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Smoke Control Systems Analyses

Balancing Ducts Versus Door Vents in Class B Bulkheads

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16. Abstract

Concern exists over the use of "balancing" ducts as part of a shipboard ventilation system. These ducts are used in lieu of door vents in allowing for the movement of ventilation return-air from individual compartments to common areas (passageways). The common areas act as plenums, from which the air is then returned to the fan rooms for recirculation.

Of primary concern is the fact that these balancing ducts are often installed in the overheads of compartments and might spread the propagation of smoke should a fire occur, thus further endangering the integrity of egress routes. To attempt to quantify the potential hazard associated with the use of balancing ducts, a series of tests were conducted. These tests compared the use of balancing ducts to the vents installed in compartment doors. A test scenario of an accommodation area on a passenger vessel was used for this series of tests.

The results of this test series concluded that balancing ducts pose no greater threat to personnel safety than do door vents. These results, however, are confined to the parameters used in this test series. Different scenarios, (i.e., large compartments) and system configurations might necessarily yield different results. This is an area under further study.

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METRIC CONVERSION FACTORS

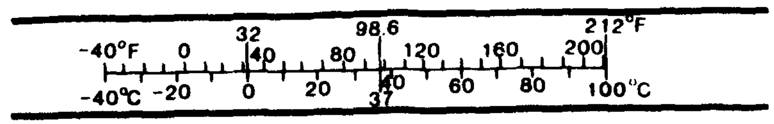
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

Analyses of past shipboard fires have shown that the majority of the reported personnel casualties resulted not from the direct effects of the fire itself, heat, but from the effects of the smoke and toxic gases produced by the burning items. As part of a continuing effort to minimize the hazards to personnel, the U.S. Coast Guard has implemented a long-range plan to investigate various aspects of current design practices for ships and shipboard systems. The Marine Fire and Safety Research Branch was tasked with researching methods to improve personnel safety through smoke containment and control systems. This report addresses one aspect of this effort; the use of **Balancing Ducts** as a method of replacing **Door Vents** in shipboard ventilation systems, and whether or not the balancing ducts constitute an undue hazard to personnel safety when compared to the door vents.

1.1 Background

Recent questions have been raised by various member nations of the International Maritime Organization (IMO) concerning the use of balancing ducts. The main concern is whether or not they are in compliance with the requirements as delineated by the International Convention for the Safety Of Life At Sea (SOLAS), and should their continued use be allowed. The issue recently came to the attention of the U.S. Coast Guard when it was discovered that several U.S. built ships were incorporating this design. Although there is no question that balancing ducts do not meet the requirements of the Coast Guard's Code of Federal Regulations (46 CFR), no definitive study had been conducted to verify that they do, in fact, constitute an additional hazard to personnel safety. For this reason, the U.S. Coast Guard initiated this study to determine what impact, if any, the use of balancing ducts have on personnel safety.

The concept of using balancing ducts instead of door vents is not a new one. Balancing ducts have been used for some time by various international shipbuilders, apparently evolving due to two main factors:

(1) Ships being built to SOLAS requirements are restricted in the allowable size of an opening in a Class B bulkhead. This restriction allows for an opening no greater than 0.05 m^2. In certain areas where the compartment is large, or has special ventilation requirements, the allowable opening is not sufficient to accommodate the required flow of return air.

(2) In an effort by ship designers to provide an increased level of privacy for certain compartments (e.g., individual staterooms), balancing ducts are used instead of louvered door vents.

The stringent requirements regarding Class A boundaries provide no latitude that might allow for designers to misconstrue the intent of the regulations regarding the use of balancing ducts in penetrating these boundaries. However, though it is generally agreed upon by enforcement officials that balancing ducts do not meet the intent of SOLAS, some arguments have been put forth questioning the validity of the requirements restricting their use in Class B bulkheads. At the time of this test effort, the only opening allowed in a Class B bulkhead is a louvered vent located in the lower half of a compartment's door. A proposal to disallow the use of door vents was subsequently submitted during the July 1990 meeting of IMO's Subcommittee on Fire Protection. Ventilation ducting is allowed to penetrate a Class B division if it meets certain requirements. It is in the interpretation of these requirements where proponents of the balancing ducts make their arguments. In conducting this test series, the U.S. Coast Guard hopes to begin to answer some of the questions concerning the use of the balancing ducts.

1.2 Ventilation System Design

The ventilation system design in question is one that makes use of an unducted (either completely or partially) return air system. Figure 1-1 is provided as a basic schematic of a ventilation system design (using balancing ducts). An individual ventilation system is sized to service a specific area of a ship. The system is designed such that each compartment within this area receives a specific volume of air. In an effort to increase the efficiency of the system and to reduce operating costs, a certain percentage of the conditioned air supplied to the area is returned to the servicing fan room to be redistributed. What makes this system design of interest is the method used in returning the conditioned air back to the fan room. Once supplied to the individual compartments, the conditioned air will then flow, via a balancing duct or door vent, into a central area (normally a passageway). This central area then acts like a large duct or plenum, channeling the return air back to the fan room. It is this aspect of the design that poses the greatest threat to personnel safety. Should a fire occur in any of the compartments, the smoke and toxic gases will flow in the same manner as the return air, thus having the potential to expose large numbers of personnel to their hazardous effects.

<u>1.2.1 Door Vents</u>: The requirements for door vents vary significantly between the CFR and SOLAS. The CFR allows the vent to be up to 2 ft^2 (0.186 m^2) in area, where SOLAS allows only 0.05 m^2 (0.54 ft^2). Since the majority of ships which the Coast Guard concerns itself must meet SOLAS requirements, the SOLAS-sized vent was used for this test series. Figure 1-2 shows a typical SOLAS-sized door vent similar to that used in this test series.

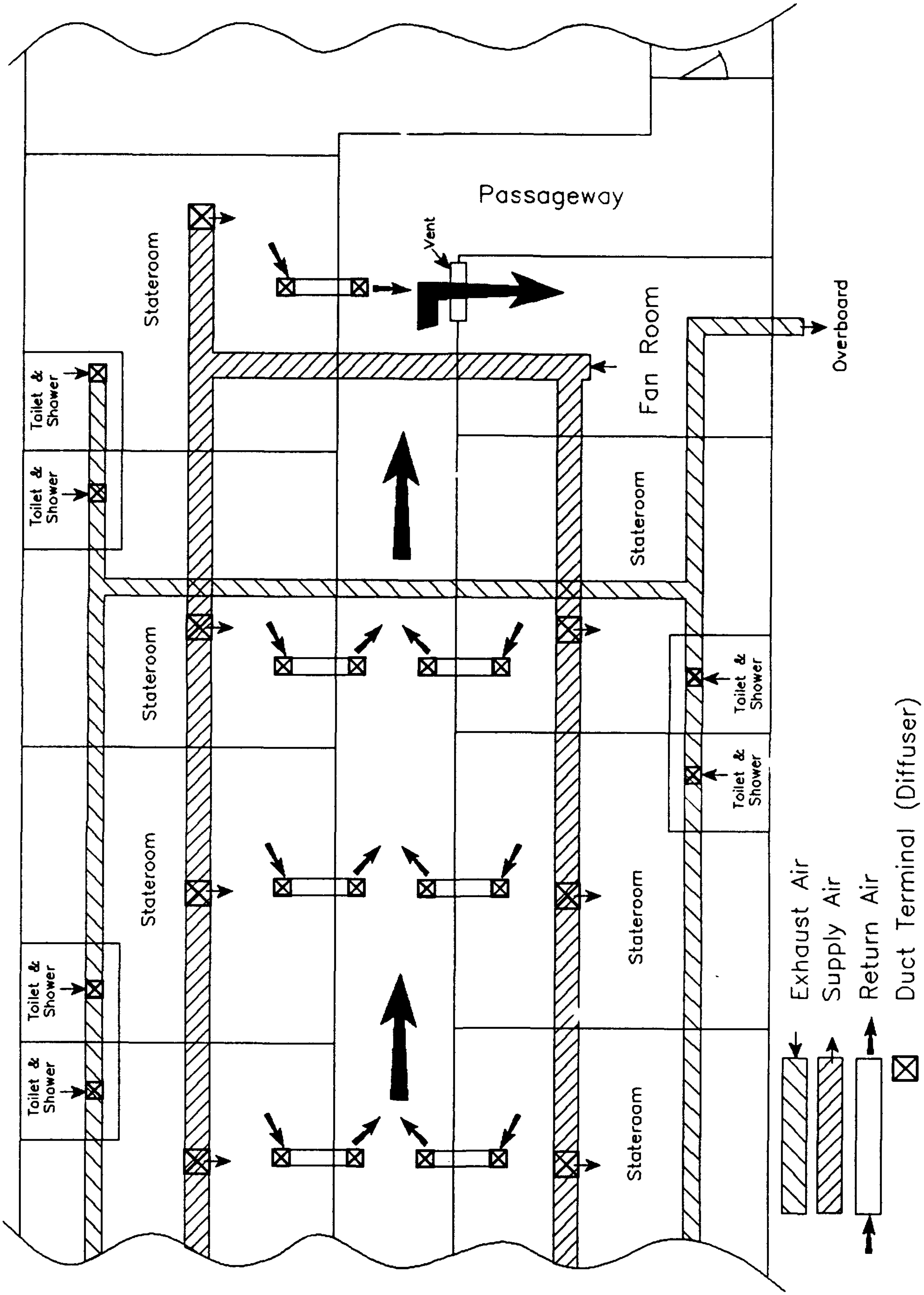


Figure 1-1 Air Movement Schematic (Plan View)

Figure 1-2 Solas-size Door Vent (taken on an actual passenger vessel)

1.2.2 Balancing Ducts: The possibility exists for balancing ducts to appear in any one of several configurations. Figure 1-3 represents a standard design and one that is quite common. Unlike the door vent which is located low in a compartment's door, balancing ducts are sometimes installed above the compartment's ceiling. As seen in figure 1-3, the duct is installed between the drop ceiling and the steel deck above. The sole purpose of the duct is to provide a path for the return air from the compartment to the central area. Balancing ducts are also installed low in a compartment, normally under the floor of an adjoining bathroom. It was felt that the high configuration represented a greater threat and warranted consideration during initial test efforts.

1.3 Objectives

The main objective of this test series is to compare the effects of using balancing ducts to those of using typical, louvered door vents. By monitoring the movement of smoke with respect to time, a relative comparison of the duct to the vent can be made. Again, the focus is on personnel safety and the potential, detrimental affects that the use of the balancing ducts may have. The results of this test series define only the impact of using the balancing ducts relative to this specific test scenario. Further testing will be required to determine any impacts of using balancing ducts in other scenarios.

A secondary objective for this test series is to identify additional associated safety measures or procedures that might be of benefit to the overall smoke control effort. For this reason, the test matrix (discussed further in Section 2.4) addresses scenarios that do more than provide comparisons between balancing ducts and door vents. Modifications to or changes in the status of both the ventilation systems and the individual vents will be investigated to determine the potential benefits or hazards.

2.0 APPROACH

To conduct a valid comparison of the balancing duct and door vent, a realistic scenario was required. It would be impossible to explore all situations with a single test series. Therefore the scenario was selected due to recent events and the potential for a large loss of life. An accommodation area of a passenger (or merchant) vessel was chosen for simulation. This scenario involved multiple accommodation compartments and an installed ventilation system similar to that described in Section 1.2.

