NUCLEAR POWER PLANT CONTROL ROOM VENTILATION SYSTEM DESIGN FOR MEETING GENERAL CRITERION 19

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Abstract

The requirement for protection of control room personnel against radiation is specified in General Design Criterion 19 of Appendix A, 10 CFR Part 50. The evaluation of a control room design, especially its emergency ventilation system, with respect to radiation protection primarily consists of determining the radiation doses to control room personnel under accident conditions.

The accident dose assessment involves modeling and evaluation of radiological source terms, atmospheric transport of airborne activity, and protection features of the control room ventilation system. Some of the assumptions and conservatisms used in the dose analyses are based on the technical review experience of existing or proposed control room designs. A review of over 50 control room designs has revealed a great variety of design concepts, not all of which seem to have been based on radiation protection criteria.

A summary of the basic control room protection requirements, design features, dose acceptance criteria, and an outline of the methods used by the Regulatory staff for accident dose evaluation are presented.

I. Introduction

The General Design Criterion 19 of Appendix A, 10 CFR Part 50, includes a specific requirement with respect to control room personnel protection against radiation under accident conditions. According to Criterion 19, control room design should provide radiation protection such that control room personnel do not receive radiation exposures in excess of 5 rem whole body, or its equivalent to any part of the body, for the duration of the accident.

The assessment of a particular control room design in terms of Criterion 19 doses includes the following considerations:

1. Radiation source term identification and evaluation.

2. Radiation transport, either by airborne contamination or via direct streaming through shielding and other structures.

3. Control room radiation protection with respect to airborne and direct streaming radiation sources.

4. Control room dose calculation models.

DISCLAIMER

A relatively large number of control room designs have been reviewed. As a result, it has been possible to identify and characterize several distinct ventilation system design concepts for protecting control room operators from airborne contaminants associated with postulated accidents. Each concept can be described in terms of its advantages and disadvantages, as well as its performance capabilities for short-term and long-term contamination situations. These attributes, when applied to a specific nuclear power plant configuration, are used to assess the acceptability of a proposed control room ventilation system.

II. Basic Protection Considerations

An accidental release of activity can result in control room operator exposure. The operators can be exposed to external gamma radiation from activity outside the control room. The concrete walls of typical control buildings normally reduce this contribution to acceptably low levels (less than one rem whole body exposure for the worst postulated accidents). Streaming through wall penetrations (e.g., door openings) is normally the only design feature that requires specific review with respect to external radiation.

The operators also can be exposed to both direct and internal radiation from activity buildup within the control room. The exposures consist of whole body gamma and beta skin radiation. If radioactive iodine is present the operators may also be subject to thyroid exposure.

Thyroid exposure is the limiting consideration in most cases. Charcoal filters are installed to remove iodine and thus reduce the thyroid exposure to acceptable levels. The difficulty with respect to iodine protection is the assessment of the level of activity inside the control room as a consequence of various postulated accidents. Aside from estimating source terms and diffusion parameters, the problem centers around the control room design itself, namely the analysis with respect to charcoal filter effectiveness for removing iodine and the determination of control room air infiltration (amount of air entering the control room when it is isolated). These considerations usually have the greatest impact on the outcome of the review of current control room designs. Subsequent sections will discuss these, as well as other considerations in depth.

III. Review of Current Control Room Designs

Since July of 1973 a total of 50 applications, in various stages of review, have been studied to determine control room design adequacy with respect to Criterion 19. It was found that most of the control room emergency systems have very little in common. Very few of the 50 designs are identical. Designs developed even by the same A/E firm differ significantly. For example, there are four basic design categories: once-through filtration, recirculating filtration, bottled air, and dual inlets. Very few of the systems within a category are identical. Equipment capacities, component selection, as well as component arrangements vary. For instance, control room isolation is implemented by a variety of damping devices ranging from slow acting, leaky dampers, to fast acting, leak tight butterfly valves. Charcoal filter flow capacity ranged from 1,000 cfm to

43,500 cfm. Charcoal depths varied from the usual 2 inch depth to as much as 18 inches. Diversity was observed in the use of component redundancy: some designs show duplicate components connected to a common ductwork (component redundancy), whereas others have two completely separate systems (system redundancy).

Much of the observed design variations are caused by differing opinions as to the degree of protection that must be provided. In some cases, one has to conclude that the dose analyses were performed after the ventilation system design had been established. Dose analyses exclusively for the sake of satisfying safety documentation requirements is not a recommended practice. Rather, it should be used as a tool for system design and component selection.

The section on Control Room Dose Evaluation should provide the basis for consistency in evaluating the protective requirements and capabilities of control room ventilation equipment. A consistent evaluating technique in conjunction with an appreciation for good versus poor design details will help reduce the number of design variations and allow for future standardization of these systems. A discussion of the presently proposed concepts should help in achieving this objective. The balance of this section describes the four concepts, their application, and their advantages and disadvantages.

A. Isolation with Filtered Pressurization

In this concept, the control room is automatically isolated upon an accident signal or upon a high radiation signal at the fresh air inlets. The operator has the option of manually initiating emergency pressurization (make-up air being directed through a standby charcoal filter train). Pressurization flow rates between 400 and 4000 cfm are typical. Five percent of the plants reviewed rely on this method of protection.

Isolation is normally sufficient for accidents resulting in an activity release of short duration. Accidents resulting in releases of long duration, such as a LOCA, may require use of the charcoal filters.

Filtered pressurization is relatively ineffective in protecting against iodine. The Regulatory staff allows an iodine protection factor (IPF)* of 20 for charcoal filters that meet Regulatory Guide 1.52 requirements. In most cases, only plants with high stacks (greater than 100 meters) would meet Criterion 19 with this system.

A basic drawback of this type of system is the fact that when the filter is in operation, the unfilterable activity (comprised of noble gases) is being drawn into the control room and contributes to the whole body gamma exposure. Usually the recommendation is made that these systems be modified to allow the filter to be used either in a pressurization or a recirculation mode. This feature adds flexibility to the system as discussed below.

*See Section V-D., the parameter IPF is defined as the ratio of the dose assuming no iodine removal over the dose assuming iodine removal.

B. Isolation with Filtered Recirculated Air

In this concept the control room is automatically isolated and the emergency recirculating charcoal filters started with the same accident or high radiation trip. Control room air is withdrawn, filtered, and returned to the control room. Typical recirculation rates vary from 4000 cfm to 15,000 cfm depending principally upon the leak tightness of the zone serviced by the system and on the calculated activity levels in the unfiltered air. About 40 percent of the plants reviewed proposed this method of protection. The majority of these systems offered the option of manually pressurizing the control room with filtered air. This mode would be selected only if it was determined that contamination is being introduced into the control room within the building housing the control room.

These systems have a much higher potential for controlling iodine than those having once-through filters. IPF's ranging from 20 to over 150 can be achieved. These are designs used mostly for plants having vents located at containment-roof level. A system having a recirculation rate of 5000 cfm and a filter efficiency of 95% would be rated as follows:

Infiltration (cfm)*	IPF**
200	25
100	49
50	96
25	191

In addition to control of iodines, systems with low infiltration rates will provide significant protection against noble gas exposure as discussed in Section V-E.

A design problem common to recirculation systems is the enhanced infiltration from isolation dampers. Typically, these dampers are located on the inlet side of the recirculating fans and may be exposed to several inches of negative pressure. Systems that are designed for low infiltration solve this problem by installing "zero" leakage butterfly valves.

C. Isolation with Filtered Recirculation and Pressurization

This system is essentially the same as the one described in B.

*Calculated values will be acceptable for infiltration rates of 0.06 volume changes per hour or greater (for dose calculation purposes). Smaller infiltration rates will be allowed only if infiltration testing is performed periodically during plant operation. For design purposes infiltration rates less than 0.015 volume changes per hour normally are not considered achievable.

** Within the range of interest, IPF is directly proportional to recirculation flow rate times filter efficiency.

However, the designer has chosen to operate the system in the pressurized mode during long-term accidents and therefore the system must be approved on this basis. About 15 percent of the designs reviewed used this method of protection.

