CONF-840806--2

DP-MS-83-136

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William C. Perkins and Dean H. Stoddard
E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, South Carolina 29808-0001

DP-MS--83-136

DE84 014961

A paper proposed for presentation at the
18th DOE Nuclear Airborne Waste Management and
Air Cleaning Conference,
Baltimore, Maryland, August 13-16, 1984
and for publication in the
Proceedings of the Conference

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A DISPERSION MODEL FOR AIRBORNE PARTICULATES INSIDE A BUILDING*

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Abstract

An empirical model has been developed for the spread of airborne radioactive particles after they are released inside a building. The model has been useful in performing safety analyses of actinide materials facilities at the Savannah River Plant (SRP), operated for the U.S. Department of Energy by the Du Pont Company. These facilities employ the multiple-air-zone concept; that is, ventilation air flows from rooms or areas of least radioactive material hazard, through zones of increasing hazard, to a treatment system.

A composite of the data for dispersion of airborne activity during 12 actual case incidents at SRP forms the basis for this model. These incidents occurred during approximately 90 plant-years of experience at SRP with the chemical and metallurgical processing of purified neptunium and plutonium after their recovery from irradiated uranium.

The model gives ratios of the airborne activity concentrations in rooms and corridors near the site of the release. All data are normalized to the data from the air sampler nearest the release point. The model can be applied in predicting airborne activity concentrations from particulate releases elsewhere, if the facility in question has similar features of floor plan, air velocity, and air flow direction.

The multiple-air-zone concept has been applied to many designs of nuclear facilities as a safety feature to limit the spread of airborne activity from a release. The model illustrates the limitations of this concept: it predicts an apparently anomalous behavior of airborne particulates; namely, a small migration against the flow of the ventilation air. The following phenomena are suggested as possible mechanisms for this migration:

- eddy currents in the air flow
- leaks of ventilation air between zones
- open doors
- movement of personnel during an incident
- inadequate flow of ventilation air
- thermal gradients

* The information contained in this article was developed during the course of work under Contract DE-AC09-76SR00001 with the U.S. Department of Energy.

I. Introduction

This report documents the results of an effort at the Savannah River Laboratory (SRL) to construct a model to predict, in accident situations, the potential range and magnitude of the spread of airborne activity inside a processing building. The model is restricted to glovebox and cabinet facilities in which actinides, including plutonium and neptunium, are handled. In some Savannah River Plant (SRP) facilities, purified plutonium and neptunium are converted to final form, such as compacted oxides. In others, scrap materials are prepared for recovery. In all cases, the multiple-air-zone concept* was used in the design of the ventilation system.

The decision was made early not to attempt a theoretical calculation of the model from first principles. The difficulty in accounting for the many perturbing influences was deemed too large. Rather, an empirical model was planned, to be based on experience at SRP.[1,2] These decisions prompted an extensive research of SRP history that identified a limited, but sufficient, number of case incidents to supply data for a model. The details of each case were obtained from a variety of informal sources, such as personal recollections, air sampler logsheets, and heating/ventilation blueprints. None of these incidents resulted in injury to any personnel or in a release to the environment. Since these case incidents occurred in actinide materials handling facilities, the resulting model applies only to airborne <u>particulate</u> actinides, as opposed to gases and fission products.

II. The Dispersion Model

Only data from incidents in actinide materials facilities at SRP operating under the multiple-air-zone concept are used in the model. The data are taken from reliable measurements of airborne activity concentrations recorded soon after these incidents. However, the model should be regarded as an order-of-magnitude method for estimating the consequences of an accidental release of particulate activity, since its precision has not been evaluated.

Discussion

In each of the incidents ~~that form~~ used to develop the model, the airborne particles tended to migrate upstream against the prevailing flow of ventilation air. It is this apparently anomalous behavior that makes theoretical calculation of this phenomenon difficult and potentially ineffective. Consequently, an empirical model based on actual incidents was considered the more practical approach. The following are suggested mechanisms for the observed upstream migration:

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* In the multiple-air-zone concept, ventilation air flows from clean areas through areas of increasing potential for radioactive contamination.

- eddy currents
- leaks of ventilation air through barriers
- movement of personnel during the incident
- low ventilation air flow
- temperature gradients

Some of the incidents used in the model illustrate situations where one or more of these mechanisms have been identified as a principal factor in a given release.

The model does not depend on the mechanism of a release or on the energy involved in causing the release. Although the input incidents involve only low-energy events, the model may be applicable to some high-energy events* if the following assumptions are acceptable.

- Since the lifetime of a shock wave from a high-energy event is much shorter than the sampling time for airborne activity, the temporary effect of the shock wave is not considered separately.

- Missiles tend to travel in a straight line, and their effect on migration of the lighter airborne particulates from the room is negligible.

- The spread of airborne activity beyond the immediate area (to other rooms or corridors) is independent of the amount of force causing the initial release. On this basis, as long as the room and cabinet ventilation systems are not damaged, the migration from the room soon after the release is the same for a low-energy release and a high-energy release.

The model is a set of ratios that describe, in terms of range and magnitude, the spread of airborne activity, given that a release occurs. Each ratio represents the maximum activity that reaches a given point with time, since only the highest concentration measured at any point is used in the model.

Features

The specific features of this model are presented in Table 1 and are shown superimposed on a typical floor plan in Figure 1. Each airborne activity value is normalized to the value from the air sampler nearest to the release point, usually in the Operating Room. Normalized values from SRP incidents are averaged to provide the model values. Table 1 also shows the specific source incident and position from which each input value was taken. The design basis for the SRP facilities, on which this model is based, is shown in Table 2 along with the operating ranges for the case incidents.

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* A high-energy event is defined as one with sufficient energy to potentially destroy both the primary containment (vessel) and the secondary containment (cabinet). A leak is an example of a low-energy event.

The data indicate that undirected releases from these SRP facilities distribute unequally between the Maintenance Room (MR) and the Operating Room (OR). The ratio is almost 5 to 1. This rather high ratio indicates that, due to the design of SRP cabinets, non-directional events would be vented more to the MR (Position 2) than to the more-frequently-occupied OR (Position 1).

The entry to the OR is an important barrier to the spread of airborne activity. The model gives two different values for Position 3, depending on the efficiency of this barrier. Position 3A represents a relatively inefficient barrier, such as a single door with a low pressure differential, louvers in the door, and/or openings around the door. Position 3B represents an efficient single door or an airlock, i.e. two doors with an air supply between them. Therefore, Figure 1 shows three entries to the OR: an airlock (3B), an efficient single door (3B), and an inefficient single door (3A).

The concentration of airborne activity migrating down corridors to nearby rooms is dependent on the value at Position 3. Consequently, two values are given for Positions 5 and 6, using data from appropriate incidents (hallway migrations) and either Position 3A or 3B. (See Figure 1 and the footnotes to Table 1.)

In contrast to the data in Table 1 which involves both physical barriers and distance, Table 3 gives the effect of distance only. These values are normalized and averaged values from incidents (1, 6, 8) where several measurements were made in a room.

III. Accident Analysis

The quantity of radioactive material involved in an accidental release is not predicted by the model. Such data must come from other analyses. If the airborne activity at the monitor nearest the release (C_1) is known, the airborne activity concentration outside the operating room (C_{3B}) is:

$$C_{3B} = \frac{0.028}{100} C_1$$

The concentration at another position may be calculated from C_1 and the appropriate ratio from the model.