All tests were performed at the U.S. Coast Guard's Fire and Safety Test Detachment (F&STD) in Mobile, Alabama. An area on the Albert E. Watts, one of the Detachment's test ships, was modified to simulate an accommodation area. One compartment was

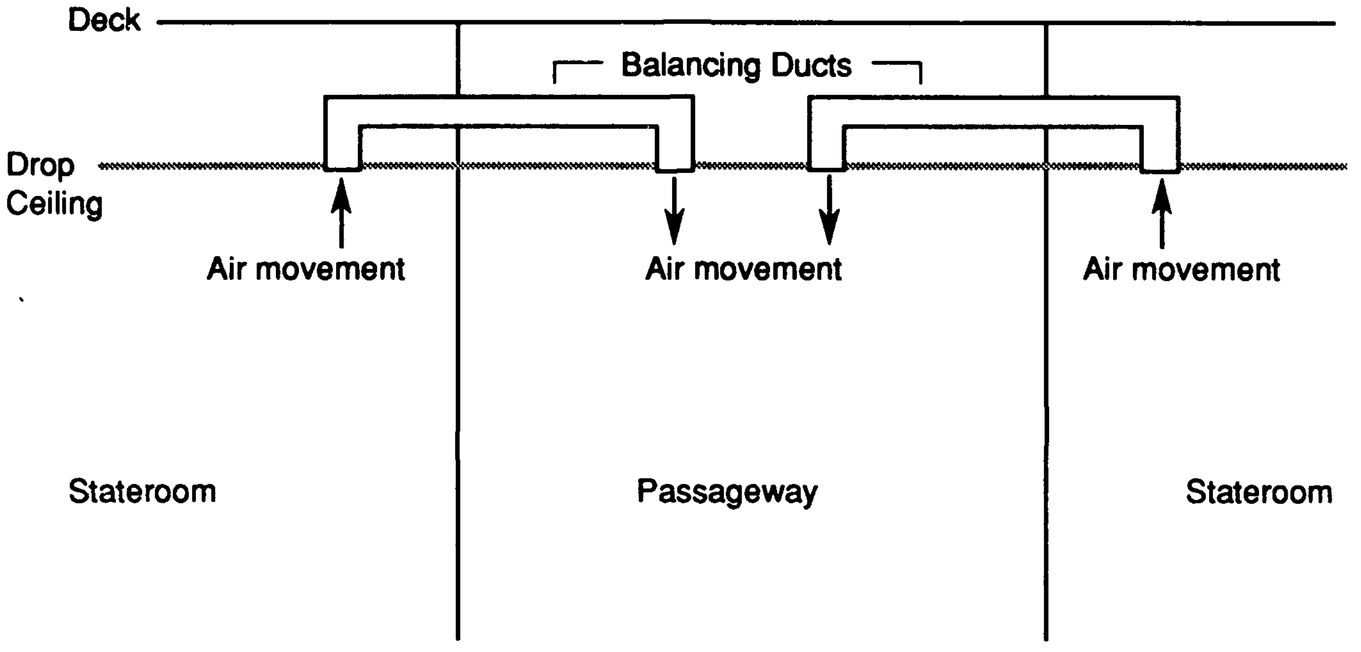


Figure 1-3 Balancing Ducts

designated to be the test compartment which would function as the source of the fires. The simulated fire scenario was a waste basket fire located next to a sofa, which served as the primary source of the heat and smoke. Using a variety of instrumentation, each test in this series was recorded visually and electronically. A test matrix, consisting of a multitude of vent and ventilation test scenarios, was developed and used in comparing the balancing duct and door vent configurations. Most test scenarios in Table 2-1 consisted of two configurations, one using the door vent and one using the balancing duct. The data from each test configuration was then analyzed to make the necessary comparisons.

Table 2-1

Scenario No.	SCENARIO LISTING Description
1	Basic Configuration - No Changes (sofa only)
2	Basic Configuration - No Changes (fully furnished)
3	Basic Configuration - No Changes (test fire)
4	Shut down ventilation system - Passageway smoke detector
5	Shut down ventilation system - Stateroom smoke detector
6	Shut down ventilation system and close balancing - Stateroom smoke detector
7	Shut down supply fan ONLY - Passageway smoke detector
8	Shut down supply fan ONLY and close balancing duct - Stateroom smoke detector
9	Close supply vent and balancing duct for Config.#2 - Stateroom smoke detector
10	Close supply and exhaust vents & (balancing duct for Congig.#2) - Stateroom smoke detector
11	Basic configuration - No changes in vents or systems, open port hole at peak fire temperature
12	Balancing ducts and door vents open - No changes in ventilation system

2.1 Test Area

A section of the after deckhouse on the test vessel Albert E. Watts was modified to simulate an accommodation area of a cruise ship. Figure 2-1 represents the test area on the 01 level of the after deckhouse of the Watts (after modification). There are not as many staterooms available as one might encounter in a typical cruise ship accommodation area, yet the area would certainly be representative of most merchant vessels. However, since the main focus of the testing was on the test compartment and the passageway, the test area was considered adequate for either situation.

The test compartment was arranged to simulate a typical stateroom. Figure 2-2 is representative of a typical stateroom on a cruise vessel. The test compartment area measured approximately 15 feet (4.6 m) in depth, 12½ feet (3.8 m) wide, and a little over 7 feet (2.1 m) high (to the drop ceiling). Figure 2-3 shows the test compartment with a full complement of furniture. All bulkheads and decks were constructed of steel. The forward bulkhead consisted of 3/16 inch (0.48 cm) steel, with the remaining partitions and decks consisting of 1/4 inch (0.63 cm) steel. It must be noted that due to the age of the test vessel and deterioration resulting from previous tests, many of the existing 1/4 inch steel bulkheads and decks were severely pitted and rusted. In some instances the rust had caused complete penetration. These areas were patched with new steel. A drop ceiling was installed in the test compartment to further simulate the general construction practices used by commercial shipbuilders in designing a stateroom. Although many commercial vessels may still use a flammable material in the drop ceilings, a fire resistant, composite ceramic, acoustical ceiling tile manufactured by Armstrong Company (Fed. Spec. No. SS-S-118B, Coast Guard App. No. 164.009/215/0) was used for this test series. SOLAS allows for a thin veneer of combustible material to cover the ceiling material. Some older vessels may still have ceilings that are constructed totally of combustible materials. The ceiling tile was supported by a light gauge steel framework. Due to the number of tests scheduled, and to reduce the time and costs required to replace the ceiling, it was considered practical to use a material with a better chance of surviving multiple tests. Lighting for the compartment was provided by two portable halogen lamps placed on the floor of the compartment. Additional light was available through the 10 inch diameter porthole located in the starboard bulkhead. No special coverings were installed on any of the bulkheads or deck. The compartment was initially painted white to provide better contrast for photography.

The passageway adjacent to the test compartment measured approximately 87 feet (26.5 m) in length and 4 feet (1.2 m) in width. The height and characteristics of the boundaries and installed drop ceiling were identical to those of the test