The advantage of pressurization is that it minimizes the amount of unfiltered air entering the control room by infiltration. The leak tightness of the control room then becomes only a secondary consideration. Of course, the disadvantage is that the noble gas exposure will be maximized since outside air is being intentionally admitted to the control room. In most cases, however, the whole body gamma exposure from the noble gases would still remain below Criterion 19 guidelines. The iodine protection factors for this type of system are given below for the case of a 5000 cfm, 95% efficiency filter (flows in cfm):

Make-Up Air*	Recirculated Air	IPF (Assuming No Infiltration)	IPF (Assuming 10 cfm Infiltration)
400	4600	238	159
750	4250	128	101
1000	4000	96	80

The Regulatory staff normally assumes a 10 cfm infiltration rate, notwithstanding pressurization. This is to account for the possibility of backflow of contamination into the control room when doors are opened or closed. This flow would be reduced or eliminated if the design rules out the possibility of backflow by installing devices such as two-door vestibules.

A question that has not been answered satisfactorily as yet, is whether "isolation with recirculation" or "pressurization" is the best continuous mode of operation. This depends primarily on the assumptions as to unfiltered inleakage. The Regulatory staff plans to measure infiltration on a number of actual control rooms to help determine the best operational mode. Isolation with recirculation has the advantage of limiting the entrance of noble gases (not filtrable) and it is also the better approach when the accident involves a short term "puff release." However, with pressurization there is a feeling of more security in that the question of infiltration becomes mute. Also, with the addition of a second charcoal filter in the inlet duct (assuring double filtration of make-up air) the pressurization design becomes very effective against iodine.

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*Make-up air should be sufficient to pressurize the control room to at least 1/8 inch water gauge. If the make-up rate is less than 0.5 volume changes per hour, supporting calculations are required to verify it. If the make-up rate is less than 0.25 volume changes per hour, periodic verification testing is required in addition to the calculations.

D. Dual Inlets

This concept utilizes two remotely located inlets. The inlets normally are placed such that any potential release point lies between the two inlets, thus assuring that one of the two inlets is free of contamination. This guaranteed supply of fresh air is used to pressurize the control room for minimizing infiltration. About 35 percent of the plants reviewed proposed dual inlet systems.

The viability of the dual inlet concept depends on whether or not the placement of the inlets assures one inlet free from contamination. This possibility depends, in part, on building wake effects, terrain, and the existence of wind stagnation or reversal. For example, consider a case where the inlets are located at the extreme edges of the plant structures; e.g., one on the north side and one on the south side. It is conceivable that under certain low probability conditions both inlets could be contaminated from the same point source. The designer who is skeptical about this possibility is encouraged to witness a smoke visualization test either in a wind tunnel or at an actual site. These tests show that the complex turbulence patterns set up in and around a group of buildings can result in contamination spreading throughout the complex, upwind as well as downwind of the release point.

If the inlets were to be located several hundred feet outboard of the structure the probability of both being covered probably would approach zero. The staff normally requires at least a once-through charcoal filter for the make-up air in those cases where the inlets are located on or close to the plant structures. Filters usually are not required for plants with inlets 200 feet or more away from any plant structure (provided of course that all potential source points, including toxic material containers, are located such that simultaneous contamination of both inlets is not possible).

The acceptance of a dual inlet system is based primarily on assuring that the inlet selected for operation can deliver pressurization air while at the same time assuring that the closed inlet does not allow any flow. The review involves a careful examination of the ducting and damping of the system. The ducting should meet seismic Category I criteria as well as be protected against missiles. The damping devices (normally butterfly valves) must meet the single active failure criterion. This results in each inlet having a parallel set of two valves in series (4 valves total). When applying the single failure of an active component criterion it should be noted that there must be a guarantee of both flow and no flow in each inlet.

E. Bottled Air

In some plant designs the containment pressure is reduced below atmospheric within one hour after a design basis accident (DBA). This assures that after one hour significant radioactive material will not be released from the plant. This type of design makes it feasible to maintain the control room above atmospheric pressure by use of bottled air. Normally the staff requires periodic pressurization tests to determine that the rated flow (normally about 300 to 600 cfm) is sufficient to pressurize the control room to at least 1/8 inch water gauge. It is also required that the system be composed of several

separate circuits (one of which is assumed to be inoperative to account for a possible single failure). The staff also requires at least a once-through filter system for pressurization as a stand-by for accidents of long duration. About five percent of the plants reviewed proposed this method of operation.

IV. Dose Acceptance Criteria

The Criterion 19 dose guideline of 5 rem whole body or its equivalent is used to determine system acceptability. The following specific criteria are applied:

1. Whole body gamma radiation from direct shine radiation of sources external to the control room and from the airborne activity within the control room should not exceed a total of 5 rem.

2. Beta skin dose from airborne activity within the control room should not exceed 30 rem. The dose is evaluated by assuming a 7 mg/cm^2 depth dose (this takes into account the shielding effect of the insensitive superficial skin layer) and a semi-infinite cloud geometry.

3. Thyroid dose from the inhalation of radioactive iodine should not exceed 30 rem. The dose is determined by use of ICRP Publication No. 2 parameters and a breathing rate of 3.47×10^{-4} m^3/sec.

V. Control Room Dose Evaluation

Each of the three dose components;i.e., the thyroid dose due to inhalation of iodine radioisotopes, and the whole body gamma and beta skin doses due to exposure to noble gas radioisotopes, is calculated on the basis of source strength, atmospheric transport,dosimetry, and control room protection considerations, as illustrated in Equations 1 through 3.

$$D_j^I = \frac{C_1 \cdot (X/Q)_j}{IPF} \sum_i^{IODINES} T_i E_i S_{ji} \qquad (1)$$

$$D_j^\gamma = \frac{C_2 \cdot (X/Q)_j}{GF \cdot PF_j} \sum_i^{NOBLE\ GASES} E_i^\gamma S_{ji} + I \qquad (2)$$

$$D_j^\beta = \frac{C_2 \cdot (X/Q)_j}{PF_j} \sum_i^{NOBLE\ GASES} E_i^\beta S_{ji} + I \qquad (3)$$

where :

$D_j^I, D_j^\gamma, D_j^\beta$ = the thyroid, whole body gamma, and beta skin dose, respectively, (rem)

j = time interval index, intervals of 0 to 8 hrs, 8 to 24 hrs, 1 to 4 days, and 4 to 30 days are typical

C_1 = 294, dose conversion factor (includes breathing rate of 3.47×10^{-4} m^3/sec

IPF = iodine protection factor, ratio of integrated iodine dose at inlet to integrated iodine dose within control room (see Subsection D)

$(X/Q)_j$ = meteorological factor (see Subsection B) (seconds/$meter^3$)

i = isotope index

T_i = effective half-life in the body (days)

E_i = effective energy absorbed in thyroid (Mev/dis)

S_{ji} = quantity of isotope released in j^{th} time interval (see Subsection A) (Ci)

C_2 = 0.25, semi-infinite cloud dose conversion factor

GF = geometric factor, converts semi-infinite gamma dose to a finite dose (see Subsection C)

PF_j = purge factor, corrects for slow increase in concentration in the case of a tight, isolated control room (see Subsection E)

E_i^γ = average gamma energy (Mev/dis)

I = symbolic indication of iodine contribution, represents a negligible fraction of dose when iodine filtration is used

E_i^β = average beta energy (Mev/dis)

The major input parameters defined in the equations above are based on the following considerations:

A. Source Term (S)

The source terms should be based on design basis assumptions acceptable to the AEC for purposes of determining adequacy of the plant design for meeting the criteria contained in 10 CFR Parts 50 and 100. For the most part, these design basis assumptions can be found in Regulatory Guides that deal with radiological releases. For instance, when determining the source term for a loss-of-coolant accident (LOCA), the assumptions given in Regulatory Guides 1.3 and 1.4 should be used. Guides 1.5, 1.24, 1.25, and 1.77 should be referenced for the evaluation of other design basis accidents.

In the case of a LOCA, 100% of the noble gases and 25% of the iodines present in the reactor core are assumed to escape to the containment and are initially available for release. The reduction of the amount of material available for release by containment sprays, recirculating filters, or other engineered safety features is taken into account. Reference to the respective Guides should be made for the balance of the assumptions. The source term for each isotope of iodine, xenon, and krypton is calculated in terms of curies released within each time interval of interest. The release rate for accidents of relatively short duration, such as a waste gas decay tank rupture or a main steam line break for a BWR, should be determined in such a way as to maximize control room operator exposure.