IV. Basis for the Model

The model is based on the data available from incidents at SRP that meet the following criteria:

- An event releasing significant airborne activity in particulate form from a containment structure, such as a glovebox. (Note that small releases become indistinguishable from background at short distances from the release point.)
- A multiple-air-zone concept for ventilation of the area.
- Adequate instrumentation for data collection.

Description of Air Samplers

Input data for the model was obtained mainly from air samplers that measure room air activity by collecting samples of particulates in the air. These samples are considered representative of air present in the room and are converted to an average concentration for the time period of the sample.

Samples are collected by filtration or by impaction. The filtration method draws air at 6 cfm through a fiberglass filter paper. The impaction method draws air through an orifice and impacts it on a planchet at 40 cfm. With the sample rate and collection efficiency known, the collected sample is counted to determine the concentration of activity present. Some filtration and impactor samples are counted while being collected; these counters are connected to a high-activity alarm system. These devices are called constant air monitors (CAM).

Case Incidents

The twelve incidents used to form this model are listed in Table 4 and are discussed individually below. In most cases, the vicinity of the release was either unoccupied or occupied by workers already wearing protective clothing and masks. Evacuation of the work area and the surrounding areas prevented exposure of other personnel. In no case was there a significant release of radioactive material to the environment.

Glovebox Fire. An overheated piece of equipment started a fire in a glovebox containing dry PuO_2 and PuF_4 powders. A plastic bag melted on a bagport near the fire, releasing airborne Pu activity to the room. Of the three entries to this room, the one nearest the fire was apparently sealed so that no air or activity moved past it, the one directly across the room was louvered for air passage but air flow through it was practically nonexistent at the time, and the door most remote from the fire was solid (non-louvered) with a small space underneath.

A simplified drawing, showing air flow directions and the relative airborne activity concentrations taken from air sampler and constant air monitor (CAM) data, is given in Figure 2. Air is supplied directly to each room from ducts shown in Figure 2. Air exhausts from the room through the glovebox, a chemical hood, and a wall-mounted exhaust fan. The pressure differential between the room and the glovebox is normally about 0.05 in. H_2O.

Cabinet Fire. A fire started from an overheated piece of equipment in a glove cabinet containing dry wastes contaminated with plutonium. A cabinet glove burned, releasing airborne Pu activity to Operating Room 1. Entry to this room is by a door from Operating Room 2 (OR2) and by an airlock to a personnel corridor. Constant Air Monitor (CAM) data, verified by impactor sampler data 500 ft^3 of air), showed no detectable airborne activity in OR2, in the airlock, or in an adjacent control room. (Pressure differentials for ventilation air at these doorways are maintained between

0.01 and 0.10 inches of H_2O.) Pressures inside cabinets are maintained between 0.7 and 1.0 inches of H_2O below the operating rooms. Maintenance rooms (MR) behind the cabinets are maintained at 0.01 to 0.10 inches of H_2O below the operating rooms.

A schematic drawing of this incident is shown in Figure 3. Air locks in this area are about 8 ft x 8 ft x 8 ft with ventilation air supplied from the ceiling. Doors are solid (not louvered) with narrow spaces beneath. Air flows into an air lock from the personnel corridor and then from the air lock into the operating room. Air is also supplied to operating rooms through ceiling diffusers and exits the rooms through wall-mounted grilles near the floor. A relatively small amount of room air also exits through the cabinets. OR1 is about 40 ft long and 10 ft wide.

Damper Malfunction. Glove cabinets were pressurized briefly when a mechanical malfunction occurred in a cabinet exhaust damper. Airborne activity measurements showed that the activity on the maintenance side (MR) of the line was 8.0 times that on the operating side (OR). No activity was detected in the OR or MR airlocks.* This incident is shown in Figure 4, and occurred in the same facility as Incident Number 2. Cabinet air pressure in this line is normally maintained between 0.7 and 1.0 inches of H_2O below the Operating Room air. The pressure differential between the Operating Room and the Maintenance Room is maintained between 0.01 and 0.10 inches of H_2O; the Maintenance Room is at a lower pressure so that any leakage of ventilation air goes from the Operating Room to the Maintenance Room.

Routine Maintenance. This case is composed of data from three typical maintenance jobs where containment was broken for the work, and small airborne releases were recorded in the Maintenance Room. The average airborne activity concentration in the MR airlock was 0.7% of the activity in the MR. The average outside the MR airlock entry was <0.015% of the activity in the MR. The movement of workers through the airlock may explain these relatively-high, average-concentration ratios.

These jobs were performed on the same facility described in Incidents 2 and 3, Figures 3 and 4.

Filter Change Error. Cabinet ventilation was accidentally lost for about two minutes during routine filter change operations in the cabinet exhaust treatment system. During this time the pressure inside the cabinets was higher than the pressures in the operating and maintenance room; the ventilation and room exhaust

* The OR1 airlock value is calculated by:

$$\frac{100}{800} \times (<0.1) = <.01$$

systems were not affected by the maloperation of the cabinet exhaust system. The cabinets are designed to allow some inleakage from the operating and maintenance rooms into the cabinets. Loss of the cabinet ventilation caused an air reversal at these inleakage points, releasing particulate contamination to both sides of the cabinet. The airborne activity concentration in the MR was 4.15 times that in the OR (see Figure 5). Airborne activity was not detected in the MR airlock; the concentration there was ≤ 0.017 times the OR concentration. See Incident 2 for ventilation details.

<u>Pressurized Containment Hut</u>. A temporary containment hut was constructed in a regulated corridor near a scrap processing facility. Air flow into this hut was 140 linear ft/min (1250 cfm) from ventilators in the corridor ceiling. The hut was being used to open shipping packages containing plutonium oxide scrap from offsite, and the packages were not expected to be pressurized. However, when one of the packages was opened, the contents (several welded cans) were suddenly expelled from the container along with a puff of aerosol (smoke). The operator felt a surge of pressure against his protective suit. Some of the airborne alpha activity detected outside the hut may have escaped through a 6-in. flap in the wall of the hut. A schematic drawing of this incident is shown in Figure 6. Dimensions of the corridor are about 5 ft wide and 25 ft long. To extract adequate data from this incident, it was necessary to use some values from portable air samplers.

<u>Unexpected Reaction in a Scrap Dissolver</u>. An unusual reaction occurred in a small scrap dissolver, probably because the scrap contained traces of plutonium hydride. Although no process material was observed outside the dissolver (on the cabinet floor), air samples were taken in the maintenance and operating rooms. The airborne activity concentration in the maintenance room was 2.5 times that in the operating room. The pressure inside this cabinet is maintained about 0.9 inches of H_2O below the operating room and about 0.8 inches of H_2O below the maintenance room. Pressure in the maintenance room is about 0.1 inches of H_2O below the pressure in the operating room. No airborne activity was detected in any of the airlocks (see Figure 7).

<u>Release to Corridor</u>. While operators in a storage room were trying to loosen a stuck cap on a $^{238}PuO_2$ container, an airborne activity release occurred. Airborne activity was detected in the regulated personnel corridor and some other process rooms, as shown in Figure 8. Some other rooms may have been contaminated, but data are not available. Typically, air flows at about 50 cfm, from this regulated corridor into the process rooms where measurements were made. This corridor is about 6 ft wide. Air is supplied to each room in this area, but not to the regulated corridor. Air exhausts from each process room through a room exhaust system.

<u>Leak to Cabinet Sump</u>. Corrosion caused a leak in a vessel located in a ^{238}Pu scrap recovery facility consisting of several gloved cabinets. This leak dripped into a cabinet sump under the leaking vessel. The liquid-detector in the sump failed to alarm. Airborne alpha activity spread from the cabinet to the operating

room and to the regulated corridor outside the entry door, as shown in Figure 9. The release to the corridor was aided by low air flow from the regulated corridor into the operating room and by openings around the entry door. The widths of the operating room and the regulated corridor are each about 5 feet. Activity was undetectable in nearby rooms.

