through the annulus to permit calculation of dose or dose reduction factors directly from the result of the experiment, independent of the concept of a participation factor. Similarly, a first-pass transfer function could be obtained by pulse injection at any point in the annulus, rather than in the return leg, and this result could similarly be included in the resulting dose analysis.

The possible direct use of the measured function can be demonstrated for the simple case designated as the actual flow pattern in Table H.4-4.

If we inject a brief pulse S∆T of material in the return leg, and there exists full mixing in the annulus, tracer material will begin arriving immediately at the outlet of the annulus as:

$$PA_2(T) = SPe^{-P_T}\Delta T$$

and the total amount that will be delivered as:

$$\int_0^{\infty} PA_2(T)dT = S$$

More generally, for an arrival function G(T):

$$PA_2(T) = SPG(T)\Delta T$$

where:

$$\int_0^{\infty} G(T)dT = 1/P$$

By assuming full mixing in the ductwork at the completion of each pass, no time delay in the ductwork, and a fraction I-R recirculation on each pass (as in Table H.4-4), the effects of repeated application of the measured function can be described.

The presence of a continuous source S during the last pass results in an outflow at time t:

$$PA_2(T) = PS\int_0^{t} G(t - T_1)\Delta T_1$$

where the function G would be replaced with some other measured first-pass function in this expression if it were available (as would the last integrand in the subsequent equations that relate to previous passes).

At each time $t - T_1$, there existed an incoming recirculated flow associated with duration of the source during the previous pass, and this also contributes an outflow at time t:

$$PA_2(t) = P^2 S(1-R)\int_0^t G(t-T_1)\int_0^{T_1} G(T_1 - T_2)dT_2 dT_1$$

The total activity outflow is determined by extending this process to all previous passes and adding all contributions. The value of each multiple integral can be found from the use of the Laplace transform, where:

$$\mathcal{L}[G(T)] = g(s)$$

and the summation is found to be:

$$\mathcal{L}[PA_2(t)] = PS\left[\frac{g(s)}{s} + \frac{(1-R)Pg^2(s)}{s} + \frac{(1-R)^2 P^2 g^3(s)}{s} + \dots\right] = PS\left[\frac{g(s)}{s[1-(1-R)Pg(s)]}\right]$$

Similarly, the transform of the activity discharged from time 0 to t is:

$$\mathcal{L}\left[\int_0^t \dot{A}_3 dt\right] = \left[\int_0^t RPA_2(t)dt\right] = RPS\frac{g(s)}{s^2[1-(1-R)Pg(s)]}$$

The two following examples provide some insight regarding the significance of a participation factor.

With full mixing, but only in a volume fraction f, as used in the reference calculations, we find:

$$G(T) = 1/f(e^{-Pt/f})$$

$$g(s) = \frac{1}{f(s+P/f)}$$

$$\mathcal{L}[A_3] = \frac{SRP}{fs^2(s+RP/f)}$$

and the inverse transform gives the same result as in Table H.4-4:

$$A_3 = St\left[1 - \frac{1 - e^{-RPt/f}}{RPt/f}\right]$$

Similarly, with all flow assumed to be slug flow, but only through a volume fraction f, all pulse activity arrives as a pulse of area 1/P, delayed by a transit time f/P:

$$G(T) = (1/P)\delta(T - f/P) \text{ where } \delta = 1 \text{ for } = T = f/P$$

$$= 0 \text{ for } T \neq f/P$$

$$g(s) = \frac{e^{-fs/p}}{P}$$

$$\mathcal{L}[A_3] = \frac{RS}{s^2[e^{fs/P} - (1 - R)]}$$

and the inverse transform is obtained:

$$A_3 = St[1 - (1 - R)^n]\ n = 1, 2, 3\ldots$$

$$n < (Pt/f) < n + 1$$

In the recirculation phase, Pt = 1.07 for 100 minutes (20 minutes–2 hours). Thus, the 100-minute dose reduction factor with full volume slug flow is that for between one and two passes, or equal to R. The case f = 0.5 is between two and three passes, and the reduction is then R(2-R) = 0.0975. Similarly, the factor increases to 0.23 at f = 0.2 and approaches unity, as expected, at lower participation factors.