B. Meteorology (X/Q)

The term X/Q in Equations 1-3 denotes the degree of dispersion of the activity as it is transported from the point of release to the receptor. The parameter is normally referred to as relative concentration for it can be visualized best as the ratio of the concentration at the receptor (X) to the activity release rate (Q) as shown below:

$$\frac{X\ Ci/m^3}{Q\ Ci/sec} = X/Q\ \frac{sec}{m^3} \qquad (4)$$

Relative concentration is difficult to determine when both the release point and the receptor are located within or near the turbulence created by a complex of buildings. A number of wind tunnel and field tests (References 1-6) have been performed on specific building configurations. Though these efforts have resulted in usable information for specific situations, general applicability is not possible. In order to provide a basis for evaluation, the staff has formulated an interim position using conservative interpretations of the available data. The procedure consists of first determining the five percentile X/Q(defined as the X/Q value exceeded 5% of the time at the specific site in question). This value is used as the X/Q for the first post-accident time interval. Then the value of X/Q is reduced on the basis of averaging considerations for each subsequent time interval. The detailed procedures are described below.

1. Determination of Five Percentile Relative Concentration

a. In-line, Point Source - Point Receptor

The following relation is used when activity is assumed to leak from a single point on the surface of the containment, or other structure, in conjunction with a single point receptor (e.g., single operating air intake), which is located a distance "x" from the point source (the source and receptor having a difference in elevation of less than 30% of the containment height):

$$X/Q = (3U\pi\sigma_Y\sigma_Z)^{-1} \qquad (5)$$

where:

X/Q = relative concentration at the plume centerline (sec/m^3)

σ_Y, σ_Z = standard deviation of the gas concentration in the horizontal crosswind and vertical crosswind directions, respectively, both being evaluated at distance "x" (m)

U = wind speed at an elevation of 10 meters (m/sec)

3 = wake factor based on Regulatory Guides 1.3 and 1.4

The parameters σ_y, σ_z, and U are determined on the basis of site meteorological data. The data are statistically analyzed to determine that combination of σ_y, σ_z, and U are indicative of the five percentile dispersion condition at the site. Typically, σ_y and σ_z are based on a Pasquill "F" condition (see Reference 7 pages 102 and 103). Five percentile winds speeds of 0.5 to 1.5 meters/sec are typical.

b. Diffuse Source - Point Receptor

The following relation is used when activity is assumed to leak from many points on the surface of the containment in conjunction with a single point receptor:

$$X/Q = [U(\pi\sigma_Y\sigma_Z + \frac{a}{K+2})]^{-1} \quad (6)$$

where:

$$K = \frac{3}{(s/d)^{1.4}}$$

s = distance between containment surface and receptor location

d = diameter of containment

a = projected area of containment building (m^2)

The above equation is also appropriate in the following cases:

Point source - point receptor where the difference in elevation between the source and receptor is greater than 30% of containment height.

Point source - volume receptor; a volume receptor being exemplified by an isolated control room with infiltration occurring at many locations.

c. Point or Diffuse Source - Two Alternate Receptors

This section applies to those designs having two or more control room fresh air inlets each of which meets the single failure criterion for active components, the seismic criteria, as well as any applicable missile criteria. The design details must assure that the most contaminated inlet is isolated and the least contaminated inlet remains in operation to provide control room pressurization.

(1) Dual Inlets Located on Seismic Category I Structures-The dual inlets are most conveniently placed on the seismic Category I structure contiguous to the control room. The inlets should be located to

maximizethe benefit of the alternate inlet concept. For instance, of the first three locations depicted in Figure 1, only locations B and C would be acceptable, assuming that the containment is the location of the major points of release. Location A would be unacceptable because both inlets can be simultaneously contaminated. With good inlet placement, the relative concentration is calculated by use of Equation (6). In this case the standard deviation parameters are evaluated for the inlet closest to the point of release and with K being set to zero.

(2) Remote Air Intakes-When the dual inlets are placed about 180 degrees apart from the potential release points and each inlet is located well away from any major structure (typically 200 feet or more, see Figure 1, location D), the probability of both inlets being exposed to contamination at the same time is reduced significantly. However, wind shifts and unusual meandering of the wind may still cause simultaneous exposure of both inlets. This would occur infrequently and the contamination level at the operating inlet would be low.

The staff estimates this level of contamination by assuming a plume that spreads out in all directions and is evenly dispersed in the vertical direction. The appropriate equation is:

$$X/Q = 0.16/LUX \qquad (7)$$

where:

L = vertical mixing layer, m

X = distance from source to closest inlet, m

In the cases where activity is released within the wake of the containment, L is taken as the containment height divided by $\sqrt{2}$ (the height is divided by $\sqrt{2}$ to be consistent with the policy of restricting the wake factor to one-half of the projected area of the containment building). It is assumed that the contamination level calculated by Equation (7) will cover both inlets one-half hour per day.

Further adjustments in the X/Q, as discussed in the next section, apply to all methods using Equations (5) and (6), but do not apply in the case of remote air intakes.

2. Determination of (X/Q)j

The five percentile X/Q is used for the first time interval in the calculation (normally 0 to 8 hours after accident occurence). For subsequent time intervals, the X/Q is reduced to account for long term meteorological averaging. Consideration of other factors may require further reduction of X/Q. For instance, an allowance may be considered for the time the operator leaves the plant vicinity. This is defined as the occupancy factor. Typical values for this factor appear in Table 1. Note that the table also presents two other factors involving wind speed and wind direction. These factors

account for the effects of changes in wind speed and direction over progressively longer periods of time.

Typically, wind speeds of about 1 m/sec represent the five percentile case whereas speeds of 3 m/sec represent the 40 to 50 percentile case. The staff allows credit for higher wind speeds during long term accidents as indicated in Table 2. The values shown in Column 1 of the table can be used when meteorological data are not available. When available, the factors can be calculated by use of the wind percentiles given in Column 2.

When determining wind speed from site meteorological data, only the wind direction sectors that result in receptor exposure are used. Figure 2 defines the number of 22.5 degree sectors that is considered in obtaining the short term and long term wind speeds. The s/d ratio in the figure is the distance from the building surface to the receptor divided by the diameter or width of the building normal to the direction of the wind. Figure 2 was determined by analyzing the growth of the lines of equal concentration in planes parallel to the ground using results from Reference 2.

Figure 2 also is used to determine the fraction of time the wind is blowing from the sectors in question. The average wind direction frequency F is obtained by summing the annual average wind direction frequency of the sectors in question. Table 3 is then used to evaluate the appropriate wind direction factors. Column 1 of the table is used when F is not available and Column 2 is used when F has been determined.

TABLE 1

EXAMPLE OF FACTORS USED TO CALCULATE EFFECTIVE RELATIVE CONCENTRATIONS FOR SELECTED TIME INTERVALS

Adjustment factors	0 - 8 hrs	8 - 24 hrs	1 - 4 days	4 - 30 days
Occupancy	1	1	0.60	0.40
Wind speed	1	0.67	0.50	0.33
Wind direction	1	0.88	0.75	0.50
Overall reduction	1	0.59	0.23	0.066

TABLE 2

WIND SPEED FACTOR

Time after accident	Column 1 Representative wind Speed Factors*	Column 2 Corresponding wind speed percentile
0 - 8 Hrs	1	5
0 - 24 Hrs	0.67	10
1 - 4 days	0.50	20
4 - 30 days	0.33	40

TABLE 3

WIND DIRECTION FACTOR

Time after	Column 1 Representative wind direction factors **	Column 2 Relations used to estimate wind direction factor when F has been determined
0 - 8 Hrs	1	1
8 - 24 Hrs	0.88	0.75 + F/4
1 - 4 Days	0.75	0.50 + F/2
4 - 30 Days	0.5	F

*Defined as the ratio of the five percentile wind speed to the wind speed appropriate for the time interval in question.

** Defined as the fraction of time the wind is blowing activity toward the receptor.

C. Geometry Factor (GF)

The whole body gamma dose from noble gas radioisotopes is easily evaluated on the basis of immersion in an infinite cloud. Since control structures are usually effective in shielding out most of the gamma radiation from outside the control room, the dose inside the control room is substantially less than what the infinite cloud model predicts. A correction for this effect can be made by using a geometry factor which is a ratio of infinite-to-finite cloud doses, namely:

$$GF = \frac{\text{DOSE FROM AN INFINITE CLOUD}}{\text{DOSE FROM A CLOUD OF VOLUME V}} \tag{8}$$

where V is the control room volume. Taking into account geometric effects and gamma attenuation (using 0.733 Mev as the average gamma energy for noble gases considered in control room dose analyses) by air, it can be shown that Equation (8) becomes:

$$GF = \frac{1173}{V^{0.338}} \tag{9}$$

where the control room geometry is represented by a hemisphere of volume V(cubic feet). Equation (9) is plotted in Figure 3.