Building Air Reversal. Malfunction of the building air-supply fans caused an air reversal in a process area. Airborne activity was released from facilities in one room and migrated through the doorway into the regulated corridor as illustrated in Figure 10. This door is solid (non-louvered) with small tolerances on each side.

Glove Failure. Failure of a glove on the maintenance side of a process cabinet released airborne Pu activity to the maintenance room (MR). The activity migrated into the airlock adjoining the MR entry door. The airlock is about 5 ft wide. Other distances and air flow directions are shown on Figure 11. The entry to the MR from the airlock is a single, nonlouvered door. No activity was detected in a second airlock at the OR entry.

Release During Container Removal. As a product secondary container was moved from a cabinet to the entry hood, airborne Pu activity was released into the maintenance room (MR), apparently because of low air flow into the entry hood. This activity migrated to other regulated rooms and facilities in this building, as shown in Figure 12, partly because of a ventilation air inbalance in the building at the time. Subsequent helium leak tests revealed a migration path through some electrical conduits connecting some of the rooms. These paths were closed.

Ventilation air flows from the operating area (OR) to the maintenance area (MR) through racks at each end of the process line. The pressure differential is about 0.02 inches of H_2O. Air exhausts from the maintenance area through filters below each cabinet on the maintenance side. There are airlocks at each entry; each airlock has an air supply in the ceiling (see Figure 12).

V. Conclusions

It is concluded that the multiple-air-zone concept is an effective method of controlling released airborne particulate activity.

Since the model is based on average values from actual incidents, it may provide a method for assessing the efficiency of safety features in mitigating the consequences of incidents in other facilities. Should airborne activity migrate substantially more than predicted by the model, analysis should be made to determine why the multiple-air-zone concept, combined with physical barriers, fails to provide effective containment.

VI. Acknowledgment

The authors wish to acknowledge the advice and direction of W. S. Durant and W. V. Wright in the preparation of this model and also the assistance of personnel of the Separations Department, Health Protection Department, and Separations Technology Section of the Savannah River Plant in obtaining the necessary data.

VII. References

1. E. B. Sheldon, et al. Experience with Processing Irradiated Fuel at the Savannah River Plant (1954-1976). USERDA Report DP-1467, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC (September 1977).

2. M. L. Hyder, et al. Processing of Irradiated Enriched Uranium Fuels at the Savannah River Plant. USDOE Report DP-1500, E. I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC (April 1979).

Table 1. Dispersion values.

Position Description	Relative Activity*	Source of Activity Value			Model Value**
		Incident Number	Figure Number	Position Number	
1. Operating Room (OR)	100	-	-	1	100
2. Maintenance Room (MR)	800	3	4	2	
	415	5	5	2	
	250	7	7	2	490
3. Outside Single OR Entry Door:					
A. Low Air Flow	1.4	1	2	4	
	0.58	1	2	5	
	0.7	4	-	-	
	2.7	9	9	2	1.4
B. High Air Flow	0.005	2	3	2	
	0.005	2	3	3	
	0.01	3	4	4	
	0.004	5	5	4	
	0.022	10	10	2	
	0.048	11	11	2	
	0.1	12	12	4	0.028
4. Outside Airlock	<0.005	2	3	†	
	<0.01	3	4	†	
	0.015	4	-	-	
	<0.004	5	5	†	
	0	11	11	3	
	0.02	12	12	5	
	0	12	12	6	0.008
5. Regulated Corridor					
A. from 3A	0.28	1	2	6	
	0.38	6	6	††	0.33
B. from 3B	0.008	6	6	††	
	0.016	9	9	3	0.012
6. Nearby Room					
A. from 3A	0.12	1	2	7	
	0.007	6	6	††	
	0.27	8	8	¶	
	0.17	8	8	¶	0.14
B. from 3B	0.00015	6	6	††	
	0.006	8	8	¶	
	0.004	8	8	¶	
	0.006	9	9	4	0.0040

* Normalized to: Position 1 = 100

** Average of Relative Activity Values

† Inferred Value; not shown on the figure

†† Calculated from: (Figure 6, Position 2 or 3) x (Model Value, Position 3A or 3B)

¶ Calculated from: (Figure 8, Position 2 or 3) x (Model Value, Position 3A or 3B)

Table 2. Pressure differentials for ventilation air.

	ΔP (in H_2O) Between		
	OR and Corridor	Cabinet and OR	MR and OR
Case Incidents:	0.01 - 0.1	0.7 - 1.0	0.01 - 0.1
Design Basis:	*	0.8	*

* Designed to maintain ventilation air flow toward areas of increasing potential contamination on a once-through basis. The ranges necessary to meet these bases at all points are taken from the Case Incidents.

OR - Operating Room

MR - Maintenance Room

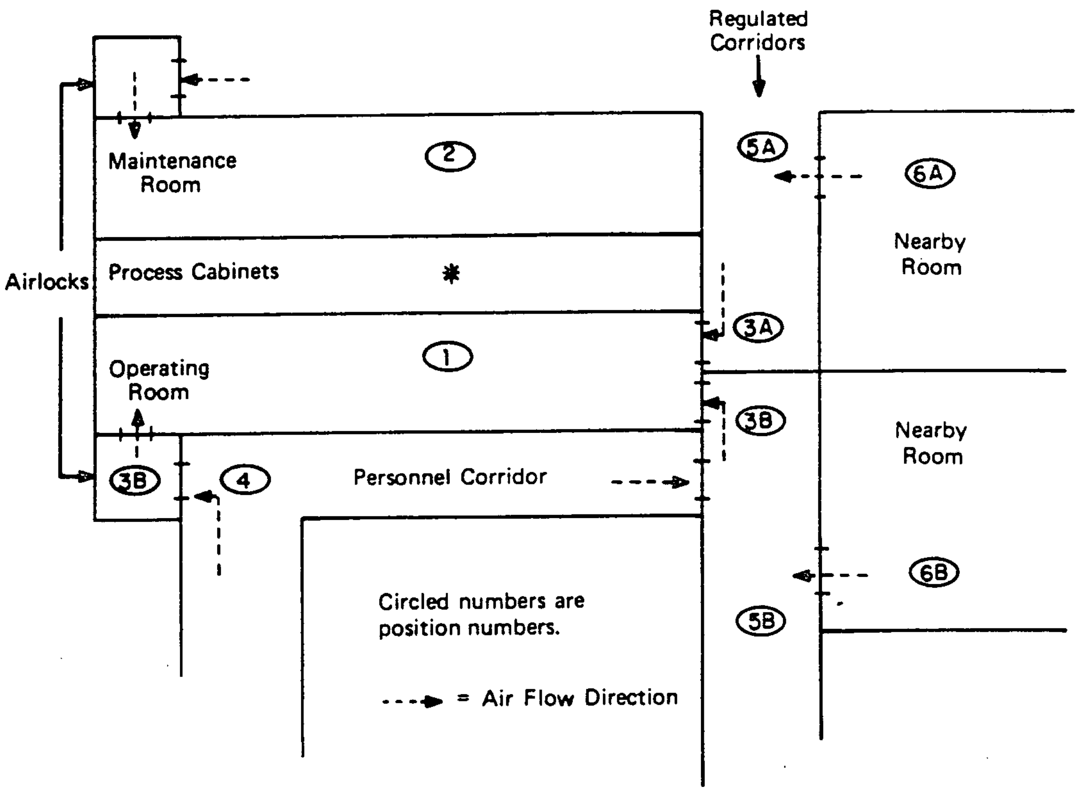
Table 3. Effect of distance on the concentration of airborne activity.