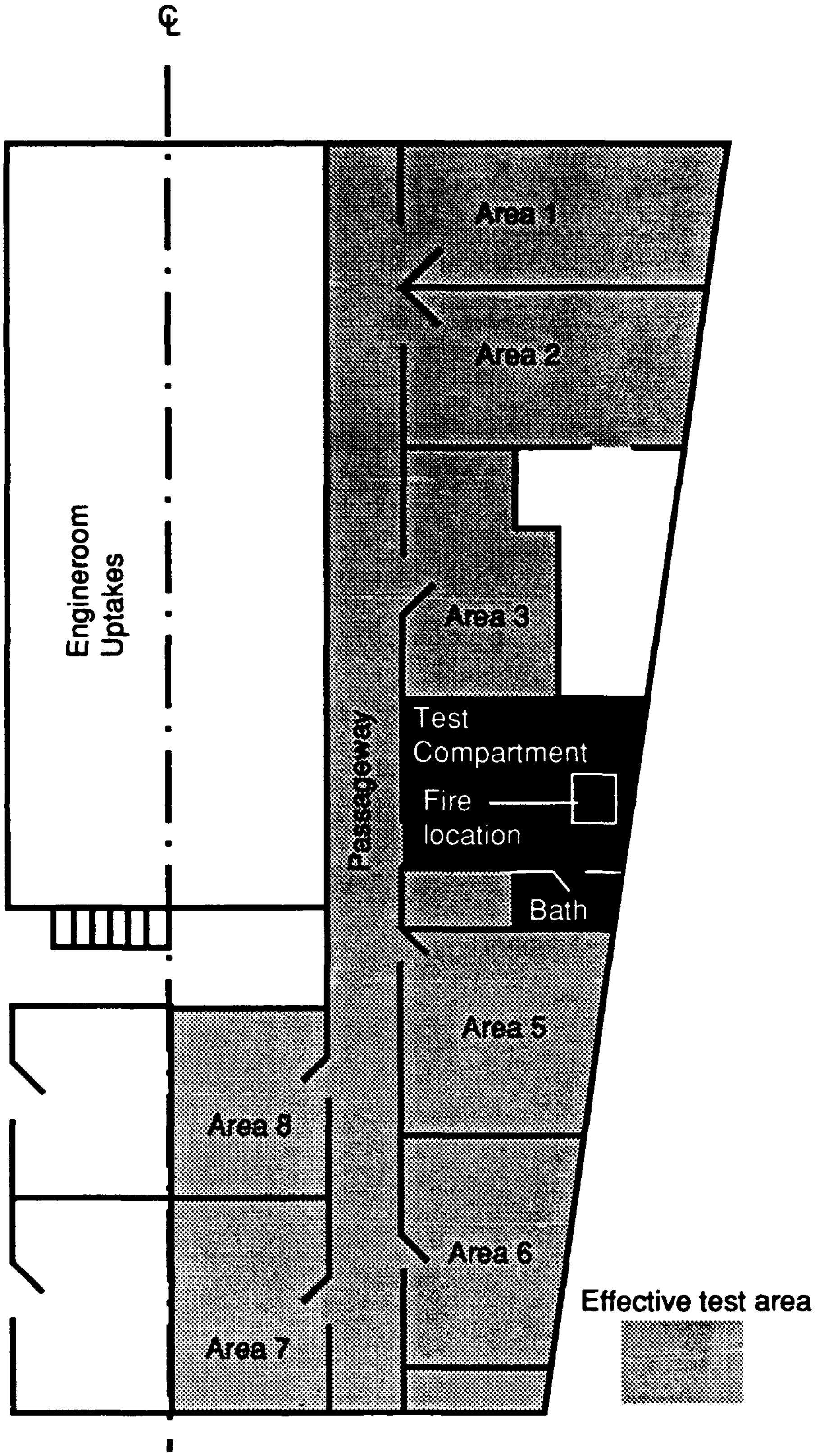


Figure 2-1 Test Area, 01 Level, After Deckhouse (A.E. WATTS), partial view

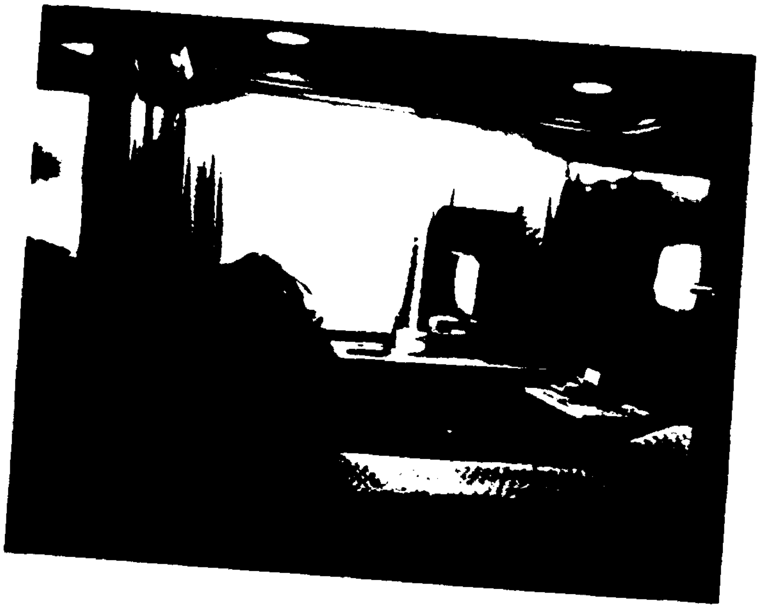


Figure 2-2 Typical Stateroom

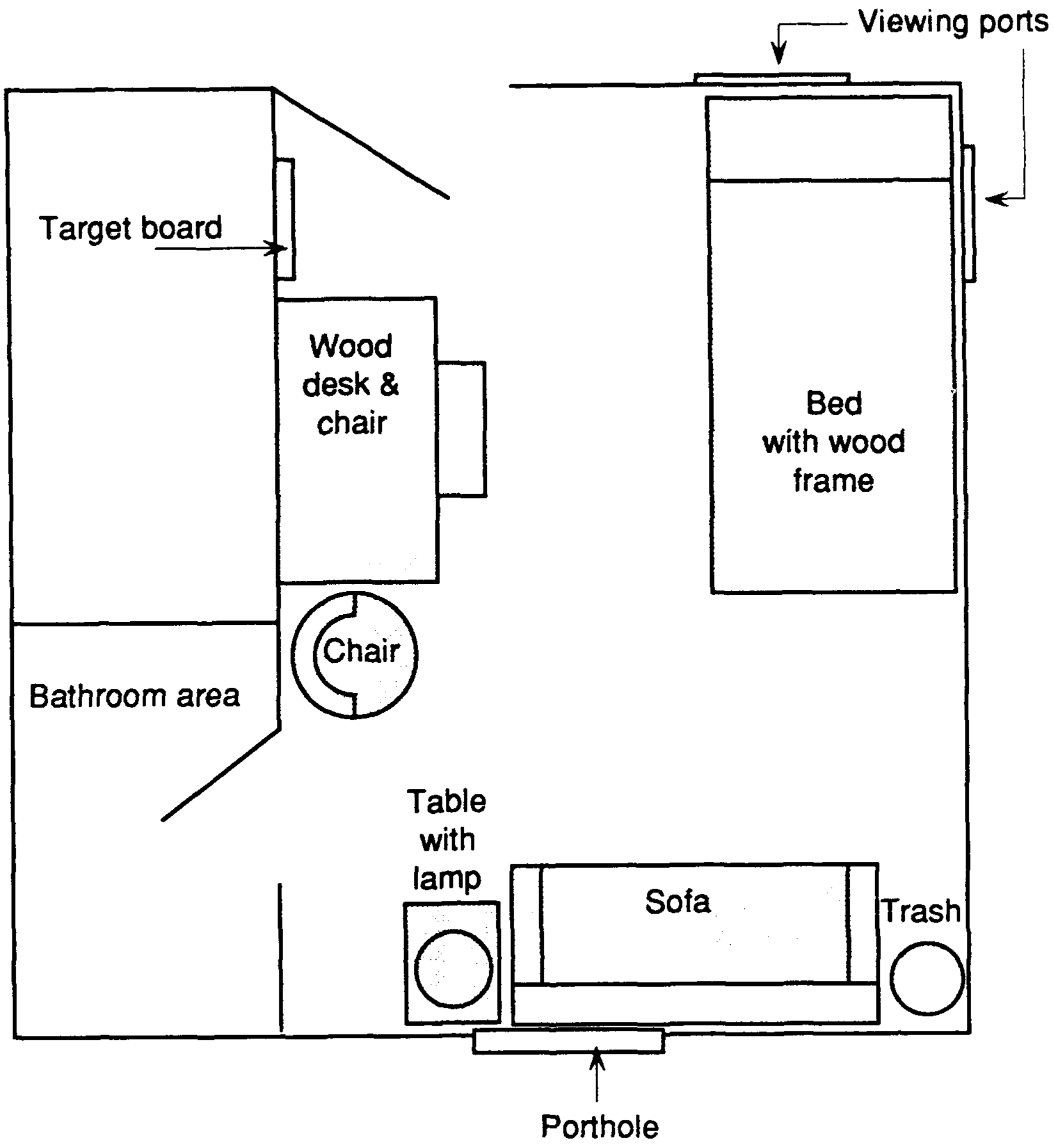


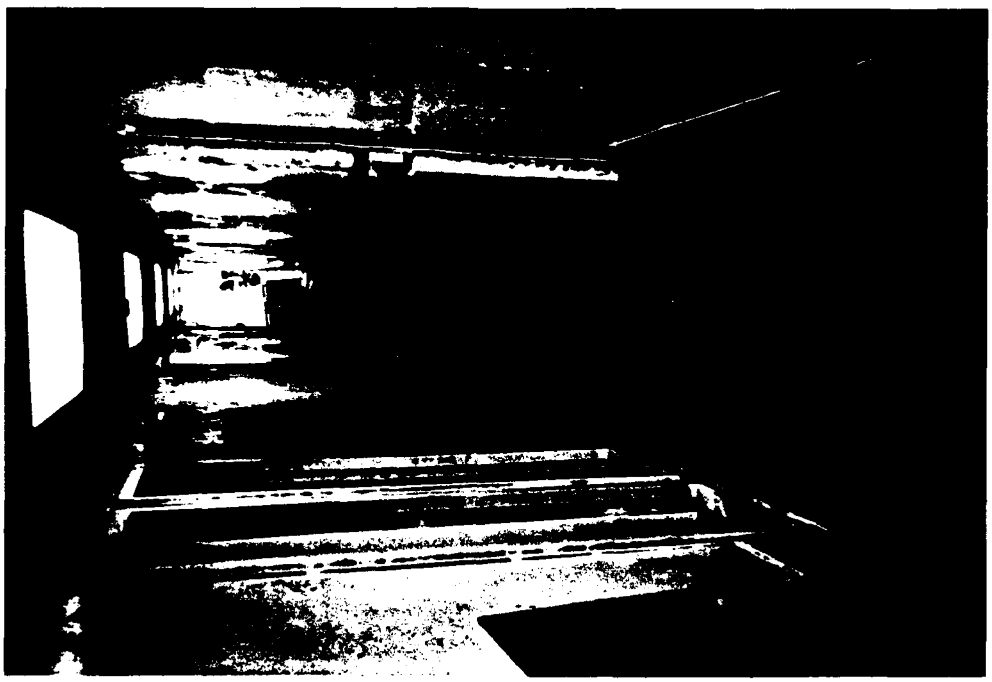
Figure 2-3 Test Compartment (with furniture)

compartment. The major difference between the two areas was the installed lighting. Dual-bulb, fluorescent lights were installed in the drop ceiling at approximately 8-foot (2.4 m) intervals along the length of the passageway (figure 2-4A). With the exception of a few modifications, all boundaries were of original construction. At the forward end of the passageway, the watertight doorway was removed and replaced with a wood door that was modified to allow video recording of the events in the passageway.

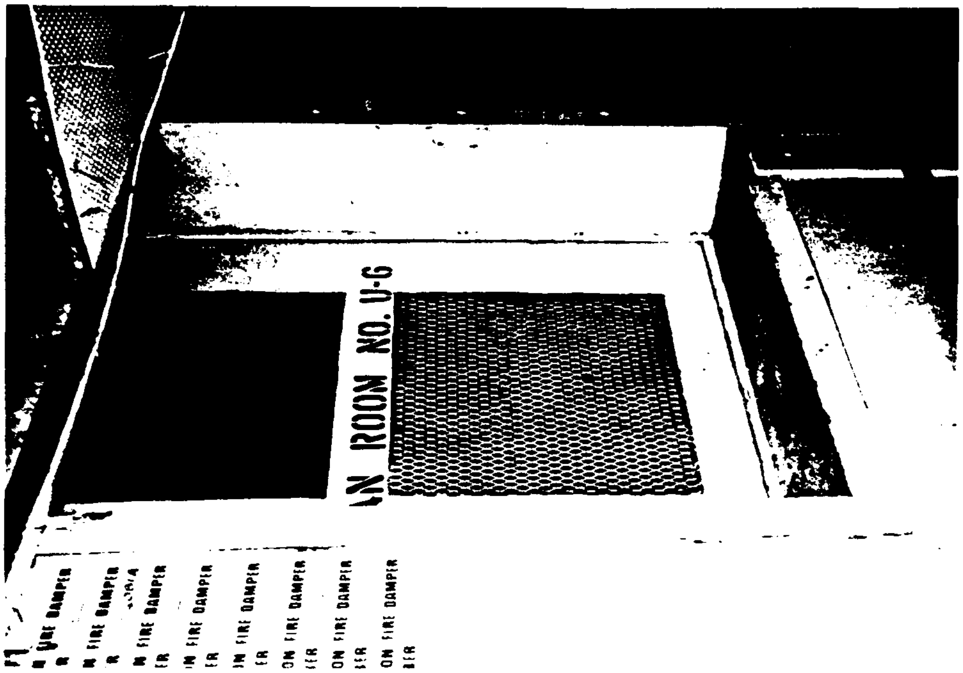
The remaining compartments within the test area were modified only to the extent necessary for the installation of a balancing duct, supply ventilation, and the door vent.

2.2 Ventilation System

The ventilation system installed for this test series was designed to represent the configuration outlined in Section 1.2. Due to space limitations and ease of installation, the fan room was located on the 02 level, one level above the test compartment. For this reason it was necessary to duct the return air from the passageway directly to the inlet of the supply fan. (Note: In many installations where the fan room is located on the same level as the compartments it serves, a duct will not be used and the return air enters the fan room through a vent connecting the fan room and the passageway. Figure 2-4B is a photograph of a typical, return-air vent arrangement connecting a passageway and a fan room. (The photo was taken in the passageway accommodation area on a cruise vessel.) The ventilation system was sized and balanced to supply approximately 200 cfm (0.094 m^3/s) to each stateroom. Of this 200 cfm (0.094 m^3/s), approximately 70 cfm (0.03 m^3/s) was exhausted from the test compartment and Area 3. An exhaust system was designed and installed to provide exhaust services for these two compartments. The remaining air (approx. 140 cfm /0.064 m^3/s) was vented from the compartments to the passageway using either the balancing ducts or the door vents. Unlike the typical installation design depicted in figure 1-3, the balancing ducts for this test series extended through the steel deck above (figure 2-5). This was done due to the lack of adequate ceiling height available on the test ship and to allow easy access to the installed smoke dampers. A make-up air vent was installed immediately upstream of the supply fan to account for the air being lost to the exhaust system. Time and funding constraints did not allow for an exhaust system that serviced all the compartments in the test area. However, due to the configuration of the ventilation systems and the effects they have on this specific test scenario, the lack of an exhaust system in the surrounding compartments did not have a significant effect on the test results. Figure 2-6 is provided as a schematic of the ventilation system as installed.