D. Iodine Protection Factor (IPF)

As outlined in Section III, there are several control room ventilation-filtration configurations which are used in reducing the iodine radioisotope concentration within the control room atmosphere. Iodine reduction is expressed in terms of the iodine protection factor (IPF) which is evaluated by considering an equilibrium balance between iodine sources and losses within the control room. Figure 4(a) shows a typical configuration, where:

F_1 = rate of filtered outside air intake

F_2 = rate of filtered air recirculation

F_3 = rate of unfiltered outside air infiltration

The balance of activity due to iodine can be written as:

$$\frac{dA}{dt} = A_0F_1(1-\eta) + A_0F_3 - AF_2 + AF_2(1-\eta) - A(F_1+F_3) \tag{10}$$

where:

A = specific activity within the control room

A_0 = specific activity outside the control room

η = filter efficiency/100

t = time

Under equilibrium conditions the left hand side of Equation (10) can be set to zero and the resulting equation yields the following equilibrium ratio of outside to inside specific activity,

$$\frac{A_0}{A} = \frac{F_1 + \eta F_2 + F_3}{(1-\eta)F_1 + F_3} \qquad (11)$$

Since dose is proportional to the specific activity, then the iodine protection factor can be expressed as :

$$IPF = \frac{\text{DOSE WITHOUT PROTECTION}}{\text{DOSE WITH PROTECTION}} = \frac{A_0}{A} \qquad (12)$$

The expression for IPF in Figure 4(a) is based on combining Equations (11) and (12).

The iodine protection factor for filtered recirculation with isolation is illustrated in Figure 4(b). It is obtained by letting $F_1 = 0$ in Equation (11).

Figure 4(c) shows a double filtration configuration. The iodine protection factor equation for this system has the same form as Equation (11), with the exception that, η in the denominator is replaced by η'. The term $(1-\eta) F_1$ in Equation (11) represents activity inflow after single filtration of contaminated air. With double filtration the same term would normally be written as $(1-\eta)^2 F_1$. However, the effectiveness of two filters in series is limited by Regulatory Guide 1.52. For example, two 2 inch deep charcoal filters each having a η of 0.95 is treated as a single filter of 4 inch depth having a η of 0.99.

Figures 5 through 7 illustrate the dependence of iodine protection factors on F_1, F_2, and F_3, for each of the configurations shown in Figure 4.

Aside from the design, testing, and maintenance criteria given in Regulatory Guide 1.52, the filter designer should review Reference 8 which provides some helpful observations on filter installation and design, based on the field inspection of the filter systems of 23 nuclear plants.

E. Purge Factor (PF)

Control rooms characterized by a high degree of leaktightness can benefit by the relatively slow build-up of activity within an isolated control room followed by a purge of the control room atmosphere at appropriate times after a release.

Given a finite isolation time, a non-equilibrium build-up of activity in the control room, followed by a purge, will result in a lower dose than in the case of instant equilibrium. It can be shown that the ratio of equilibrium to transient doses for an isolated control room followed by a purge is given by

$$PF = 1 - \frac{1}{Rt}(1 - e^{-Rt}) \qquad (13)$$

where

R = air exchange rate, air changes per hour

t = isolation time, hours

Figure 8 shows PF as a function of R and t. Equation (13) is based on the assumption that the control room is immersed in a cloud of constant activity concentration for a period of "t" hours and that immediately after the cloud passes the control room is instantaneously purged of activity. A conservatively large value of "t" should be used, depending on the specific circumstances, since the operator must 1) recognize that the external activity has fallen to a low value and 2) manually initiate control room purging. For a typical control room it is reasonable to assume that several days will elapse before conditions warrant purging.

VI. Control Room Infiltration

Infiltration is defined here as any unintentional inleakage of air into the control room. Pressure differences across the boundary of the control room air space cause infiltration through various leak paths. Typical examples of leak paths include crackage around the perimeters of doors, or duct, pipe, and cable penetrations. Structural joints, damper seals, and miscellaneous discrete cracks or openings are also candidate leakage paths. Good control room design practice minimizes microscopic openings of this type by gasketing, weather-stripping or sealing techniques. However, it should be noted that continuous distributions of microscopic capillaries and pores are possible, as in concrete, for example. Thus, complete elimination of infiltration is not always feasible.

In most cases, the principal cause for pressure differentials is due to "natural" phenomena, such as winds, temperature differences, or barometric variations. Pressure differences also can exist between the control room air space and adjoining enclosures (e.g., mechanical equipment room, turbine building, battery room, etc.) brought about by flow imbalance in the overall ventilation system.

Precise evaluation of control room infiltration is difficult. Although various empirically determined formulas are available for predicting infiltration across individual leak paths of known size and shape, this in itself is of limited value for a realistic assessment of infiltration when the control room is in the design phase. Even after construction, the control room infiltration measurement is difficult since it is sensitive to the combined effect of a number of independent variables. For example, wind direction, building geometry, internal building pressure distribution, air columns (i.e., elevator shafts, stairwells) etc., can combine in a number of ways, resulting

in different infiltration rates. Thus, to measure infiltration precisely in a specific case would require many test runs covering the entire range of environmental conditions.

Current practice is to estimate an upper limit on control room infiltration. This can be done on the basis of a gross leakage evaluation. The most direct method is to pressurize an isolated control room and record the pressurization flow rate required for maintaining a constant pressure. In the design phase, the pressurization flow rate can be estimated analytically by taking into account all identifiable leakage paths and applying appropriate pressure-flow rate equations.

The above approach characterizes the control room leak tightness in terms of a gross leakage rate. The calculated or measured gross leakage is used to determine the design basis infiltration rate that will be applied to the evaluation of the radiological consequences of postulated accidents. This rate is determined as follows:

1. The leakage from a control room pressurized to 1/8 inch water gauge is calculated on the basis of the gross leakage data. One half of this value is used to represent the base infiltration rate.

2. The base infiltration rate is augmented by adding to it the estimated contribution of opening and closing of doors associated with such activities as the required emergency procedures external to the control room.

3. An additional factor that is used to modify the base infiltration rate is the enhancement of the infiltration occurring at the dampers or valves upstream of recirculation fans. When closed, these dampers typically are exposed to a several inch water gauge pressure differential. This is accounted for by an additional infiltration contribution over the base infiltration at 1/8 inch water gauge.

It is anticipated that a better understanding and improved methods of evaluation of control room infiltration will be available in the future. An experimental program is planned for precise infiltration measurements of typical control rooms. The program will involve the use of tracer gases in a series of concentration decay measurements under a variety of atmospheric conditions. One of the objectives is to establish an empirical correlation between control room configuration, construction quality, and ventilation characteristics and its infiltration characteristics.

VII. Summary and Recommendations

Acceptance of a control room design with respect to General Design Criterion 19 is measured by its capability for protection against postulated accidents within or in the vicinity of the plant. The Regulatory staff reviews control room acceptability by evaluating radiation source and transport terms, and by applying conservative modeling of the control room ventilation system. A similar approach should be used by A/E firms in conjunction with control room design and equipment selection. This would provide for an earlier establish-

ment of an acceptable control room protection system, as well as reduce the efforts associated with design modifications resulting from Licensing technical review activities.

The approach outlined in this paper should be considered as the first step in establishing standard design specifications of control room ventilation systems. Combined efforts on the part of industry and the government should produce standard designs that are proven and that meet all applicable safety criteria, including Criterion 19.

The following recommendations are made on the basis of the present status of control room protection systems :

1. Consistent evaluation techniques should be employed when determining system acceptability under Criterion 19. This paper should supply much of the methodology required for consistent dose evaluation.

2. Dose analyses should be used as a design tool, at least until such time as the systems have been standardized and approved on a generic basis.

3. The capacity of the charcoal filters should be based on the dose evaluation. The design, installation, and maintenance of the filter systems should be based on recommendations provided in Regulatory Guide 1.52 and Reference 7 (WASH-1234).

4. Careful attention should be given to the placement of fresh air inlets. They should be kept away from exhaust vents or other potential release points of toxic or radiological materials.

5. The structural details of the control room should be such as to limit infiltration when the room is isolated. All penetrations should be sealed, doors should be made leaktight with high quality weatherstripping, low leakage dampers or valves should be used, exhaust fans should be stopped, and the air balance of the entire control building reviewed to assure that inadvertent enhancement of inleakage will not occur as a result of poor system design or operation.