Distance from Release, ft	Source of Value: Figure Number	Source of Value: Incident Number	Source of Value: Position Number	Value	Model Value*
0	-	-	-	-	100
12	12	12	2	38	40
15	2	1	2	7	
	6	6	2	27	20
21	2	1	3	3.3	
	6	6	3	0.5	
	12	12	3	5.0	3

* Average value; one significant figure.

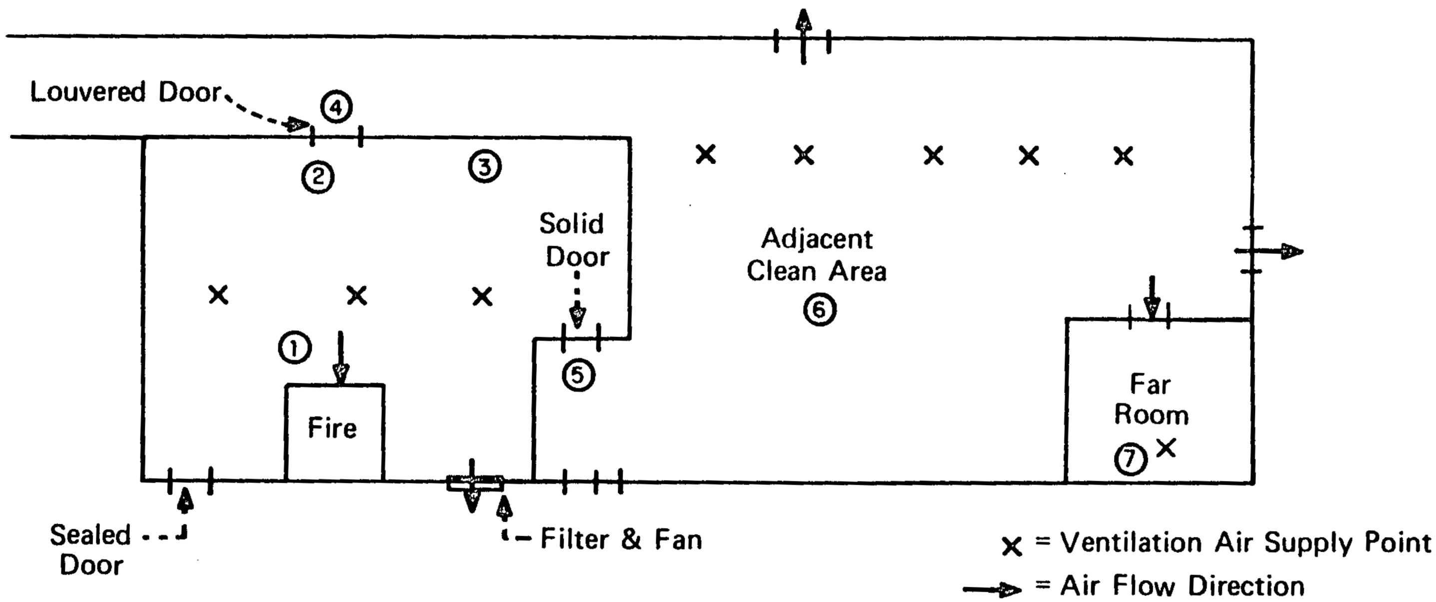
Table 4. Incidents used in the model.

Incident Number	Figure Number	Incident Description
1	2	Overheated equipment started fire in glovebox containing Pu, bagport breached.
2	3	Overheated equipment in cabinet started fire, glove breached.
3	4	Exhaust damper malfunctioned, cabinets pressurized.
4	-	Routine maintenance work, containment opened.
5	5	Cabinets pressurized during filter change.
6	6	Pressurized package of Pu scrap opened in a temporary hut.
7	7	Uncontrolled reaction in a scrap dissolver.
8	8	Release to regulated corridor from pressurized PuO_2 container in storage room.
9	9	Undetected leak to cabinet sump under Pu scrap dissolver.
10	10	Air reversal in Np process area.
11	11	Pu cabinet glove failure.
12	12	Release from cabinet during removal of a container.



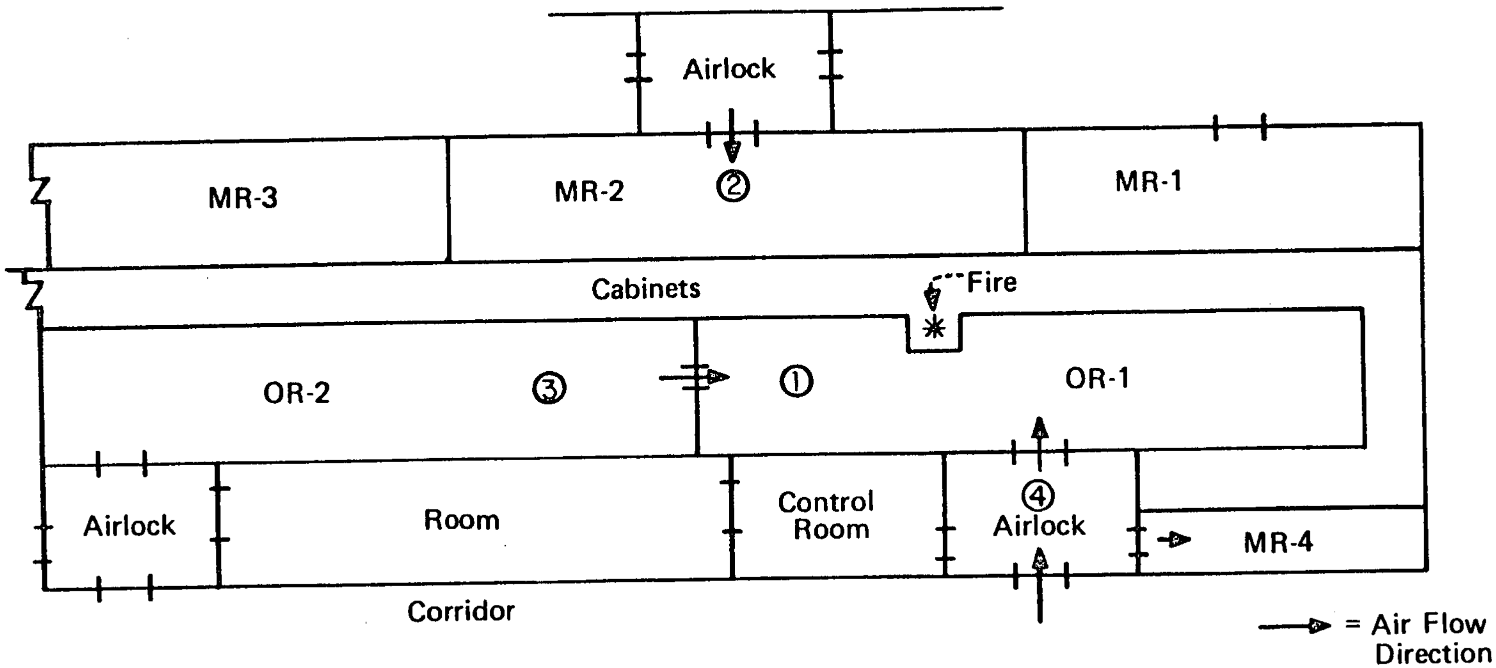
Position Number	Relative Airborne Activity
1	100
2	490
3A	1.4
3B	0.028
4	0.008
5A	0.33
5B	0.012
6A	0.14
6B	0.0040