A. Test passageway lighting



B. Return air vent

Figure 2-4

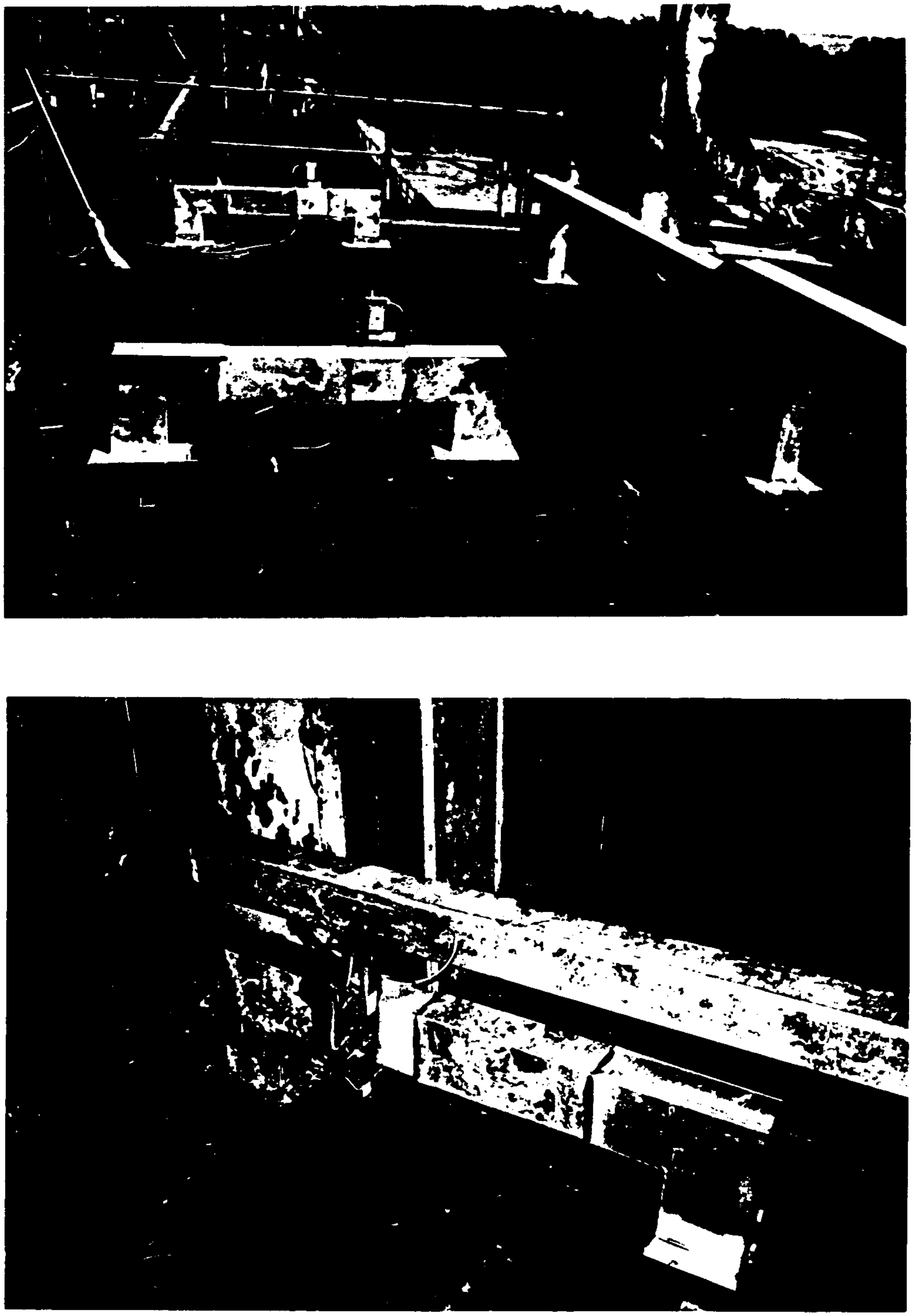


Figure 2-5 Balancing Ducts

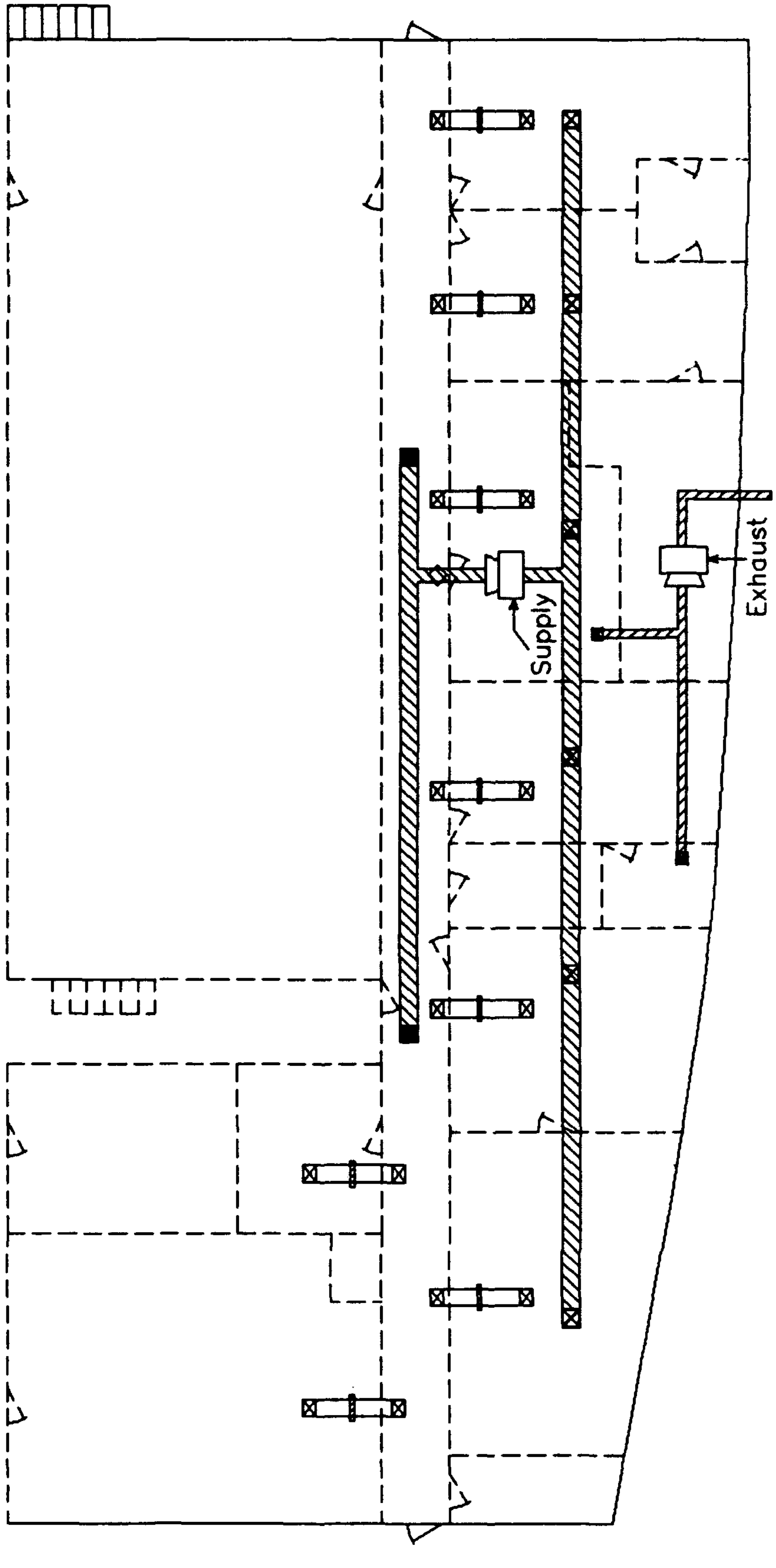


Figure 2-6 Test Area Ventilation System

2.3 Fire Parameters

Based on the stateroom configuration as shown in figure 2-3, the primary source of fuel for the fire is the sofa located adjacent to the starboard bulkhead. The scenario for the ignition source is a plastic waste basket containing paper, into which a hot item (match, cigarette, etc.) is deposited. The basket is situated such that when it is burning, the flames will impinge directly on the arm of the sofa. The primary fuel within the sofa itself is the non-fire retardant, flexible polyurethane foam used in the cushions. Depending on the availability of oxygen to sustain the fire, a typical sofa of this configuration constitutes enough fire load to have the potential to cause flashover within the test compartment. Additionally, several test scenarios addressed a fully furnished stateroom to determine if the possibility existed for auto-ignition of a second fire source; i.e., the bed, chair, or desk.

Based on the characteristics exhibited by the furniture fires, a standard fire source was designed to simulate, as closely as possible, the same parameters. The main items of interest were the generation of heat and smoke. The standard fire consisted of a wood (pine) crib situated above a small pan of diesel fuel. A single, flexible polyurethane foam cushion was placed on top of the wood crib to assist in obtaining the smoke characteristics demonstrated by the furniture fires. Figure 2-7 shows the arrangement of the standard fire.

2.4 Test Matrix

Table 2-2 represents the test matrix used for this test series. The various scenarios presented in the matrix were designed to meet the objectives as stated in Section 1.3. Each scenario in the matrix can be further divided into two configurations; one configuration representing the use of the door vent, and one representing the use of the balancing duct. (Note: For Scenarios 6, 8, and 10, there was no configuration using the door vent.) To further assist the Test Director in conducting each test, a Configuration Sheet (figure 2-8) was developed for each test configuration. This sheet provided a quick and easy reference for ensuring the correct status of the vents and ventilation systems. Since each configuration was normally conducted at least twice, each configuration sheet was applicable to at least two test numbers. Additionally, as can be seen in Table 2-2, tests of similar scenarios and configurations were not run sequentially. This was done to prevent artificially inducing similar test results.