6. All emergency conditions (e.g., fire, smoke, toxic gas,) including radiological releases should be identified and the proposed concepts for control room emergency ventilation systems reviewed against the entire spectrum of postulated events to assure adequate protection.

VIII. References

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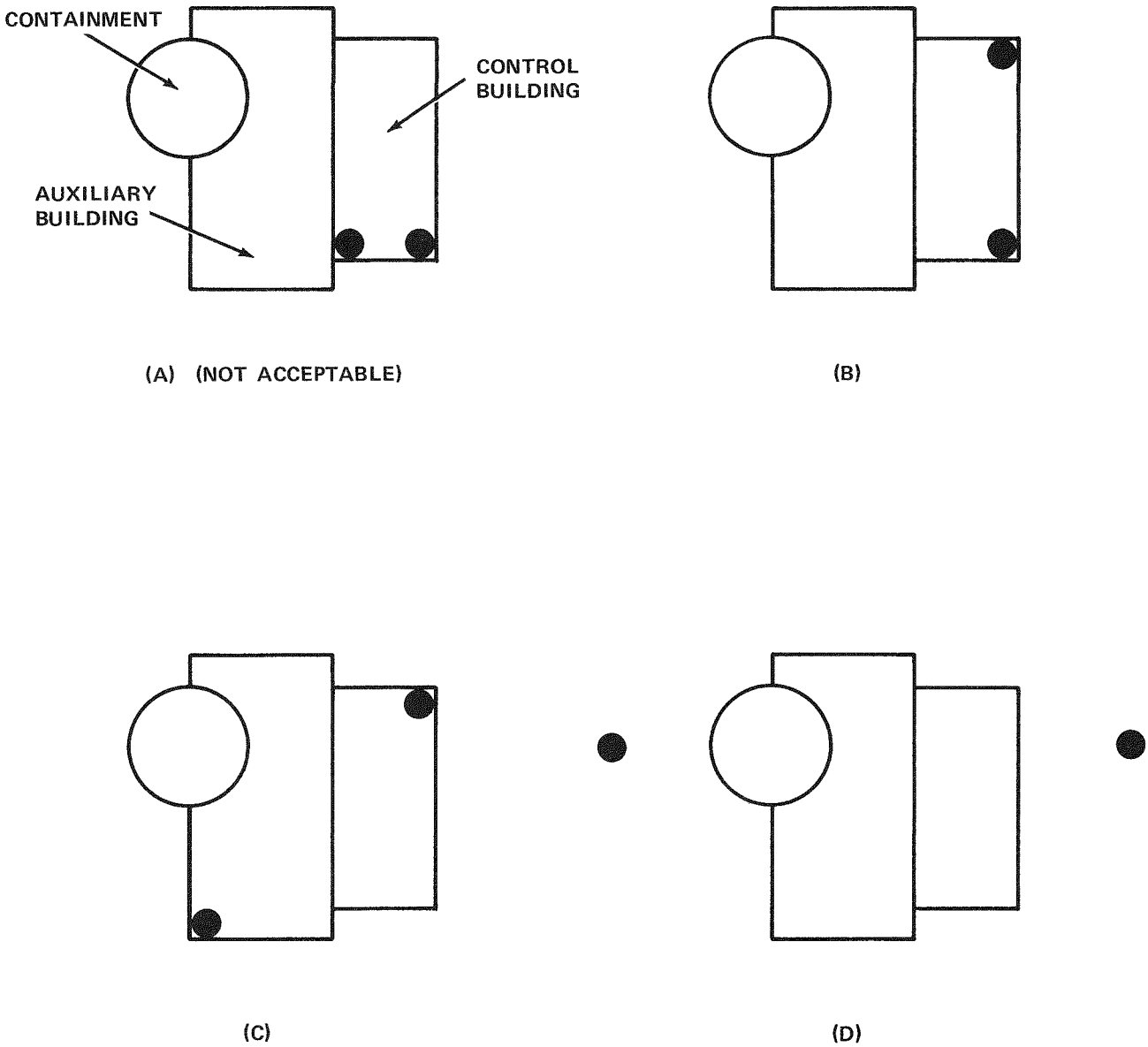


Figure 1 Alternative Locations for Dual Inlets

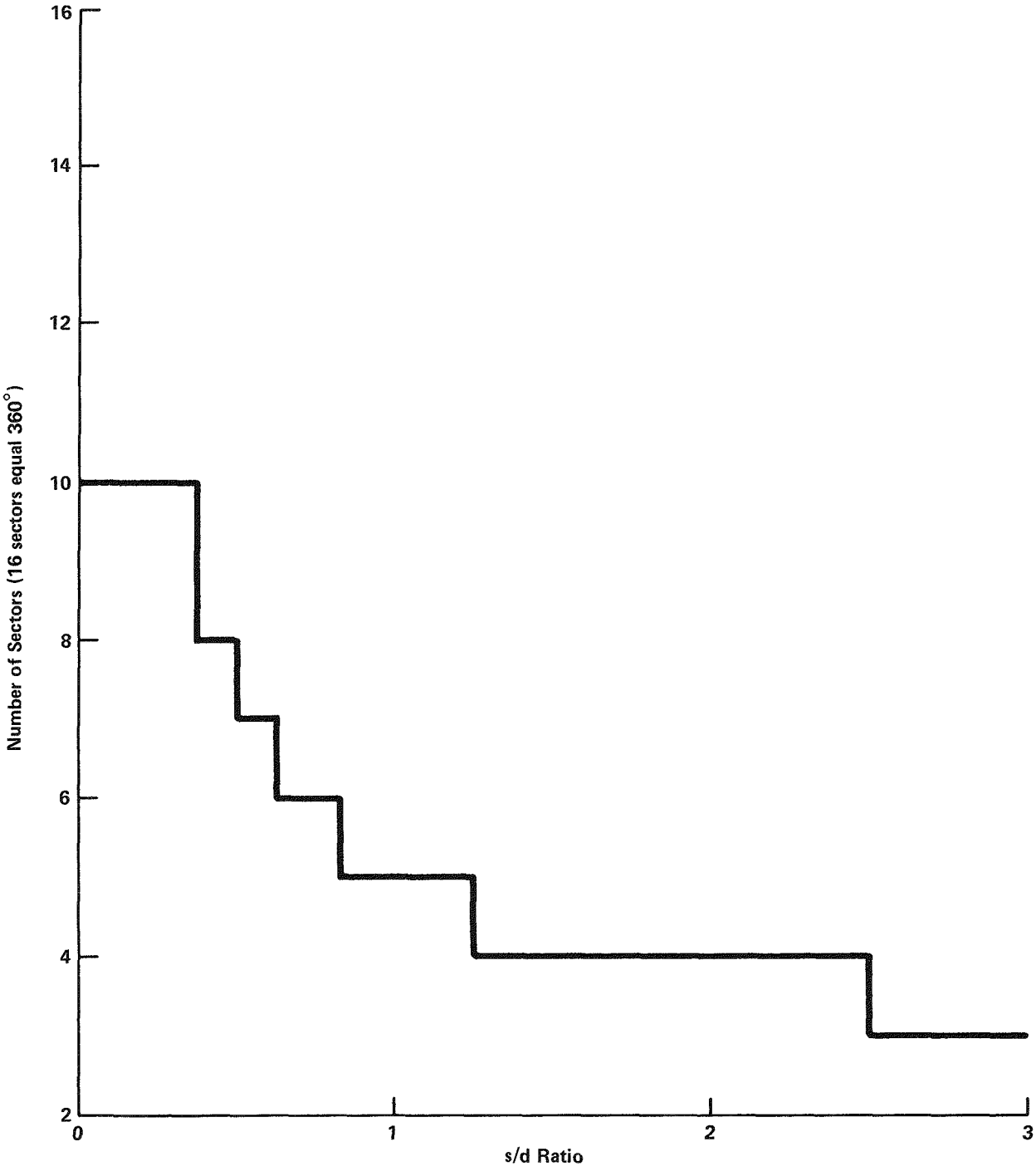


Figure 2 Number of Wind Direction Sectors to be Used in Determining Wind Direction Frequency and Wind Speed