The participation factor, as used in the reference calculations, is simply an assumed reduction of capacitance to allow for the effects of non-uniformity in the mixing and transport process. The previous development and examples also suggest a physical interpretation of the factor as applied during recirculation. The convolution of a measured arrival concentration function effectively describes the behavior of particles which are confronted on each pass with a choice of transport paths through the full annulus, with each path characterized by a transport and mixing process. In contrast, the use of a participation factor is seen to represent a special case wherein a uniform process applies to all flow, where the process is conservatively defined by assuming all flow to be directed through a reduced transit and mixing volume. The same process then applies uniformly during successive passes through the same volume fraction.

H.4.5 Proposed Minimum Factors of Credit for Shield Building Effectiveness

On the basis of the previous discussion, certain minimum factors of dose reduction might be associated with the effectiveness of the Shield Building, the application of which seems warranted even in the absence of mixing tests. Suggested values for these factors and their application to the potential doses described in Table H.4-1 and Table H.4-2 result in the following adjusted doses for a nominal initial leak rate of 0.01/day.

Dose Component Shielding Building	Minimum Credit	Adjusted Thyroid (Dose, rem)	Adjusted Whole-Body (Dose, rem)
0–4.5 min unfiltered leakage	10	6.4	–
0–20 min filtered leakage		21.6	3.6
20 min–2hr recirc release	20-thyroid 6-whole body	6.7	2.2
Total Shield Building		34.7	5.8
Auxiliary Building		18.2	1.9
Direct Leakage		18.2	0.2
Total 2-hour dose		71.1	7.9
Total 2-hr dose using Safety Guide 4 Meteorology Values		121	13.4

At least two of the proposed credits have precedent, and all appear more than justified on a technical basis, as summarized in the following brief discussion of each item.

a. Positive Pressure Period

Full mixing in only one-fiftieth of the annulus results in at least a ten-fold reduction in direct thyroid dose during this period, which factor has previously been recognized for a similar application. Sufficient mixing to accomplish at least this reduction should occur on the basis of dispersion effects and the leakage volumes involved, and the most realistic model suggests that leakage would be conveyed upward by thermal currents to displace or mix with the air volume that is relieved through the filters during this expansion period.

Also, an arbitrary assumption of direct leakage with little or no mixing during this brief initial interval is regarded as an unrealistic and unnecessary extension of Safety Guide 5.

Application of the conservative assumption of full instantaneous availability of fission product leakage to a secondary containment volume during this period would seem to warrant a reasonable mixing assumption consistent with the 100% instantaneous mixing that is assumed within the containment.

b. Recirculation of Halogens

A factor approximately equal to the minimum recirculation ratio is shown to apply to thyroid doses during recirculation, independent of mixing effects. The same factor has been recognized with regard to the standby gas treatment system for a BWR.

c. Recirculation of Noble Gases

Mixing of the recirculated flow in only 20% of the annulus volume is shown to obtain a reduction of six during the 20-minute to 2-hour period, with decay during holdup neglected and without credit for first-pass mixing.

H.4.6 Dose Analysis With As-Built Inleakage Characteristics

The increase in Shield Building exhaust during the 10-minutes to 2-hour period is the only change that will affect the off-site dose estimates. The 10-minute to 20-minute activity release will be approximately two times larger and the 20-minutes to 2-hour activity release will be approximately six times larger. Since these contributions represent only part of the 0-2-hour dose (Table H.4-1) the 0-2-hour thyroid dose will be only approximately 64% higher. Thus, the total 0–2-hour thyroid dose for 0.005/day license leak rate (note Table H.4-1 is for 0.01/day leak rate) will increase from approximately 22 rems to approximately 33 rems (Table H.4-5) at the site boundary which is still far below the l0 CFR l00 guideline of 300 rems.

H.4 REFERENCES

1. Docket 50-327: PSAR, Section 14.3.5; and AEC Safety Evaluation, Item 11.2, March 24, 1970
2. Albertson, M. L., Y. B. Dei, R. A. Jensen, and Hunter Rouse, “Diffusion of Submerged Jets,” Proceeding, ASCE, Vol. 74, No. 10, December, 1948, pp 1157-1196

Table H.4-1
Comparison of Thyroid Dose Calculations for Normalized Total Containment Leakage Rate of 0.01/Day, All Doses in Rems