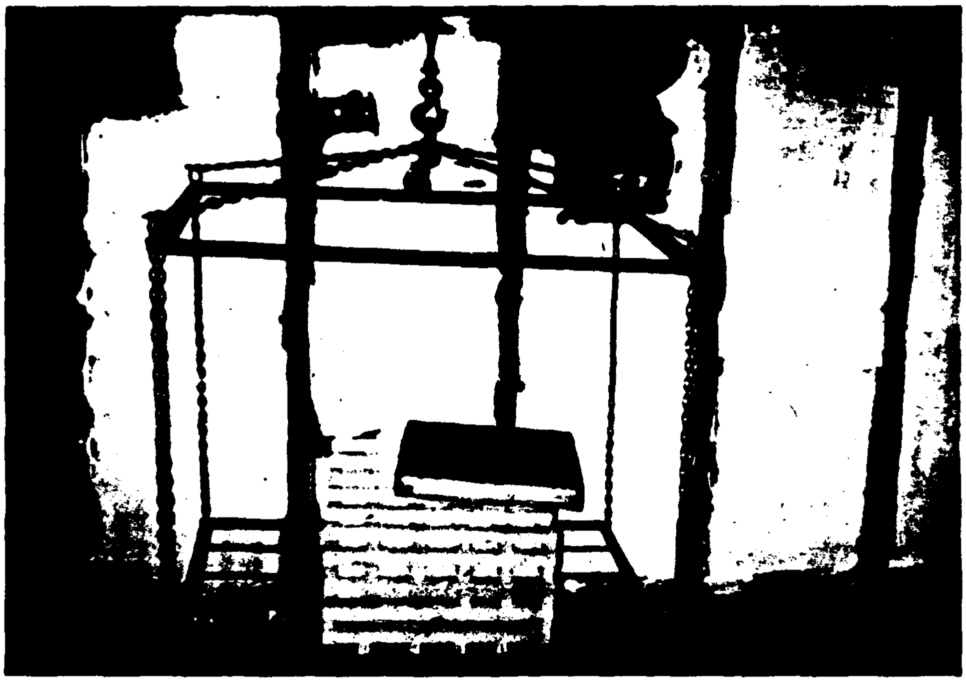


Figure 2-7 Standard Test Fire Configuration

Table 2-2

TEST MATRIX

Test No.	Scenario #/ Configuration #	Supply Fan	Exhaust Fan	Door Vent	Jumper Duct Damper	Supply Vent Damper	Exhaust Vent Damper
1	1/1	ON	ON	OPEN	CLOSED	OPEN	OPEN
2	2/1	"	"	"	"	"	"
3	1/1	"	"	"	"	"	"
4	1/2	"	"	CLOSED	OPEN	"	"
5	2/2	"	"	"	"	"	"
6	2/1	"	"	OPEN	CLOSED	"	"
7	3/2	"	"	CLOSED	OPEN	"	"
8	3/1	ON/OFF	ON/OFF	OPEN	CLOSED	"	"
9	7/1	ON/OFF	ON	OPEN	CLOSED	"	"
10	4/2	ON/OFF	ON/OFF	CLOSED	OPEN	"	"
11	5/2	"	"	"	"	"	"
12	5/1	"	"	OPEN	CLOSED	"	"
13	6/2	"	"	CLOSED	OPEN/CLOSED	"	"
14	7/2	"	ON	"	OPEN	"	"
15	8/2	"	"	"	OPEN/CLOSED	"	"
16	9/1	ON	ON	OPEN	CLOSED	OPEN/CLSD	"
17	9/2	"	"	CLOSED	OPEN/CLSD	OPEN/CLSD	"
18	10/2	"	"	"	OPEN	CLOSED	OPEN/CLSD
19	4/1	ON/OFF	ON/OFF	OPEN	CLOSED	OPEN	OPEN
20	7/1	ON/OFF	ON	"	CLOSED	"	"
21	10/2	ON	ON	CLOSED	OPEN/CLSD	OPEN/CLSD	OPEN/CLSD
22	3/2	ON	ON	"	OPEN	OPEN	OPEN
23	4/2	ON/OFF	ON/OFF	"	OPEN	OPEN	OPEN
24	5/2	"	"	"	"	"	"
25	5/1	"	"	OPEN	CLOSED	"	"
26	6/2	"	"	CLOSED	OPEN/CLSD	"	"
27	8/2	"	ON	"	OPEN	"	"
28	11/2	ON	"	"	OPEN/CLSD	OPEN/CLSD	"
29	11/1	"	"	OPEN	CLOSED	"	"
30	12/-	"	"	"	OPEN	OPEN	OPEN

Figure 2-8

SCENARIO #9 (see note)

TEST NO.(s): 7 & 19

FUEL SOURCE: Cribs, Cushion and Diesel Fuel

SYSTEM & DAMPER CONFIGURATION:

	Initial	Final	Closure Key
Supply Fan:	ON	OFF	Psgwy Smoke Det.
Exhaust Fan:	ON	ON	--------
Supply Damper(s):	OPEN	OPEN	--------
Exhaust Damper(s):	OPEN	OPEN	--------
Door Vent(s):	OPEN	OPEN	--------
Jumper Duct Damper(s):	CLOSED	CLOSED	--------

COMMENTS:

- This test is to observe the effects of leaving the exhaust system running. Will determine if the spread of smoke is reduced (slowed) by exhausting a percentage from the head. (Note: Smoke still must reach the vent in the head's door).

- This may also cause surrounding staterooms to be under negative pressure, thereby inducing the smoke spread into other staterooms. This may exacerbate the smoke problem!

- Supply fan (only) will be shut down upon passageway smoke detector actuation.

NOTE: If test #7 exhibits a detrimental effect, test #19 will not be run.

3.0 TEST SET-UP AND PROCEDURES

A variety of instrumentation was used for this test series. This section will address the types of equipment used and their placement within the test area. This section will also discuss the procedures used in preparing the test area for each test and the procedures used in conducting each test.

3.1 Instrumentation

Table 3-1 represents a listing of the types of instrumentation used in this test series. Much of the instrumentation was not installed solely for the purpose of providing comparison data for the balancing ducts and door vents. Thermocouples, calorimeters, radiometers, the load cell, etc., were all used to define the fire, as well as its physical effects within the confines of the test compartment and surrounding areas. The secondary objective of this test series must be remembered. The collected data will also be used in identifying other potential areas of interest within the broad spectrum of smoke containment and control.

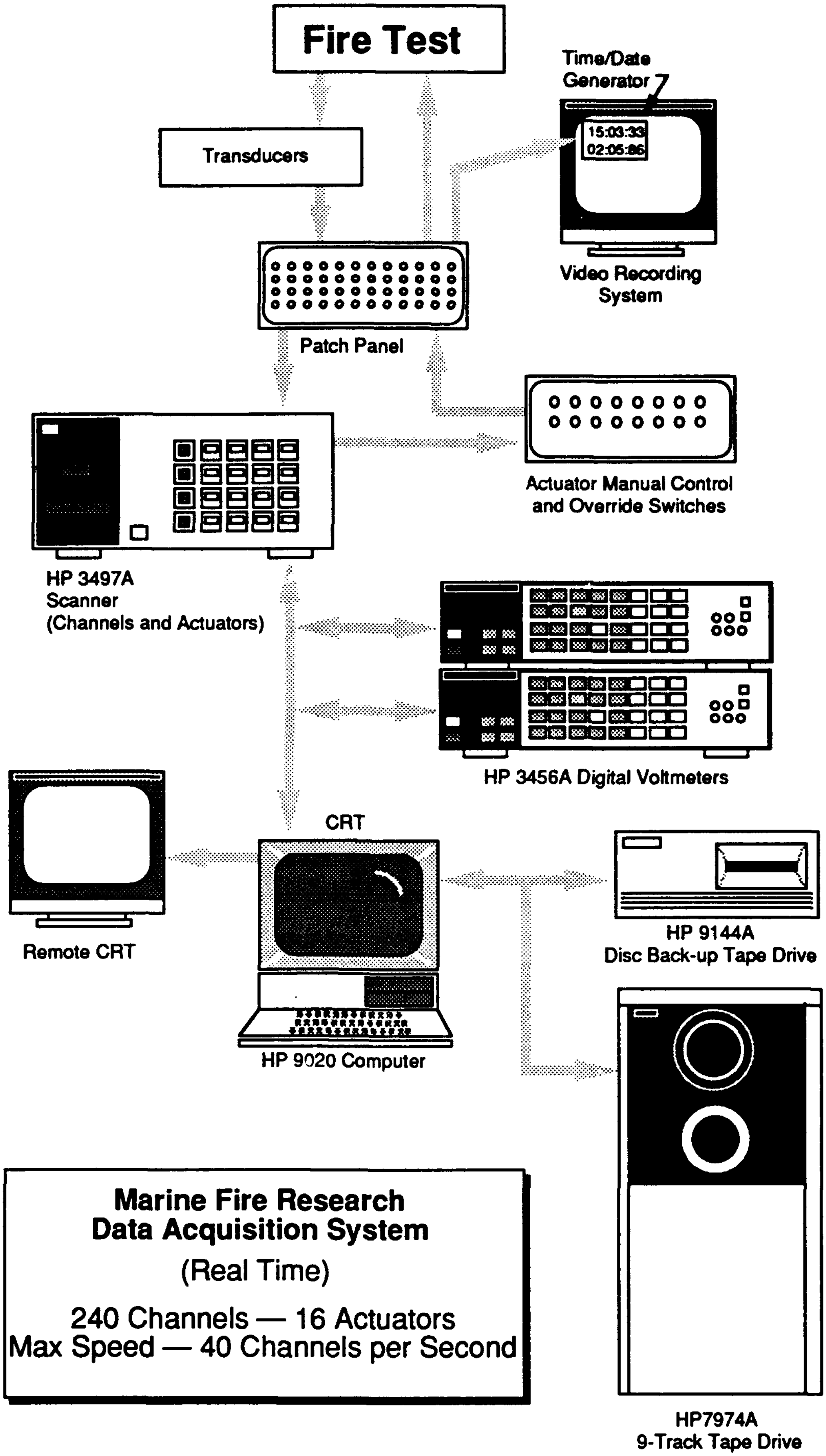
All of the electronically recorded data was collected and stored by a computer data acquisition system. This system consists of a Hewlett Packard, Model 9020 computer and various associated equipment. Figure 3-1 is provided as a basic schematic of the data acquisition system. All sensors and analyzers are connected, via the transducers and patch panel, to the computer. The computer system is provided with a scanner that continually queries each sensor or analyzer (channel) at a preset time interval. The data acquisition system can accommodate up to 240 channels of information and has the ability to scan each of these channels once every 6 seconds. The actual number of channels used will vary for each test series, and the scan rate will be determined by the Test Director. Additionally, channels can be easily added or deleted after the test series has begun. This provides for a greater degree of flexibility for the Test Director should parameters change during the course of a test series. For this test series, 157 channels were utilized at a scan rate of once every 15 seconds. The data acquisition system is also provided with multiple means of storing the data. The data is initially saved on a 9-track tape drive. This, in turn, is backed up daily on a "hard" disc. This ensures no, or at most minimal, data is lost should a problem occur. Upon completion of a test series, the Test Director has the ability to take all the stored data back to the office, load the data on an identical computer system, and then manipulate and analyze the data as required.

Table 3-1

INSTRUMENTATION LIST	
INSTRUMENT	**DESCRIPTION**
Anemometer R.M. Young Co. Model 04401A	0.00 to 360.00, Degrees Azimuth output range; +/- 1% accuracy; 1% repeatability; 5 sec. response time.
O_2 Analyzer Beckman Instruments Model 755	0.00 to 25.0% output range; 1% accuracy; 1% of full scale repeatability; 20 sec. 90% full scale response time.
Barometer Indicator H.E. Sostman Model 2400	27.00 to 31.50 Hg output range; +/- 1% accuracy; 1% repeatability; 10 sec. full scale response time.
CO Infrared Analyzer MSA Model LIRA 303	0.00 to 10.00 % output range; 1% accuracy; 1% repeatability; 10 sec. 90% full scale response time.
CO_2 Infrared Analyzer MSA LIRA 303	0.00 to 25.00 % output range; 1% accuracy; 1% repeatability; 10 sec. 90% full scale response time.
Weight Indicator B.L.H. Electronics Model 450A	0.00 to 500.00 lbs. output range; 1% full scale accuracy; 0.1% full scale repeatability; 3 sec. full scale response time.
Smoke Density Laser Spectra-Physics Inc. Model 155A-1	0.00 to 100.00 % transmittance output range; 2% accuracy; 1% repeatability; 2 msec. response time.
Humidity Indicator American Instrument Co. Model 15-6376 RH/MA	0.00 to 100.00 % R.H. output range; +/- 1% accuracy; 1% repeatability; 1 min. 65% full scale response time.
Thermocouple Type K Thermo-Electric Co. Model Type K	0.00 to 1000.00 deg C output range; +/- .75% accuracy; .75% repeatability; 12 sec. 63% of change response time.
Bi Flow Probe - Air Fabricated Model S-261	-3750.00 to 3750.00 ft. in min. output range; 7% accuracy; +/- 1% repeatability; 50 msec. response time.
Pressure Differential Transducer Setra Model S-261	-1.00 to 1.00 inches H_2O full scale output range; 1% accuracy; +/- 1% repeatability; 5 msec. response time.

Table 3-1
(continued)

INSTRUMENTATION LIST	
INSTRUMENT	**DESCRIPTION**
Radiometer-150 Medtherm Corporation Model 64P-10-24T	0.00 to 10.00 BTU/sqft/sec. output range; +/- 3% accuracy; +/- ½% repeatability; < 290 msec. response time.
Calorimeter Medtherm Corporation Model 64-20-20K-10MG	0.00 to 20.00 BTU/sqft/sec. output range; +/- 3% accuracy; +/- ½% repeatability; < 290 msec. response time.