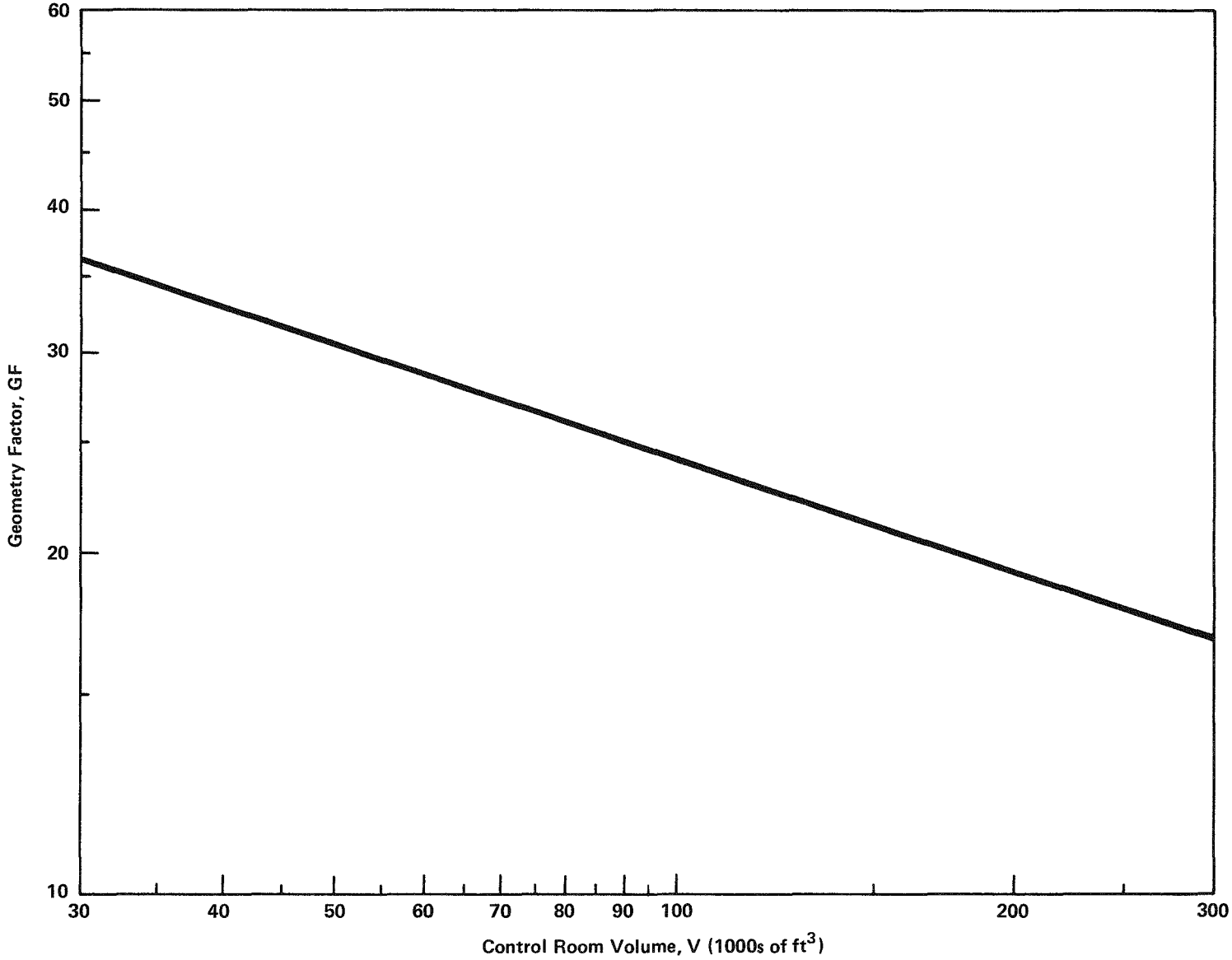
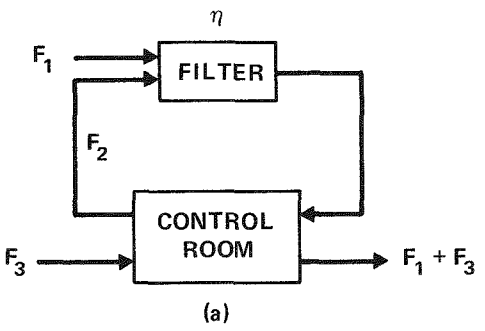
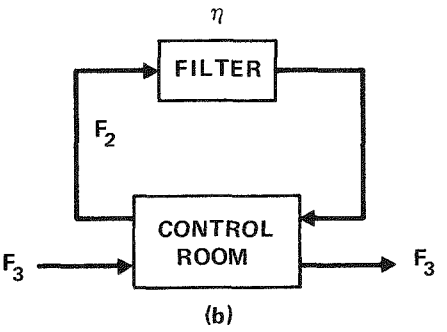


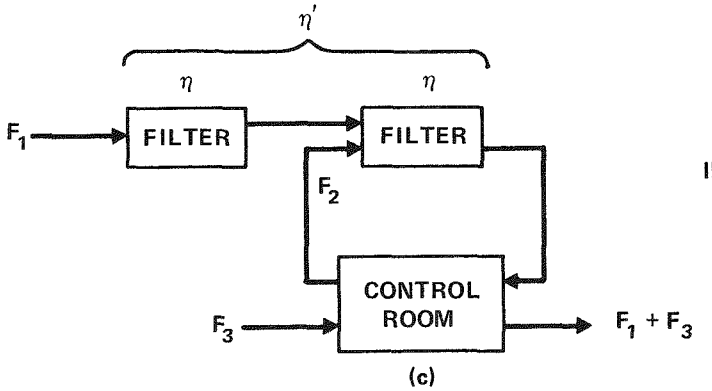
Figure 3 Infinite-to-Finite Cloud Geometry Factor vs. Control Room Volume