FIGURE 1. Dispersion Model



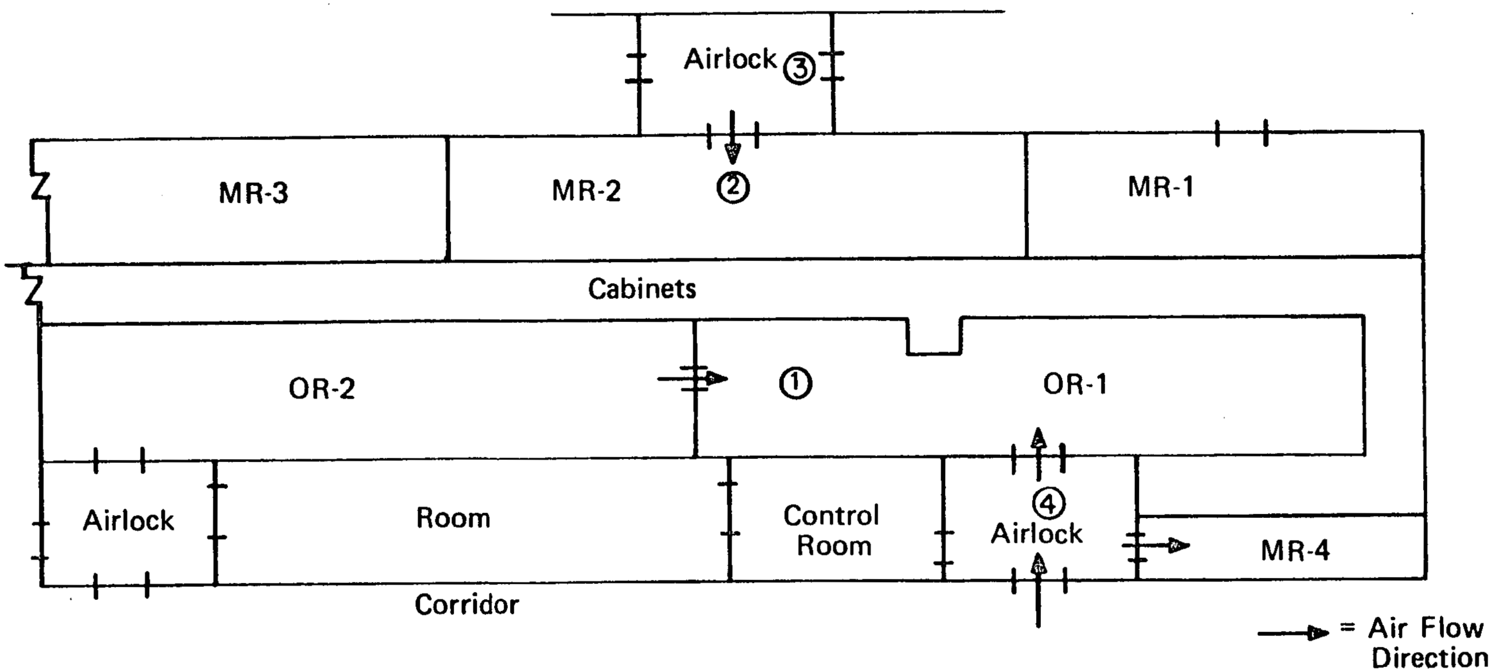
Position	Relative Airborne Activity	Description of Position and Approximate Distances	Air Flow Direction
1	100	Above glovebox	-
2	6.7	Across room from fire, 15 feet from 1	Toward fire
3	3.3	Far end of room, 15 feet from 2	Toward fire
4	1.4	Outside louvered door, 20 feet from 1	Negligible Flow
5	0.58	Outside solid door, door is 40 feet from 1	Unknown
6	0.28	Adjacent clean room, 75 feet from 4 and 30 feet from 5	Toward Fire
7	0.12	Far room, 20 feet from entry door; Door is ~45 feet from 6	From adjacent clean room

FIGURE 2. Glovebox Fire (Incident 1)



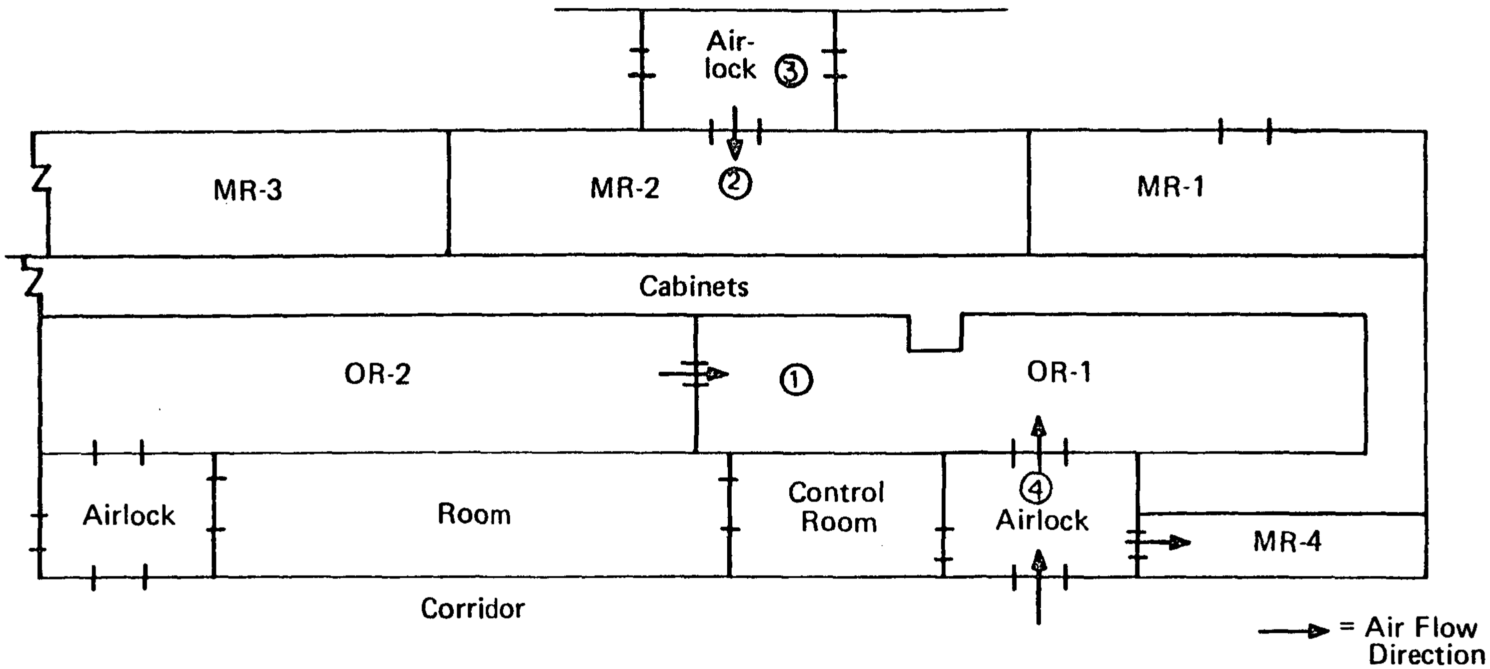
Position	Relative Airborne Activity	Description of Position and Approximate Distances
1	100	In Operating Room 1 (OR1), 10 feet from fire
2	-	Maintenance Room
3	<0.005	Adjacent Room OR2, 20 feet from 1
4	<0.005	Airlock of OR1, 12 feet from fire