	Column 1 Reference Case 95% Filter	Column 2 Reference Case Adjusted to 90% Filter	Column 3 Suggested Basis–70% Direct Transport to 90% Filter	Column 4 Total Dose Potential Single Containment With 90% Filter
Doses at Site Boundary				
Shield Building, 0.0089/day				
0–4.5 min unfiltered leakage	0.22	0.22		63.39
0–20 min filtered release	1.11	2.08	19.22	21.6
20 min–2 hr recirculation release	2.72	5.18	6.52	134.27
Total Shield Bldg.	4.05	7.48	25.74	219.26
Aux. Bldg., 0.001/day	9.12	18.23	18.23	18.23
Direct Leakage, 0.0001/day	18.23	18.23	18.23	18.23
Total 2 hr dose	31.4	43.94	62.20	255.72
Doses at Low Population Zone				
0–2 hr Shield Bldg. only	0.72	1.33	4.59	39.07
0–30 days: Shield Building	1.40	2.74	6.04	66.11
Aux. Bldg.	3.14	6.29	6.29	6.29
Direct Leakage	6.29	6.29	6.29	6.29
Total 0-30 days	10.83	15.32	18.62	78.69

This information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Table H.4-1
Comparison of Thyroid Dose Calculations for Normalized Total Containment Leakage Rate of 0.01/Day, All Doses in Rems

	Column 1 Reference Case 95% Filter	Column 2 Reference Case Adjusted to 90% Filter	Column 3 Suggested Basis–70% Direct Transport to 90% Filter	Column 4 Total Dose Potential Single Containment With 90% Filter
Doses Using Safety Guide 4 Meteorology Values Instead				
0–2 hr, Site Boundary	53.52	74.9	105.90	435.76
0–30 days, LPZ	44.60	63.3	68.86	277.47

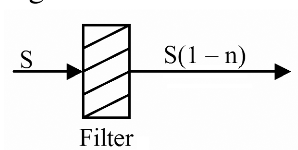
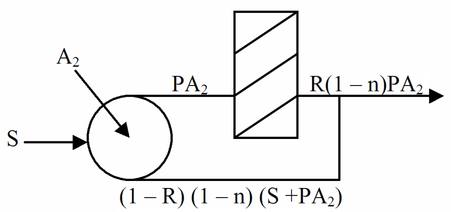
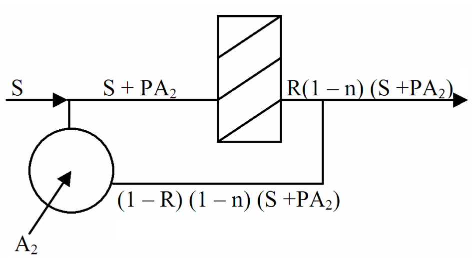
Table H.4-2
Comparison of Whole-body Dose Calculations for Normalized Total Containment Leakage Rate of 0.01/Day, All Doses in Rems

	Column 1 Reference Case 95% Filter	Column 2 Reference Case Adjusted to 90% Filter	Column 3 Suggested Basis–70% Direct Transport to 90% Filter	Column 4 Total Dose Potential Single Containment With 90% Filter
Doses at Site Boundary				
Shield Building, 0.0089/day				
0–4.5 min unfiltered leakage	0.001	0.001	0.029	0.043
0–20 min filtered release	0.060	0.060	2.405	3.598
20 min–2 hr recirculation release	0.515	0.515	0.935	13.224
Total Shield Bldg.	0.576	0.576	3.369	16.865
Aux. Bldg., 0.001/day	1.895	1.895	1.895	1.895
Direct Leakage, 0.0001/day	0.190	0.190	0.190	0.190
Total 2 hr dose	2.661	2.661	5.454	18.950
Doses at Low Population Zone				
0–2 hr Shield Bldg. only	0.103	0.103	0.6	3.005
0–30 days: Shield Building	0.42	0.42	0.944	4.044
Aux. Bldg.	0.454	0.454	0.454	0.454
Direct Leakage	0.045	0.045	0.045	0.045
Total 0–30 days	0.919	0.919	1.443	4.543

Table H.4-2
Comparison of Whole-body Dose Calculations for Normalized Total Containment Leakage Rate of 0.01/Day, All Doses in Rems

	Column 1 Reference Case 95% Filter	Column 2 Reference Case Adjusted to 90% Filter	Column 3 Suggested Basis–70% Direct Transport to 90% Filter	Column 4 Total Dose Potential Single Containment With 90% Filter
Doses Using Safety Guide 4 Meteorology Values Instead				
0–2 hr, Site Boundary	4.534	4.534	9.29	32.29
0–30 days, LPZ	4.51	4.51	4.54	16.03