$$IPF = \frac{F_1 + \eta F_2 + F_3}{(1-\eta)F_1 + F_3}$$



$$IPF = \eta\frac{F_2}{F_3} + 1$$



$$IPF = \frac{F_1 + \eta F_2 + F_3}{(1-\eta')F_1 + F_3}$$

Figure 4 Selected Control Room Filter Models

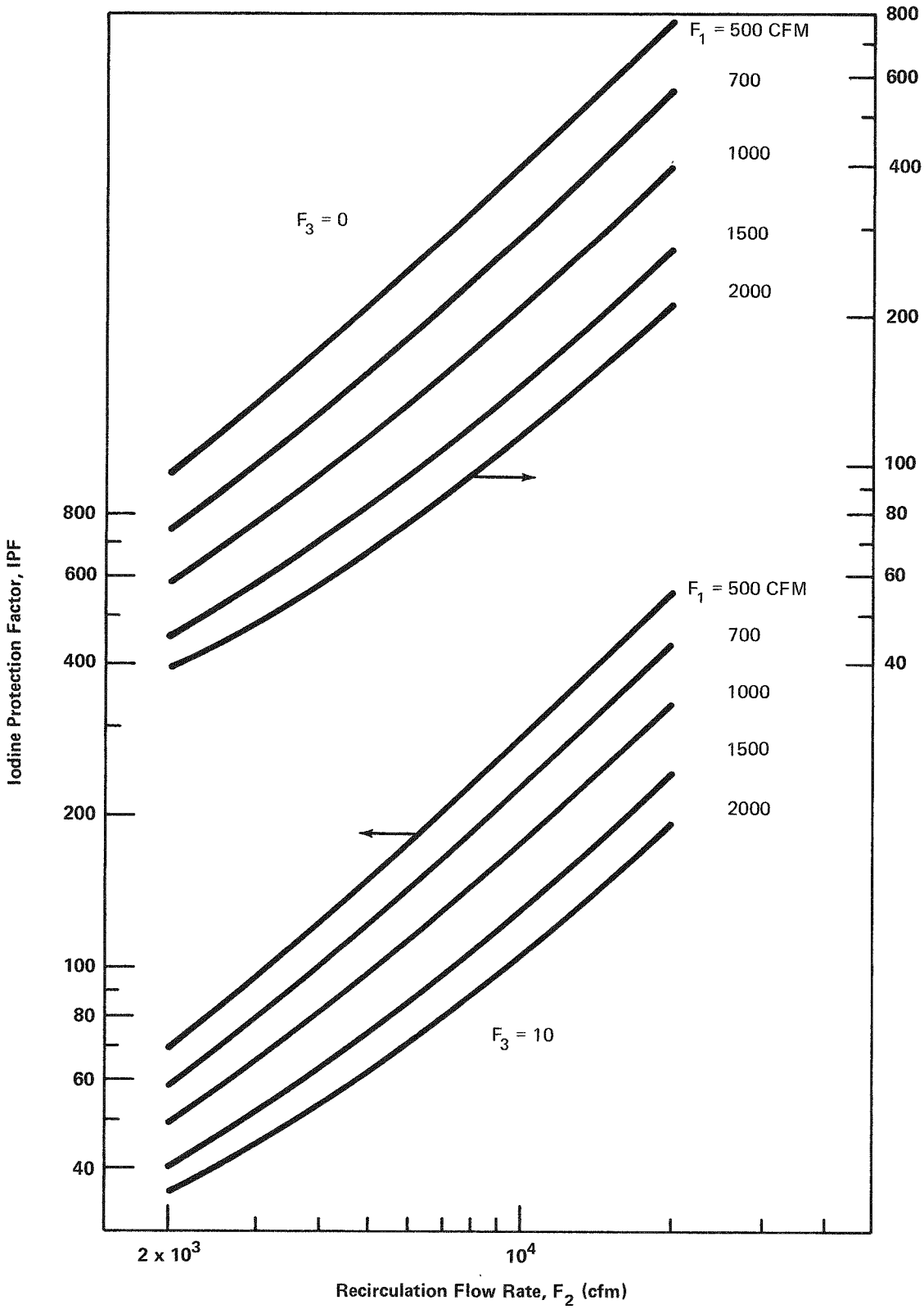


Figure 5 Iodine Protection Factor as a Function of F_1, F_2, and F_3 for a Filter Efficiency of 95%

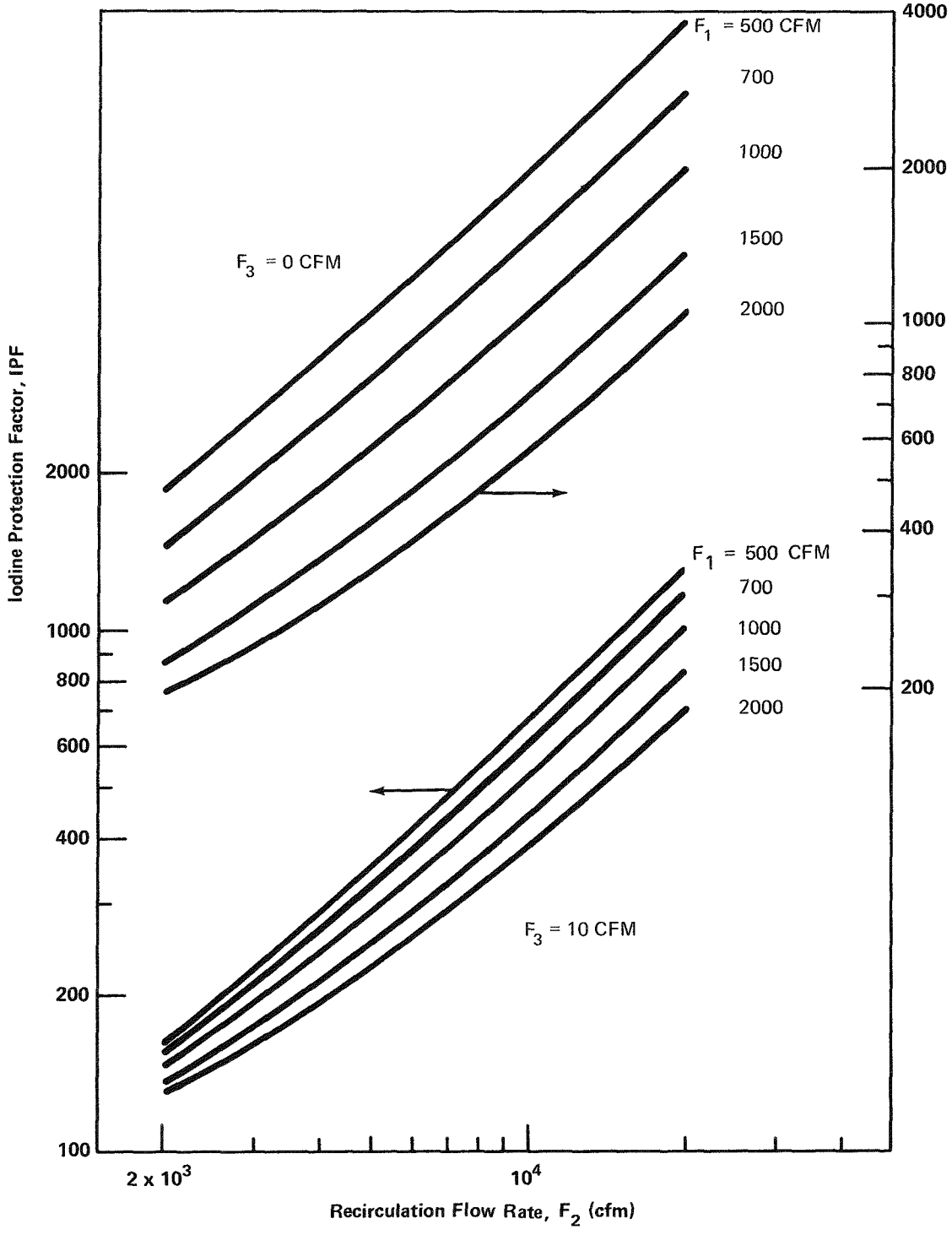


Figure 6 Iodine Protection Factor as a Function of F_1, F_2, and F_3 for a Filter Efficiency of 99%

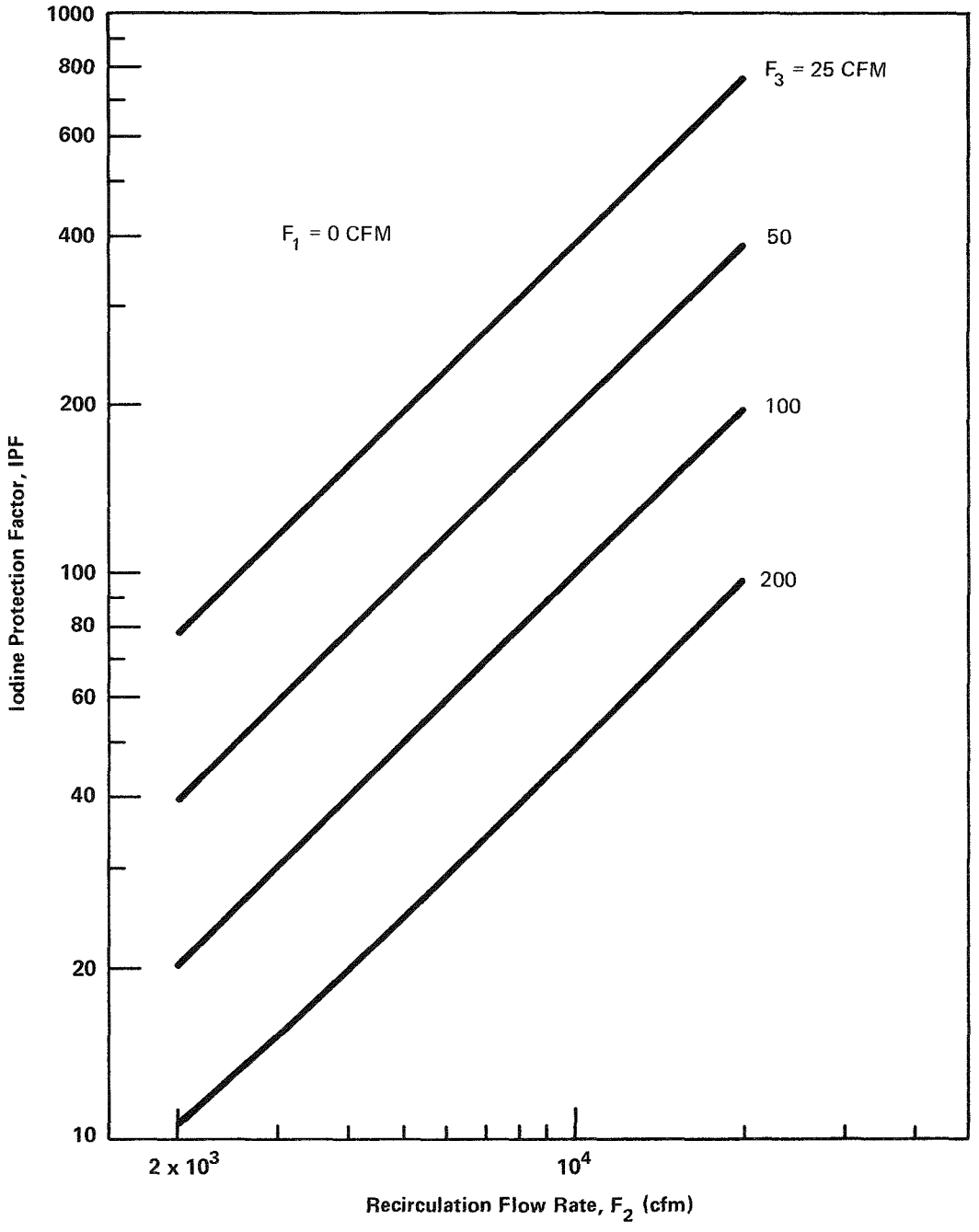


Figure 7 Iodine Protection Factor as a Function of F_2 and F_3 for a Filter Efficiency of 95%