FIGURE 3. Cabinet Fire (Incident 2)



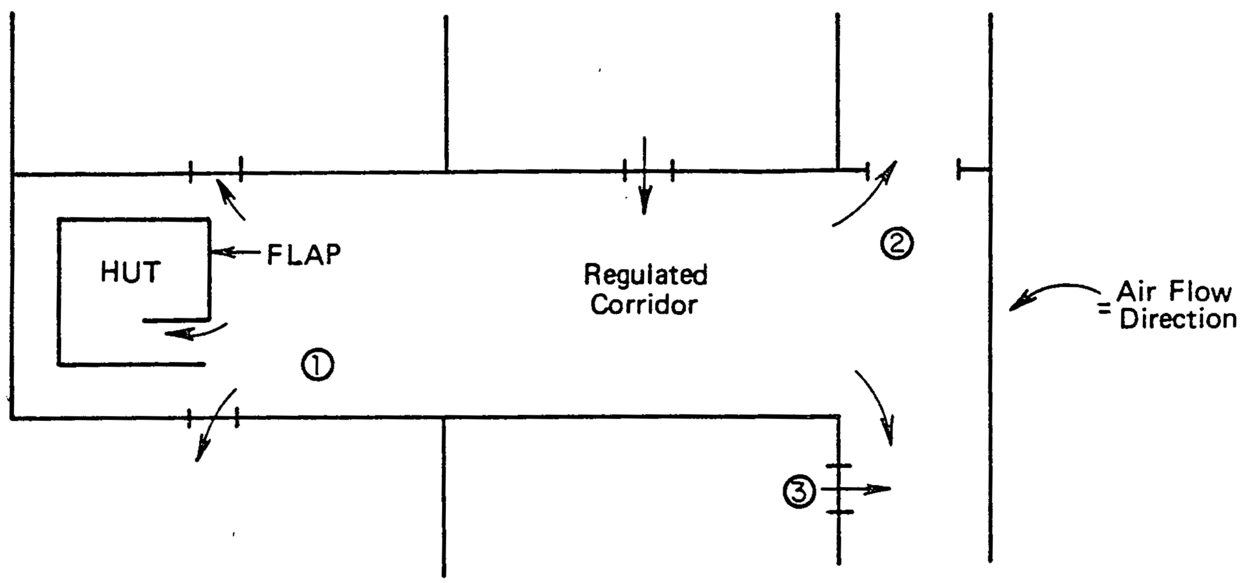
Position	Relative Airborne Activity	Description of Position and Approximate Distances
1	100	In Operating Room 1(OR1), 7 feet from cabinets
2	800	Maintenance Room 2 (MR2), 3 feet from cabinets
3	<0.1	MR2 Airlock, 12 feet from cabinets
4	<0.01	OR1 Airlock, 12 feet from cabinets

FIGURE 4. Damper Malfunction (Incident 3)



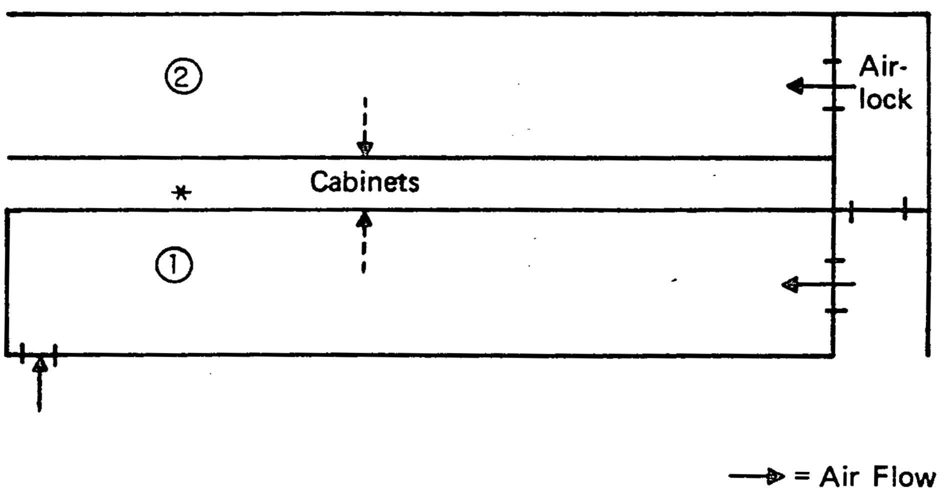
Position	Relative Airborne Activity	Description of Position and Approximate Distances
1	100	In Operating Room 1(OR1), 7 feet from cabinets
2	415	Maintenance Room 2 (MR2), 3 feet from cabinets
3	<0.017	MR2 Airlock, 12 feet from cabinets
4	<0.004	OR1 Airlock, 12 feet from cabinets

FIGURE 5. Filter Change Error (Incident 5)



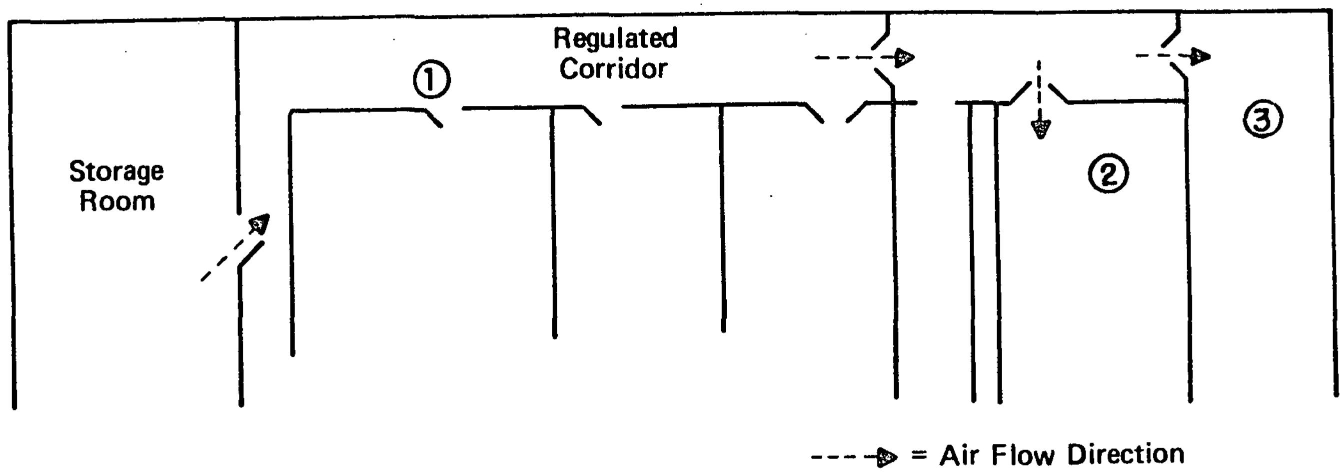
Position	Relative Airborne Activity	Description of Position and Approximate Distances
1	100	Corridor outside hut, 3 feet from hut entrance
2	27	Far end of corridor, 15 feet from hut entrance
3	0.5	Far room, 22 feet from Position 1

FIGURE 6. Pressurized Hut (Incident 6)



Position	Relative Airborne Activity	Description of Position
1	100	Operating Room
2	250	Maintenance Room