Fire Test
Time/Date Generator
15:03:33
02:05:86
Transducers
Video Recording System
Patch Panel
Actuator Manual Control and Override Switches
HP 3497A Scanner (Channels and Actuators)
HP 3456A Digital Voltmeters
CRT
Remote CRT
HP 9144A Disc Back-up Tape Drive
HP 9020 Computer
Marine Fire Research Data Acquisition System
(Real Time)
240 Channels — 16 Actuators
Max Speed — 40 Channels per Second
HP7974A 9-Track Tape Drive

Figure 3-1

3.1.1 Test Compartment: Two video cameras were installed such that the events occurring within the test compartment could be recorded. Of primary interest were the fire source and the level of the smoke layer. Therefore, one camera was focused on the load cell and the other was focused on the target board in the compartment (figures 3-2 and 3-3). Thermocouples, calorimeters, and radiometers were located throughout the test compartment to provide temperature and heat release data. The thermocouples (figures 3-4 and 3-6B) were situated such that they provided the following temperature data:

- ♦ - within the test compartment,
- ♦ - the area between the ceiling and deck above,
- ♦ - the unexposed side of the ceiling tiles,
- ♦ - the unexposed side of the deck above,
- ♦ - the unexposed side of the bulkhead.

Thermocouples were also placed on the instrument trees (to be discussed later) located in the test compartment. Units consisting of a calorimeter and a radiometer (figures 3-5 and 3-6A) were located in the various bulkheads of the test compartment such that they could provide data on the amount of heat being released from the test fire. The units were installed so that only the face of the units were exposed to the inside of the test compartment. All units were provided with fresh water cooling to ensure they were not damaged by overheating. Two instrument trees were located within the test compartment. The "trees" were simply a means of installing the sensors and analyzer heads at the desired locations and heights within the test compartment. Figure 3-7 shows the location of the instrument trees within the test area. Table 3-2 provides a listing of the instrumentation installed on each tree. The final item installed in the test compartment was an ionization-type smoke detector. The detector was installed to provide an indication of the time between fire initiation and detector actuation. This data was used in comparing the effects of ventilation system shutdown, or vent closure, using a detector in the stateroom versus one installed in the passageway. The detector was wired to a 1.5 VDC power source. When the detector was actuated, the power source provided a signal to the data acquisition system, as well as illuminating an indicator light in the control room.

3.1.2 Passageway: Like the test compartment, there were two video cameras installed in the passageway recording the events that took place (figure 3-2). One camera was placed at the forward end of the passageway looking through the specially modified door and down the length of the passageway. The second camera was located approximately midway down the length of the passageway, just forward of the test compartment's door, facing across the passageway. This camera (figure 3-8) focused on either the target board, the test compartment's door vent, or the balancing duct diffuser located in the overhead of the passageway

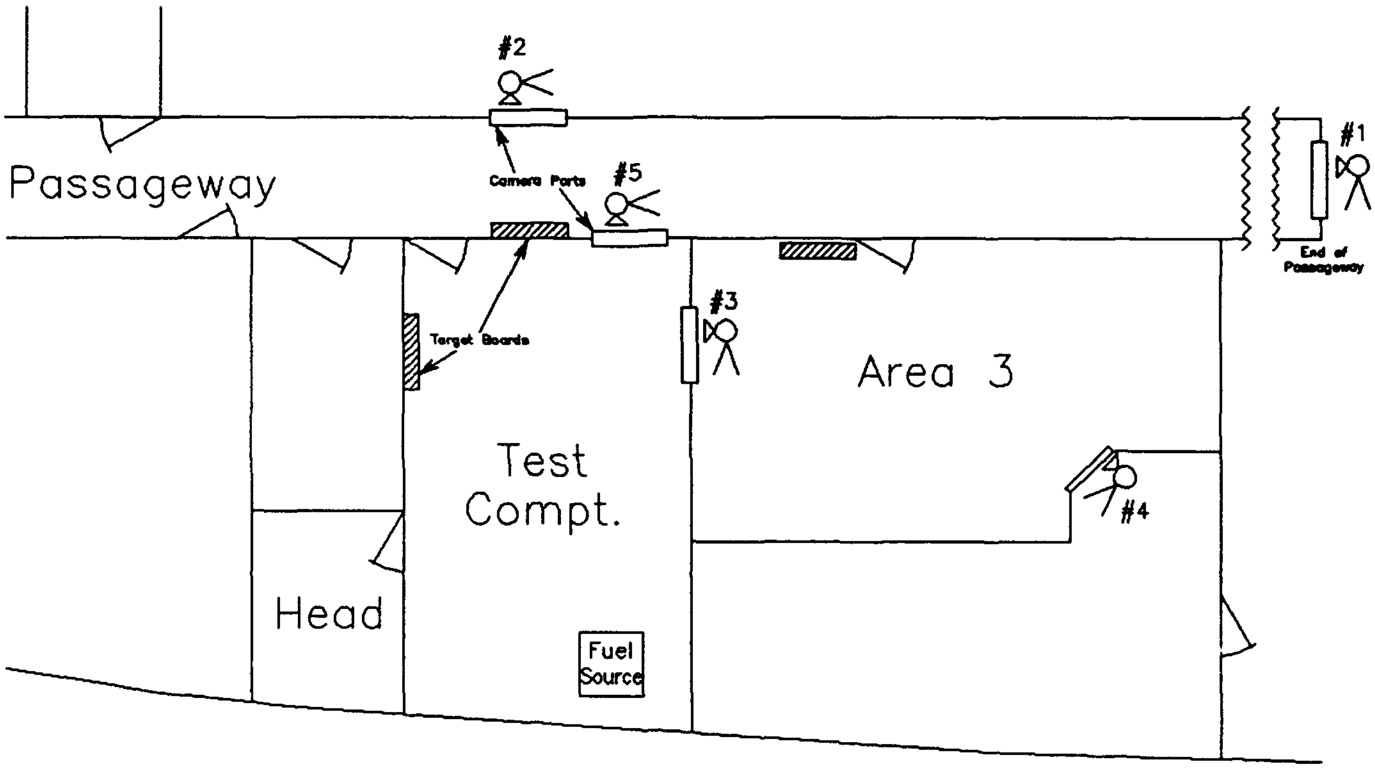
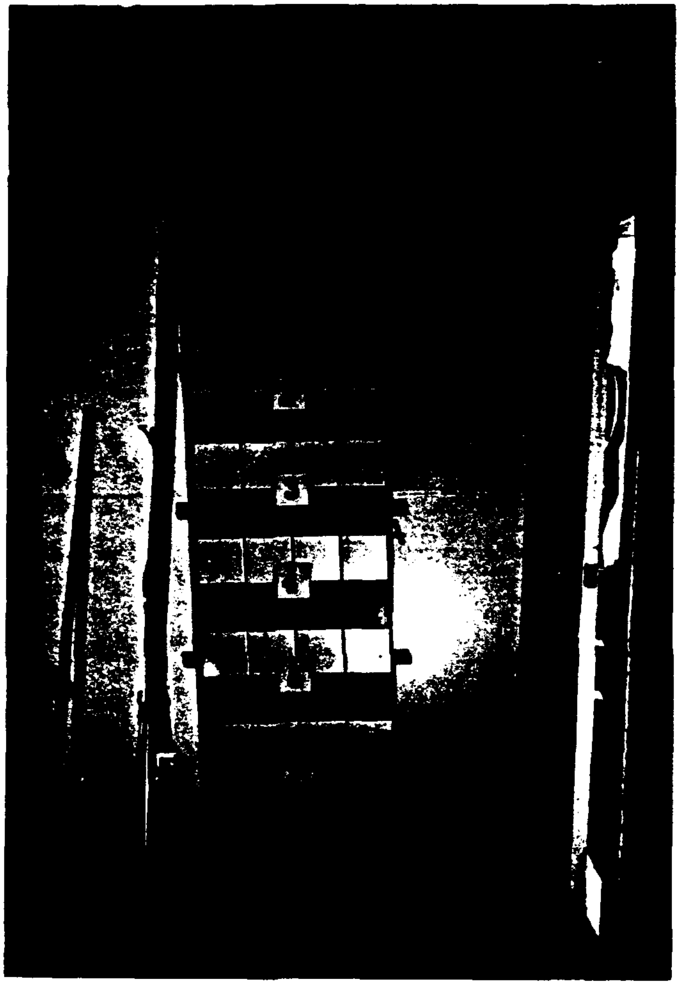


Figure 3-2 Camera Locations

A. Test compartment camera focused on fuel source. Passageway target board can also see passageway camera viewing port in doorway of forward end of passageway.

B. Test compartment camera focused on target board. Area 3 target board and instrument tree.

Figure 3-3 Cameras and Target Boards



C. Test Compartment target board. Constructed of high-temperature ceramic tile to allow for ease of cleaning between tests.