Table H.4-3
Simplified Reduction Factors for 20-minute to 2-Hour Thyroid Dose

Case	Equations	Dose Reduction Factor = $A_3/S(1-n)t$
Direct Discharge 	$\dot{A}_3 = S(1-n)$ $A_3 = S(1-n)t$	1
Actual Flow Pattern 	$\dot{A}_2 = S + (1-R)(1-n)PA_2 - PA_2$ $= S - \alpha A_2$ $Where\ \alpha = P[1-(1-n)(1-R)]$ $A_2 = \frac{S}{\alpha}(1-e^{-\alpha t})$ $\dot{A}_3 = (1-n)RPA_2$	$\frac{RP}{\alpha}\left(1-\frac{1-e^{-at}}{\alpha t}\right)$ $= \frac{R}{0.993}(0.567)\ for\ n = 0.95$ $= \frac{R}{0.915}(0.562)\ for\ n = 0.90$ $= 0.031\ for\ both$ $\approx R\left(1-\frac{1-e^{-Pt}}{Pt}\right)$
No First-Pass Mixing 	$\dot{A}_2 = (1-n)(1-R)(S+PA_2) - PA_2$ $= S(1-n)(1-R) - \alpha A_2$ *where α is defined above* $A_2 = \frac{S(1-n)(1-R)}{\alpha}(1-e^{-\alpha t})$ $\dot{A}_3 = R(1-n)(S+PA_2)$	$R\left[1+\frac{(1-n)(1-R)P}{\alpha}\left(1-\frac{1-e^{-\alpha t}}{\alpha t}\right)\right]$ $= R\left[1+0.051\left(1-\frac{1-e^{-\alpha t}}{\alpha t}\right)\right]$ $= 0.051\ for\ n = 0.95$ $= R\left[1+0.104\left(1-\frac{1-e^{-\alpha t}}{\alpha t}\right)\right]$ $= 0.053\ for\ n = 0.90$

R = Recirculation ratio = 200 cfm/4000 cfm = 0.05
Pt = 2.14 (100 min, 4000 cfm, and 0.5 participation factor)

Table H.4-4
Simplified Reduction Factors for 20-minute to 2-hour Whole-Body Dose

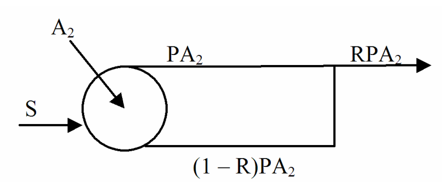
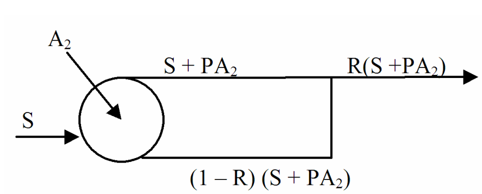
Case	Equations	Dose Reduction Factor = A_3/St
Direct Discharge 	$\dot{A}_3 = S$ $A_3 = St$	1
Actual Flow Pattern 	$\dot{A}_2 = S - RPA_2$ $A_2 = \frac{S}{RP}(1 - e^{-RPt})$ $\dot{A}_3 = RPA_2$	$1 - \frac{1 - e^{-RPt}}{RPt} = 0.0517$
No First-Pass Mixing 	$\dot{A}_2 = (1 - R)S - RPA_2$ $A_2 = \frac{(1 - R)S}{RP}(1 - e^{-RPT})$ $\dot{A}_3 = R(S + PA_2)$	$R + (1 - R)\left(1 - \frac{1 - e^{-RPt}}{RPt}\right)$ $= 0.05 + 0.95(0.0517)$ $= 0.099$
R = Recirculation ratio = 200 cfm/4000 cfm = 0.05 Pt = 2.14 (100 min, 4000 cfm, and 0.5 participation factor)		

Table H.4-5
Thyroid Dose Calculations for Normalized Total Containment Leakage Rate of 0.005/Day
(All Doses in Rems)

Doses at Site Boundary	Reference Case Adjusted to 90% Filter
Shield Building, 0.0089/day	
0–4.5 min unfiltered leakage	0.11
0–20 min filtered release	2.08
20 min–2 hr recirculation release	12.91
Total Shield Building	15.10
Auxiliary Building, 0.001/day	9.12
Direct Leakage, 0.0001/day	9.12
Total 2 hr dose	33.34

This information is HISTORICAL and is not intended or expected to be updated for the life of the plant.