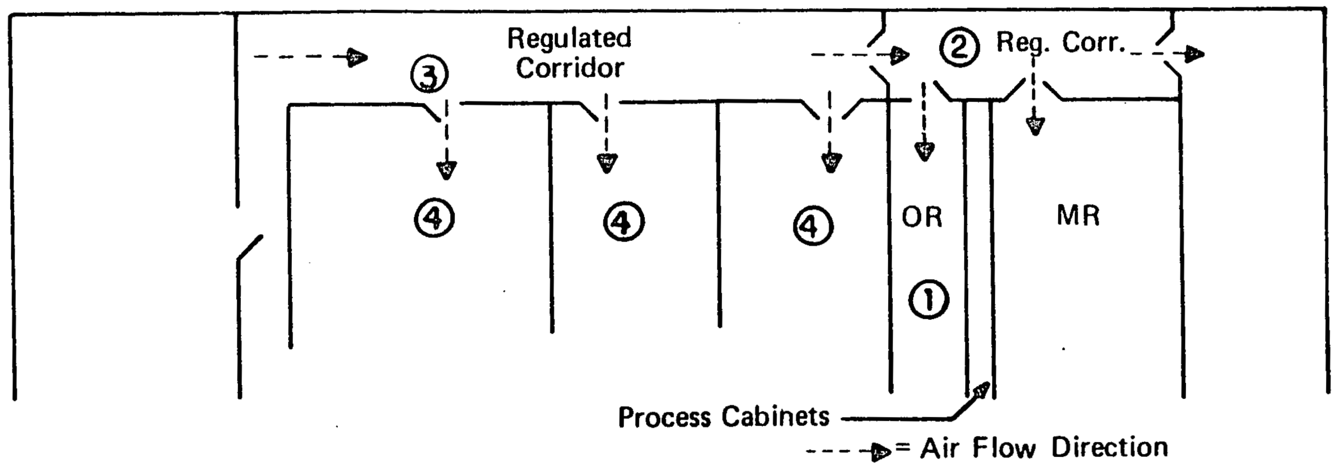
FIGURE 7. Unexpected Reaction in Scrap Dissolver (Incident 7)



Position	Relative Airborne Activity	Description of Position and Approximate Distances*
1	100	Regulated corridor
2	19	Room down corridor; door is 28 feet from 1
3	12	Far room down corridor; door is 36 feet from 1

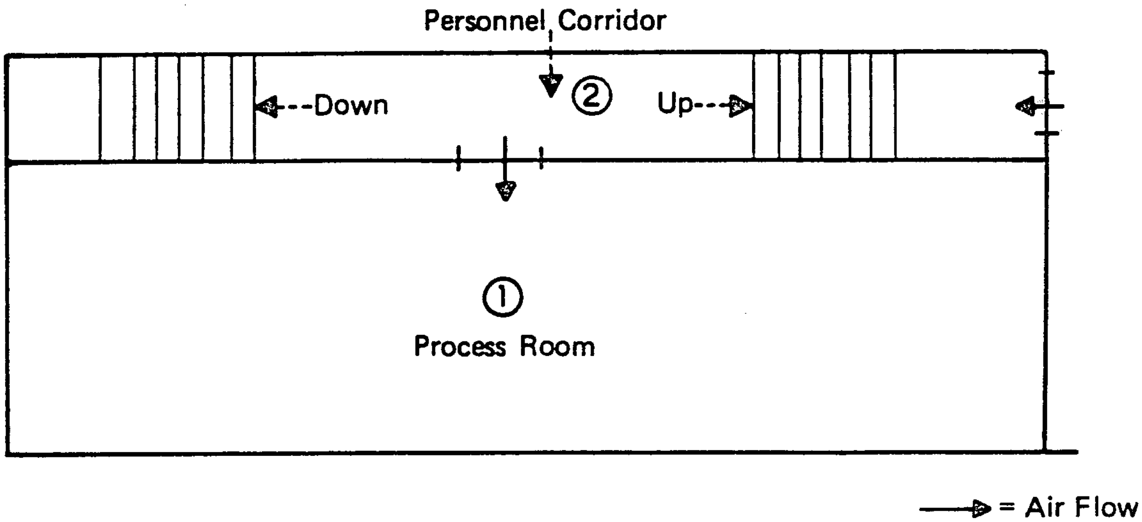
* Air samplers are about 10 feet from door in each room.

FIGURE 8. Release to Corridor (Incident 8)



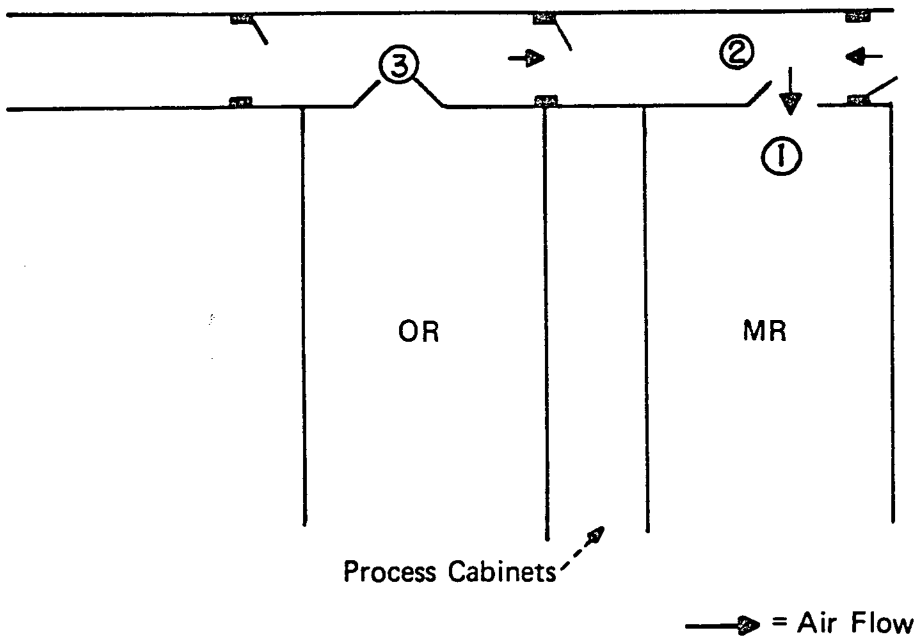
Position	Relative Airborne Activity	Description of Position and Approximate Distances
1	100	Operating Room (OR), 12 feet from entry door.
2	2.7	Regulated corridor; outside entry to OR, 3 feet from entry door
3	0.016	Regulated corridor, 22 feet from Position 2
4	<0.006	Nearby Rooms

FIGURE 9. Leak to Cabinet Sump (Incident 9)