Figure 3-3 Cameras and Target Boards

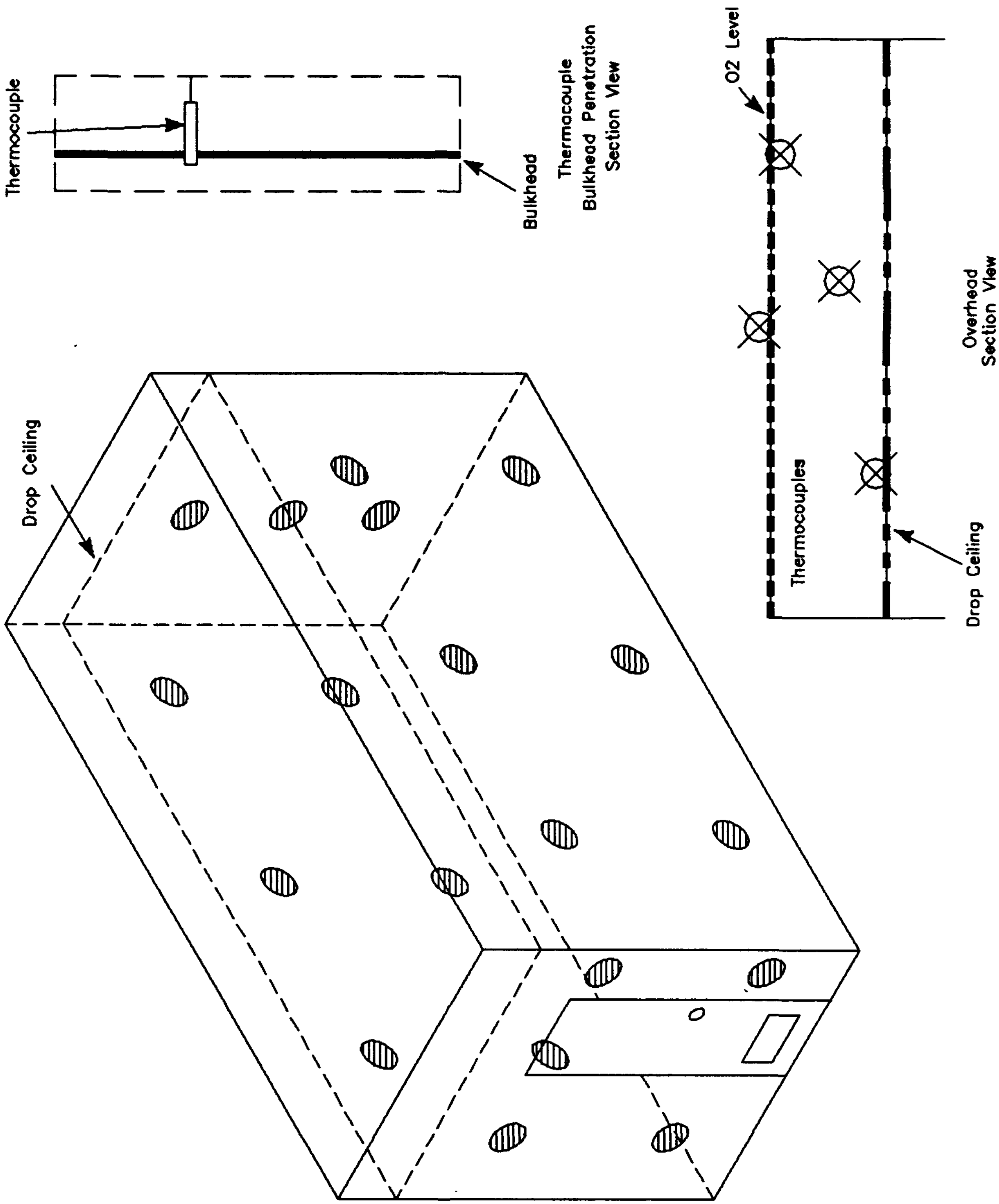


Figure 3-4 Thermocouple Locations

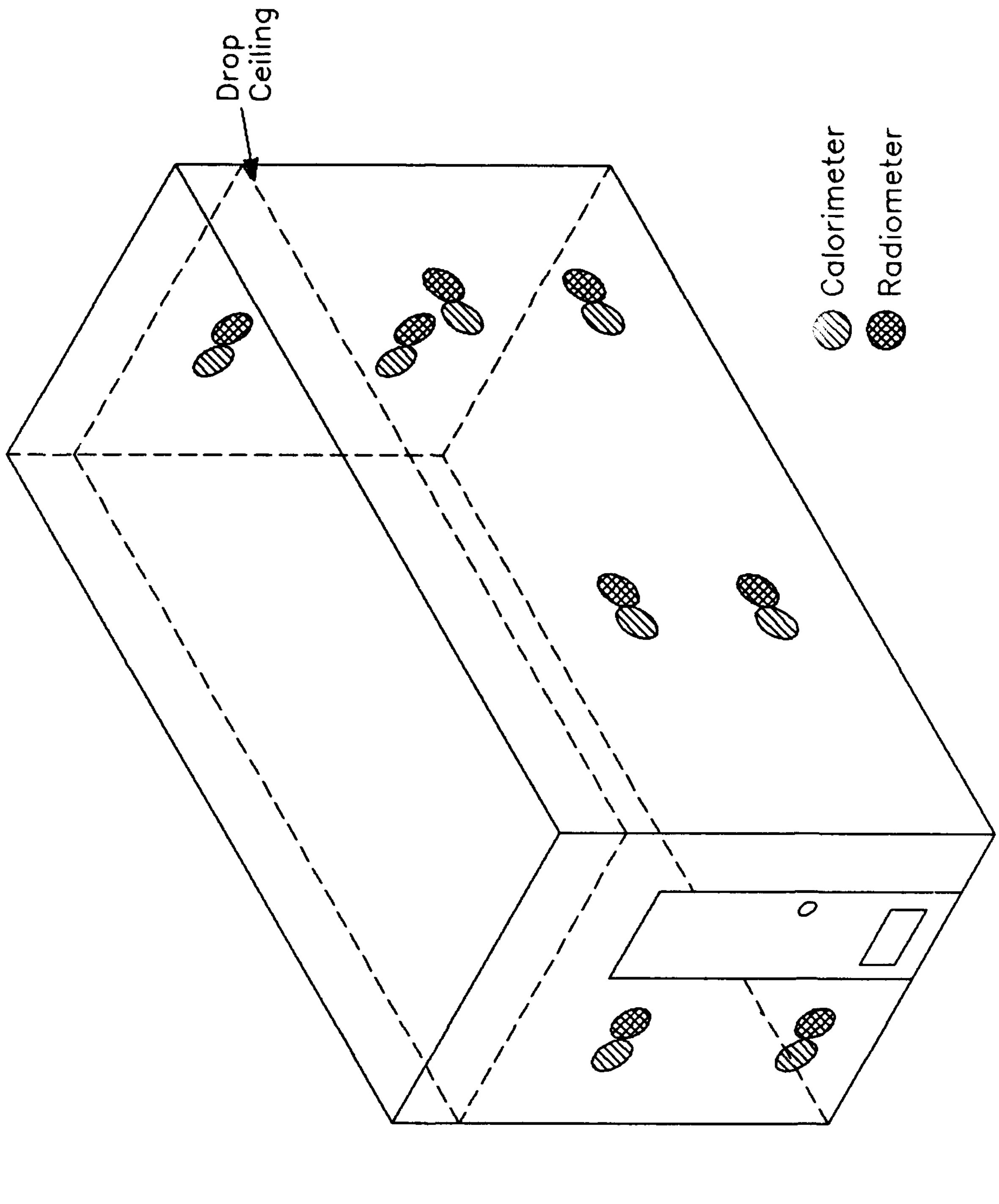
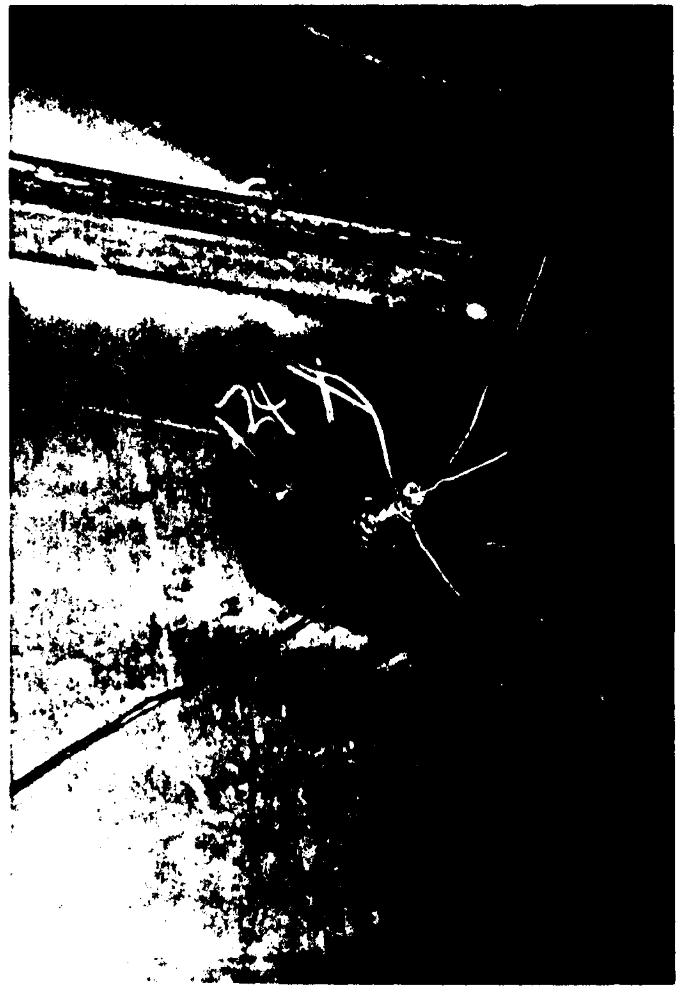


Figure 3-5 Calorimeter/Radiometer Locations

A. Calorimeter/radiometer pairs installed in test compartment bulkhead. Thermocouples installed through test compartment bulkhead.



B. Thermocouple installation on unexposed side of test compartment steel bulkhead

Figure 3-6 Test Area Instrumentation Installation

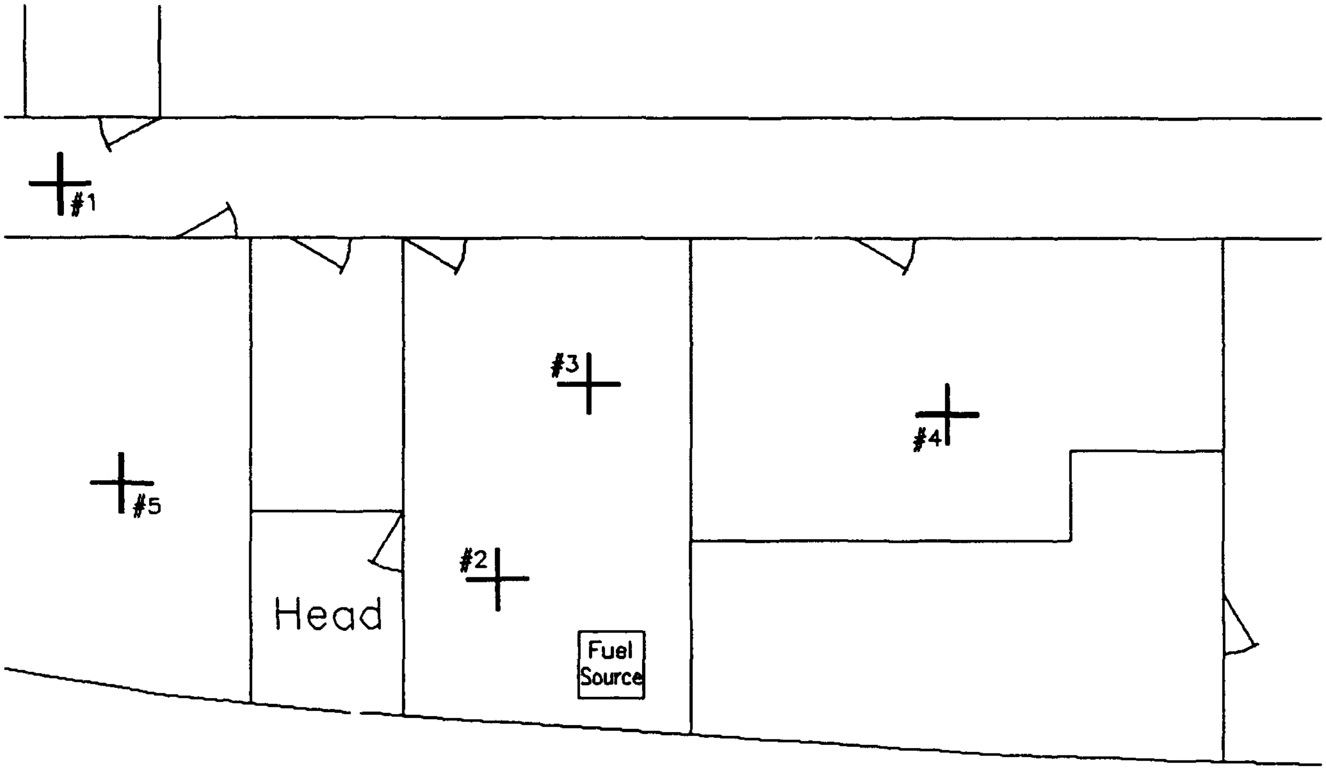
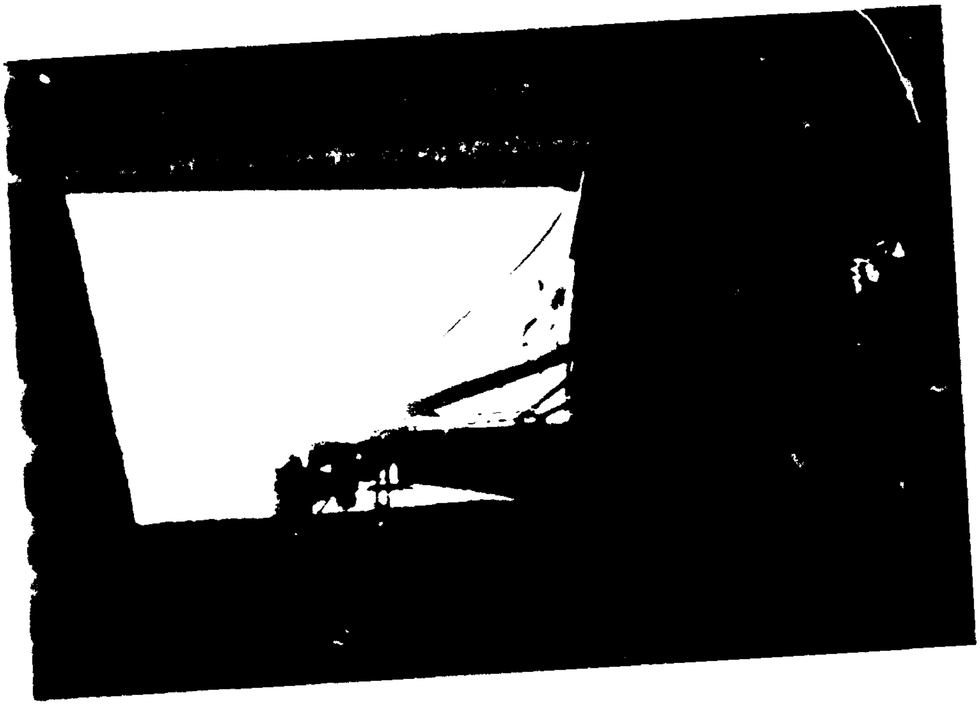