Figure H.4-1 Axisymmetric Flow Distribution from a Circular Jet

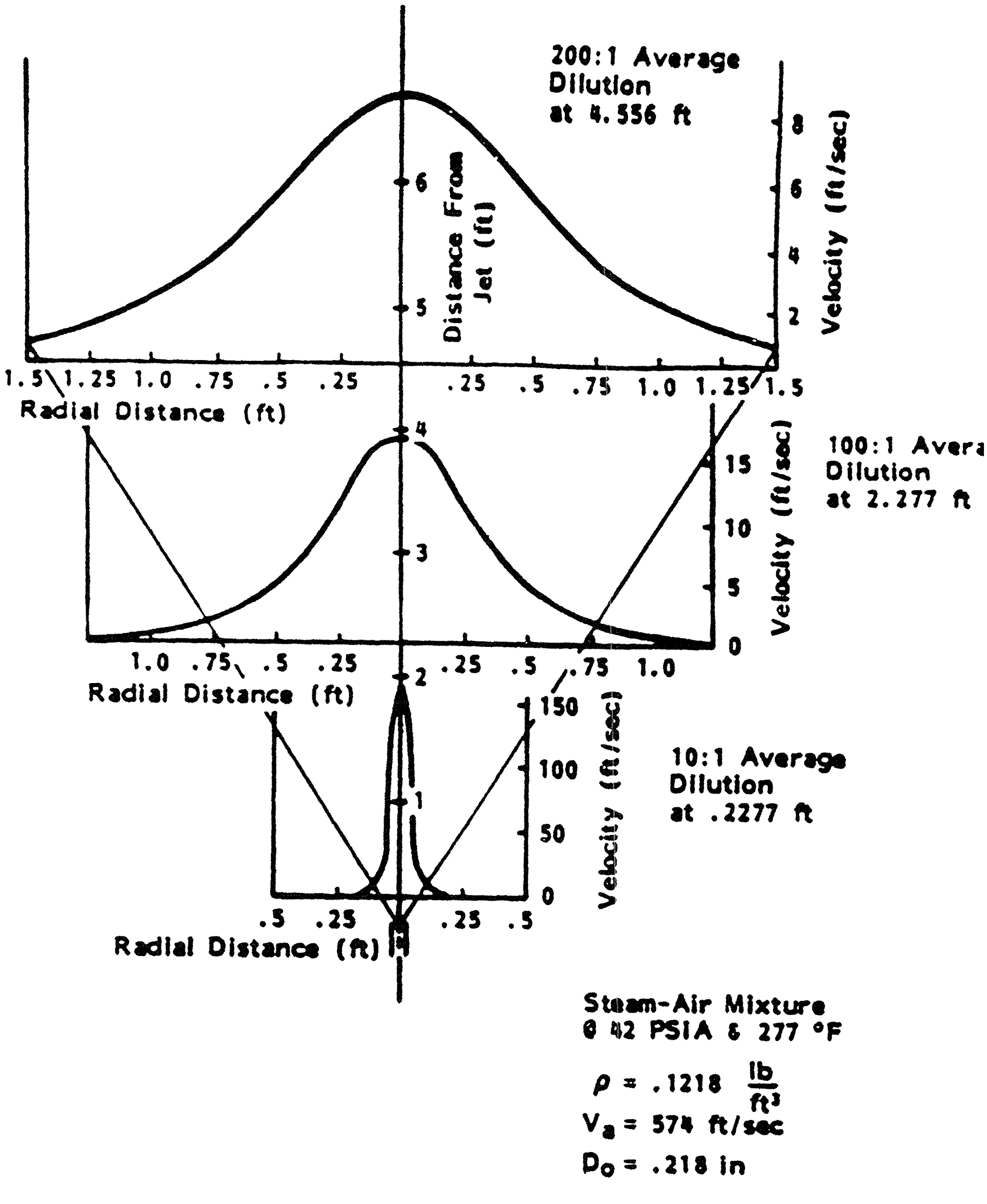
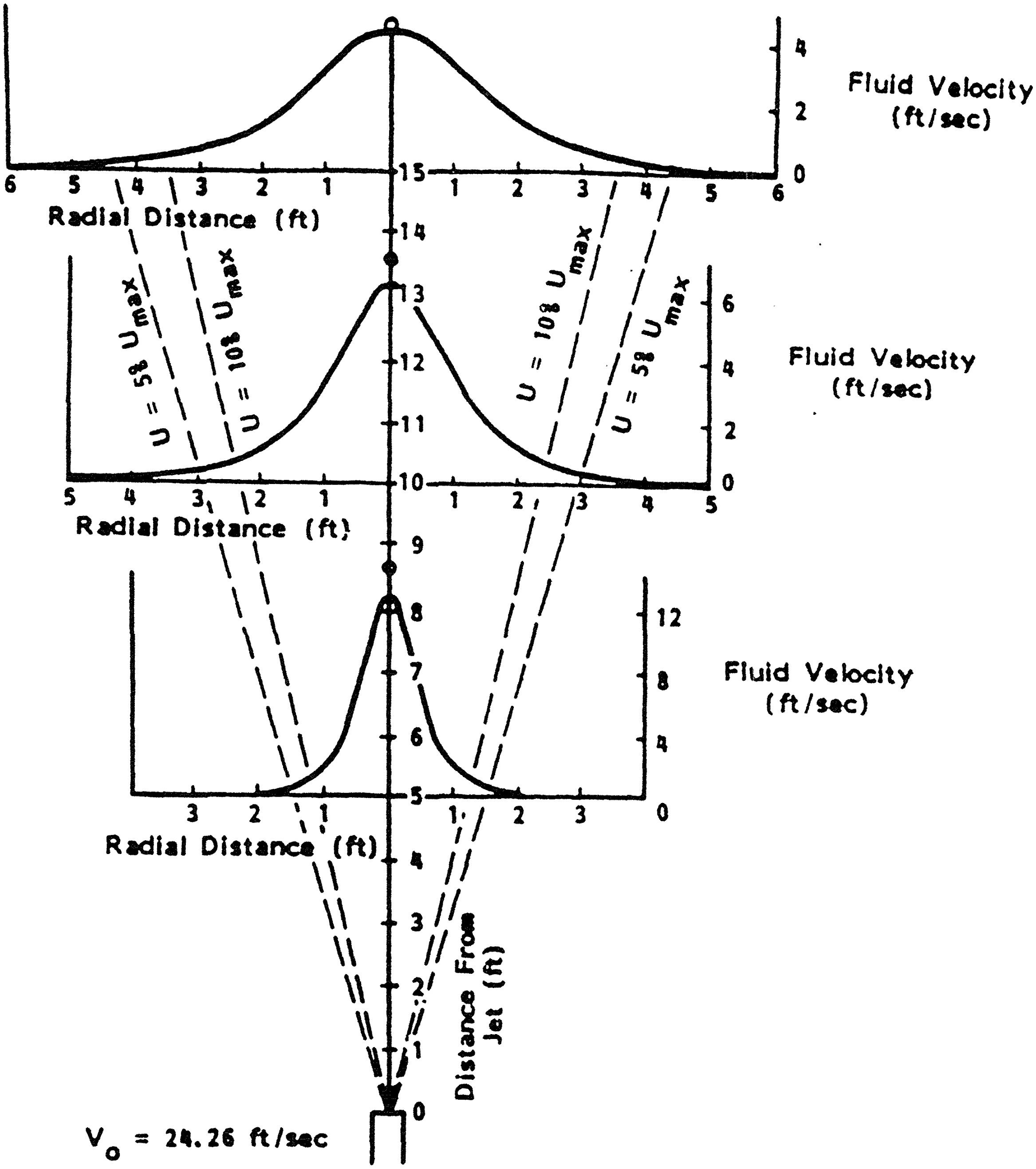


Figure H.4-2 Axisymmetric Flow Distribution from a Circular Jet



o - Experimental Values From ASCE Results

H.5 SYSTEM TESTING

The system testing consists of the following.

H.5.1 Shield Building Ventilation System Testing

The SBVS Testing is described in Section 5.5.6.

H.5.2 Auxiliary Building Special Ventilation System Testing

The Auxiliary Building Special Ventilation System Testing is described in Section 9.6.5.

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