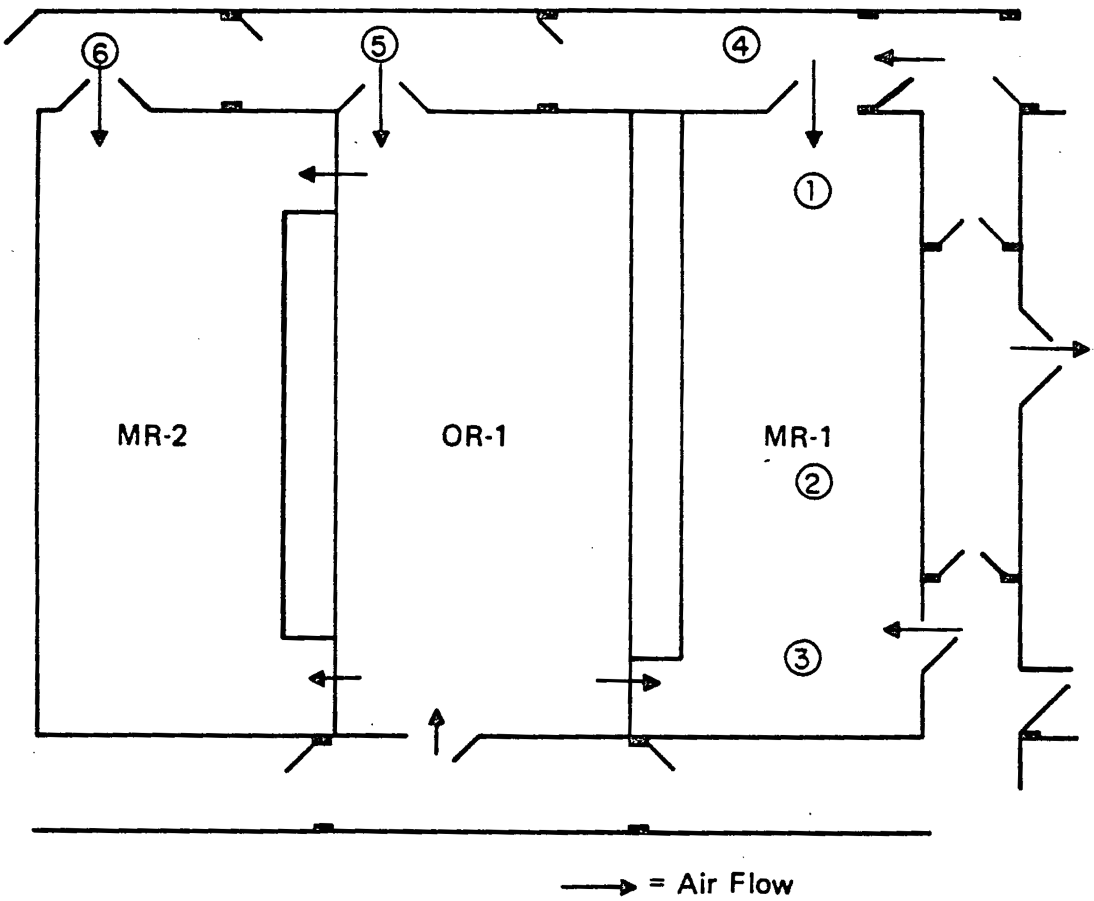
Position	Relative Airborne Activity	Description of Position
1	100	Process room
2	0.022	Regulated corridor

FIGURE 10. Building Air Reversal (Incident 10)



Position	Relative Airborne Activity	Description of Position and Distances
1	100	Maintenance Room, 5 feet from door
2	0.048	Regulated Airlock, 8 feet from 1
3	$<10^{-6}$	Adjacent Airlock, 20 feet from 2

FIGURE 11. Glove Failure (Incident 11)



Position	Relative Airborne Activity	Description of Position and Distances
1	100	MR-1, over entry hood
2	38	MR-1 center, 12 feet from Position 1
3	5.0	MR-1 end, 21 feet from Position 1
4	0.1	MR-1 airlock, 8 feet from Position 1
5	0.02	OR-1 airlock, 12 feet from Position 4
6	$<10^{-6}$	Far airlock, 24 feet from Position 4

FIGURE 12. Release During Container Removal (Incident 12)

Position Number	Relative Airborne Activity
1	100
2	490
3A	1.4
3B	0.028
4	0.008
5A	0.33
5B	0.012
6A	0.014
6B	0.0040

FIGURE 1
DISPERSION MODEL

Position	Relative Airborne Activity	Description of Position and Approximate Distances	Air Flow Direction
1	100	Above glovebox	-
2	6.7	Across room from fire, 15 feet from 1	Toward fire
3	3.3	Far end of room, 15 feet from 2	Toward fire
4	1.4	Outside louvered door, 20 feet from 1	Negligible Flow
5	0.58	Outside solid door, door is 40 feet from 1	Unknown
6	0.28	Adjacent clean room, 75 feet from 4 and 30 feet from 5	Toward Fire
7	0.12	Far room, 20 feet from entry door; Door is ~45 feet from 6	From adjacent clean room

FIGURE 2
GLOVEBOX FIRE (INCIDENT 1)

Position	Relative Airborne Activity	Description of Position and Approximate Distances
1	100	In Operating Room 1 (OR1), 10 feet from fire
2	-	Maintenance Room
3	<0.005	Adjacent Room OR2, 20 feet from 1
4	<0.005	Airlock of OR1, 12 feet from fire

FIGURE 3
CABINET FIRE (INCIDENT 2)

Position	Relative Airborne Activity	Description of Position and Approximate Distances
1	100	In Operating Room 1(OR1), 7 feet from cabinets
2	800	Maintenance Room 2 (MR2), 3 feet from cabinets
3	<0.1	MR2 Airlock, 12 feet from cabinets
4	<0.01	OR1 Airlock, 12 feet from cabinets

FIGURE 4
DAMPER MALFUNCTION (INCIDENT 3)

Position	Relative Airborne Activity	Description of Position and Approximate Distances
1	100	In Operating Room 1(OR1), 7 feet from cabinets
2	415	Maintenance Room 2 (MR2), 3 feet from cabinets
3	<0.017	MR2 Airlock, 12 feet from cabinets
4	<0.004	OR1 Airlock, 12 feet from cabinets

FIGURE 5
FILTER CHANGE ERROR (INCIDENT 5)

Position	Relative Airborne Activity	Description of Position and Approximate Distances
1	100	Corridor outside hut, 3 feet from hut entrance
2	27	Far end of corridor, 15 feet from hut entrance
3	0.5	Far room, 22 feet from Position 1

FIGURE 6
PRESSURIZED HUT (INCIDENT 6)

Position	Relative Airborne Activity	Description of Position
1	100	Operating Room
2	250	Maintenance Room

FIGURE 7
UNEXPECTED REACTION IN SCRAP DISSOLVER (INCIDENT 7)

Position	Relative Airborne Activity	Description of Position and Approximate Distances*
1	100	Regulated corridor
2	19	Room down corridor; door is 28 feet from 1
3	12	Far room down corridor; door is 36 feet from 1

* Air samplers are about 10 feet from door in each room.

FIGURE 8
RELEASE TO CORRIDOR (INCIDENT 8)

Position	Relative Airborne Activity	Description of Position and Approximate Distances
1	100	Operating Room (OR), 12 feet from entry door.
2	2.7	Regulated corridor; outside entry to OR, 3 feet from entry door
3	0.016	Regulated corridor, 22 feet from Position 2
4	<0.006	Nearby Rooms

FIGURE 9
LEAK TO CABINET SUMP (INCIDENT 9)

Position	Relative Airborne Activity	Description of Position
1	100	Process room
2	0.022	Regulated corridor

FIGURE 10
BUILDING AIR REVERSAL (INCIDENT 10)

Position	Relative Airborne Activity	Description of Position and Distances
1	100	Maintenance Room, 5 feet from door
2	0.048	Regulated Airlock, 8 feet from 1
3	$<10^{-6}$	Adjacent Airlock, 20 feet from 2

FIGURE 11
GLOVE FAILURE (INCIDENT 11)

Position	Relative Airborne Activity	Description of Position and Distances
1	100	MR-1, over entry hood
2	38	MR-1 center, 12 feet from Position 1
3	5.0	MR-1 end, 21 feet from Position 1
4	0.1	MR-1 airlock, 8 feet from Position 1
5	0.02	OR-1 airlock, 12 feet from Position 4
6	$<10^{-6}$	Far airlock, 24 feet from Position 4

FIGURE 12
RELEASE DURING CONTAINER REMOVAL (INCIDENT 12)