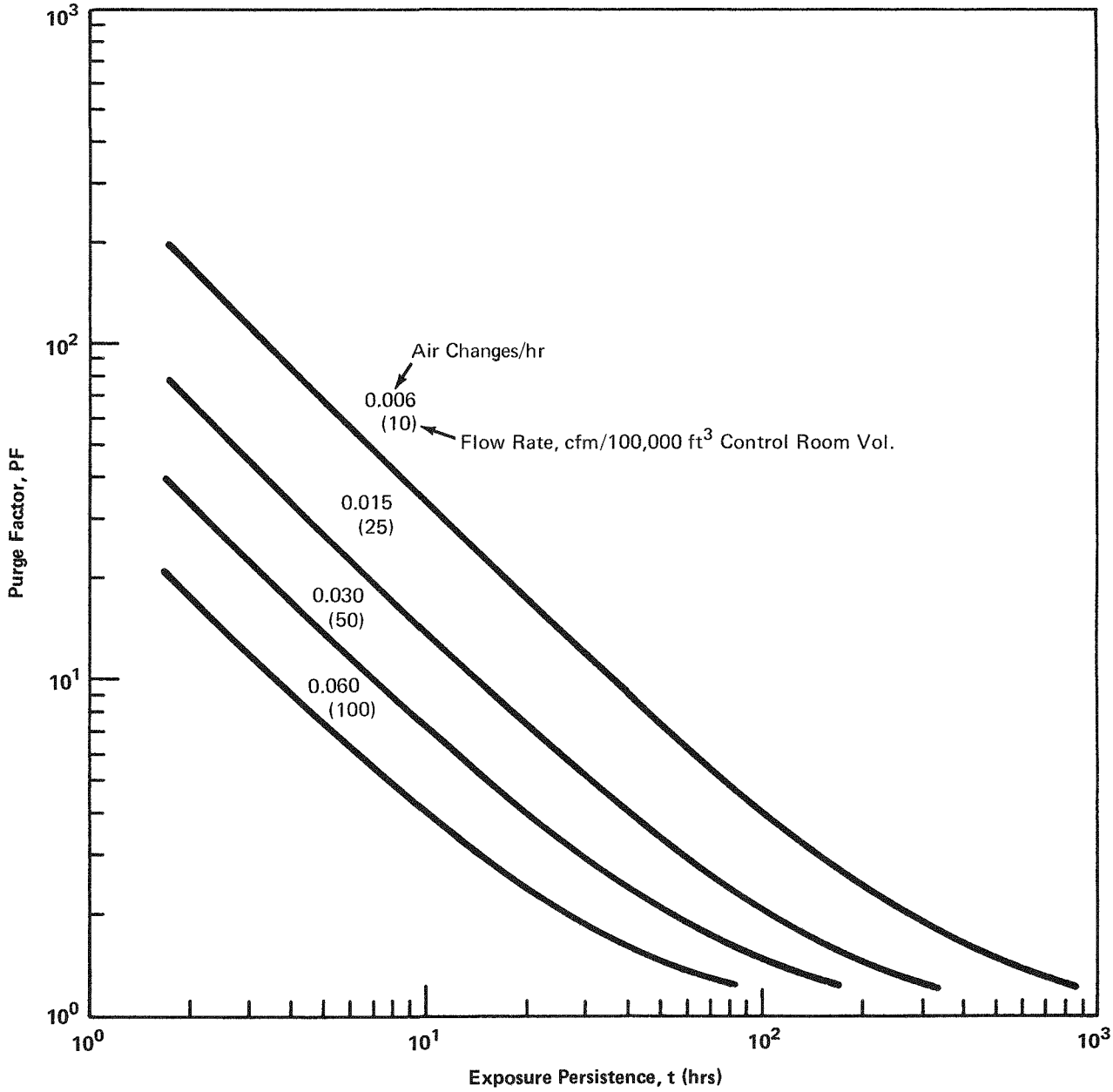


Figure 8 Purge Factor as a Function of Time for Several Infiltration Rates

DISCUSSION

SULLIVAN: This may be a little bit off the subject. Have you seen any designs for the incorporation of devices in control room ventilation systems that take into account possible hazardous chemical releases, namely chlorine?

MURPHY: For chlorine, I think that immediate isolation of the control room is the first defense against such a release. Unfortunately, I think we also have to rely on breathing apparatus for further protection in very severe accidents (we'll call them design basis type accidents) where we assume the entire chlorine car ruptured. We know that charcoal filters can be effective against chlorine. We believe that their use in chlorine accidents will help mitigate most of the lower spectrum of such incidents.

SULLIVAN: The reason I asked the question is that at the Midland Plant, we are going to be supplying process steam to the Dow Chemical Company. Being close to Dow presents some unique problems for us in this respect.

MURPHY: A regulatory guide specifically for the problem of chlorine is now underway and hopefully will be in the public document room within a month or two. This will help to determine the necessary control room protection.

DODDS: Do you have any data that has come out from plants to justify your infiltration assumptions?

MURPHY: To my knowledge there are no data on control room infiltration or infiltration of a similar structure that is so leak-tight. Of course, we know about infiltration for conventional buildings. The National Bureau of Standards, under an AEC contract, will be doing tracer tests on control rooms to determine infiltration rates and, in this way, we will be able to determine whether our present assumptions are valid.

MOELLER: You showed bottled gas being used to pressurize the control room. What is the comparison of the efficiency of using bottled air for that versus using it as a source of individual air supply to the people in the room?

MURPHY: It's much poorer. You see, what we're hoping to do here is to keep a shirt-sleeve environment inside the control room. We might be hurting in terms of whether we used bottled air to pressurize the entire room versus its use in breathing apparatus. However, I think we gain an awful lot in maintaining a shirt-sleeve environment during emergencies.

KOVACH: On the completion of the NBA study, will you consider revising the new guide?

MURPHY: Which guide is this?

KOVACH: Your assumption is based on 10 CFM. I believe the rates are considerably lower.

MURPHY: We will adjust our assumptions to bring them in line with our test findings.

PASSISI: I notice you used the paper of Halitsky as a source. I'm wondering, considering some of the discrepancies in the original Halitsky paper, if you had considered using another dilution model?

MURPHY: We have looked at the applicable wind tunnel tests and all of the field tests that are available to us and we find nothing in all of these tests to show that our modeling is not appropriate. Our position is an interim one. It requires further study, I'm afraid, in terms of both the wind tunnel testing and actual field testing, to determine whether this interim position is far off.

PASSISI: You also made reference to a 95 percent efficient charcoal filter. I wonder if you have considered the removal of particulate iodine by HEPA filters. Are you making an assumption that a certain fraction of the particulates of iodine that would be left in the containment after the initial spray action would be the type of iodine released?

MURPHY: Under most circumstances the iodine that is released to the environment is principally organic and not particulate.

PASSISI: That's contrary to Regulatory Guide 1.4 in terms of the fractions of particulate iodine left after the spray has eliminated the bulk of the elemental iodine. In a PWR with sprays, 40% of the iodine left after the first half hour of spray operation will be particulate.

MURPHY: We usually do not take any credit for the removal of particulate by the HEPA filter, since it usually results in a small dose reduction. It should be noted that the particulate will be reduced to low concentrations after about ten hours of spray operation. The iodine that is subsequently released will be essentially all organic. Nevertheless, an allowance based on HEPA filtration of particulate would probably be acceptable to the Regulatory staff.