Figure 3-7 Instrumentation Tree Locations

Table 3-2

INSTRUMENT TREES					
Height (in feet)	TREE NUMBER #1	#2	#3	#4	#5
7.0	T	T	T	T	T
6.5	$O_2/CO_2/CO$	$O_2/CO_2/CO$	O_2/CO_2	CO_2	-
5.0	T	T	T	T	T
3.5	O_2/CO_2	O_2/CO_2	$O_2/CO_2/CO$	CO_2	-
3.0	T	T	T	T	T
1.5	T	T	T	T	T
1.0	O_2/CO_2	O_2/CO_2	-	-	-

T = Thermocouple
O_2 = Oxygen gas sensing
CO_2 = Carbon Dioxide gas sensing
CO = Carbon Monoxide gas sensing



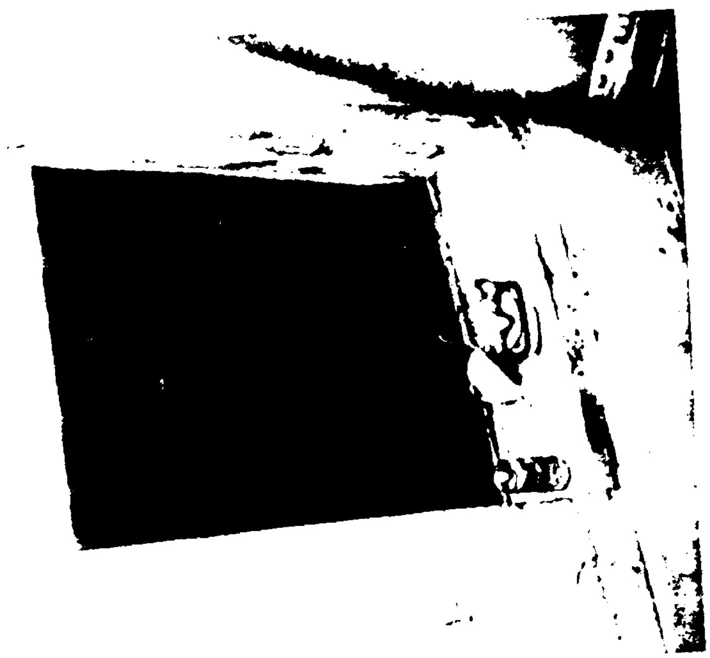


Figure 3-8 Passageway Camera (located near test compartment)

depending on the specific scenario being tested. An instrument tree was also installed in the passageway, aft of the test compartment's door (figure 3-7). Table 3-2 provides a listing of the sensors and analyzers mounted on this tree. To assist in providing a comparison baseline for the amount of smoke propagating into the passageway during each test, a series of laser obscuration meters were installed. The lasers were configured in a vertical column, just aft of the test compartment's door, focused across the passageway. Four lasers were located beneath the drop ceiling and one laser was installed in the space between the drop ceiling and the deck above (figure 3-9). Two smoke detectors (ionization-type) were also mounted on the drop ceiling, located approximately 1/3 the distance from either end. These detectors were installed in a manner identical to the one used in the test compartment, Section 3.1.1.

3.1.3 Surrounding Areas: Although the test compartment and the passageway were the main areas of interest, instrumentation was installed in the surrounding areas to monitor the level of smoke and gases, as well as record temperatures. Of the surrounding compartments, Area 3 (figure 2-1) was the most heavily instrumented. This compartment was immediately adjacent to the test compartment and was used to ascertain how quickly the smoke and fire affected an adjacent compartment. A video camera and target board were installed in Area 3 to provide an indication of the speed of infiltration and the relative density of the smoke in the compartment. An instrument tree was also installed in Area 3 (refer to table 3-2 for a listing of the instrumentation provided). A smoke detector was installed on the underside of one of the transverse steel members in the overhead of Area 3. No false ceiling was installed in Area 3, therefore smoke was capable of accumulating above the detector during the early stages of the fire and may have caused slightly longer times to actuation. This was taken into account during the analyses of the data.

The only other instrumentation installed in the surrounding compartments was an instrument tree installed in Area 5. This tree was only provided with thermocouples.

3.1.4 Ventilation Systems: Instrumentation was placed in the ventilation systems to both define the flow of air/smoke and to provide data concerning the potential detrimental impacts of smoke flowing through a particular duct or vent. Bi-flow probes were used throughout the installed ventilation systems to provide the following data: (1) is there flow, (2) what is the magnitude of flow, and (3) what is the direction of flow. Additionally, thermocouples and gas analyzers were located at various points in the ventilation systems to provide temperature data and an indication of the quality of air moving through the systems. The majority of the instrumentation was concentrated in the ducting servicing the test compartment and Area 3 for two reasons: (1) limited instrumentation assets, and (2) most of the

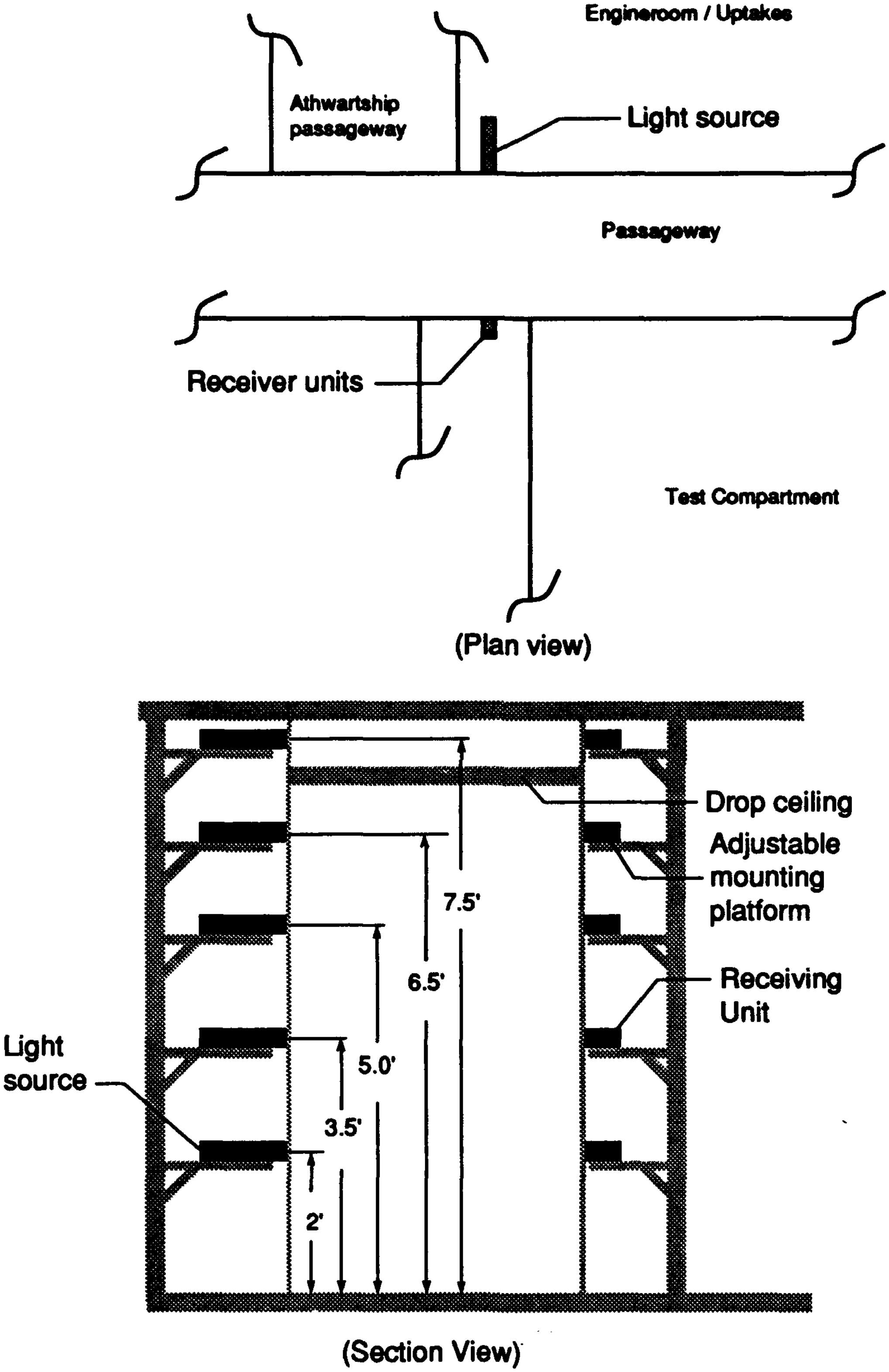


Figure 3-9 Obscuration Meters

required data could be obtained from monitoring the movement to/from these compartments. Figures 3-10 and 3-11 depict the types and locations of the instrumentation used in the ventilation ducting.

A gas analyzer tube was mounted in the return air ducting, immediately upstream of the make-up air intake, to provide an indication of the air quality being returned to the fan room. Also, bi-flow probes were installed on the external side of the test compartment's door vent (figure 3-12). A set of two probes were mounted such that they could be moved adjacent to the door vent during any tests in which the door vent was open.

Electrically-operated smoke dampers were provided for each of the installed balancing ducts and for the supply and exhaust vents for the test compartment and Area 3 (figure 3-13). Similar to the smoke detectors, the dampers were wired to the 1.5 VDC power source as a means of indicating an open or closed position. A set of contacts mounted on the damper shaft provided the necessary signal to indicate whether the damper was open or closed. Like the smoke detectors, an indicator light was installed in the control room to provide the damper status (figure 3-14) to the Test Director, and a 1.5 VDC signal was sent to the data acquisition system to provide a record of the opening/closing.

3.2 Pre-Test and Preparation Procedures

As with any live fire test, safety is of primary concern. The Supervisor of the Fire and Safety Test Detachment, working in conjunction with the Test Director, was responsible for all aspects of the test series that dealt with safety issues. He had the authority to halt a test at any point if he felt that safety was being compromised. A complete review of the test series and the procedures to be used was conducted prior to the commencement of any testing. Additionally, a check-off sheet was used for each test in the series to ensure that no safety item was overlooked and to prevent complacency. The configuration sheet mentioned earlier became an amendment to the check-off sheet and was an integral portion of the pre-test procedures. Used in conjunction with the test matrix to determine the order of testing, the check-off and configuration sheets provided the Test Director with a ready reference for the set-up of each test.

Prior to starting the test series, "transit times" for the gas analyzers were determined. A transit time represents the time lapse incurred from the instant a gas sample enters the sampling tube to the time when it enters the analyzer. A transit time is determined by the use of a known "tracer" gas; i.e., CO_2. At a known time, the CO_2 is released at the end of the sampling tube and the time lapse until it registers at the analyzer is recorded. This is accomplished for all gas sampling tubes. The transit time data is essential, with respect to reviewing the computer data print-outs, in determining real-time gas concentrations at particular sampling points.

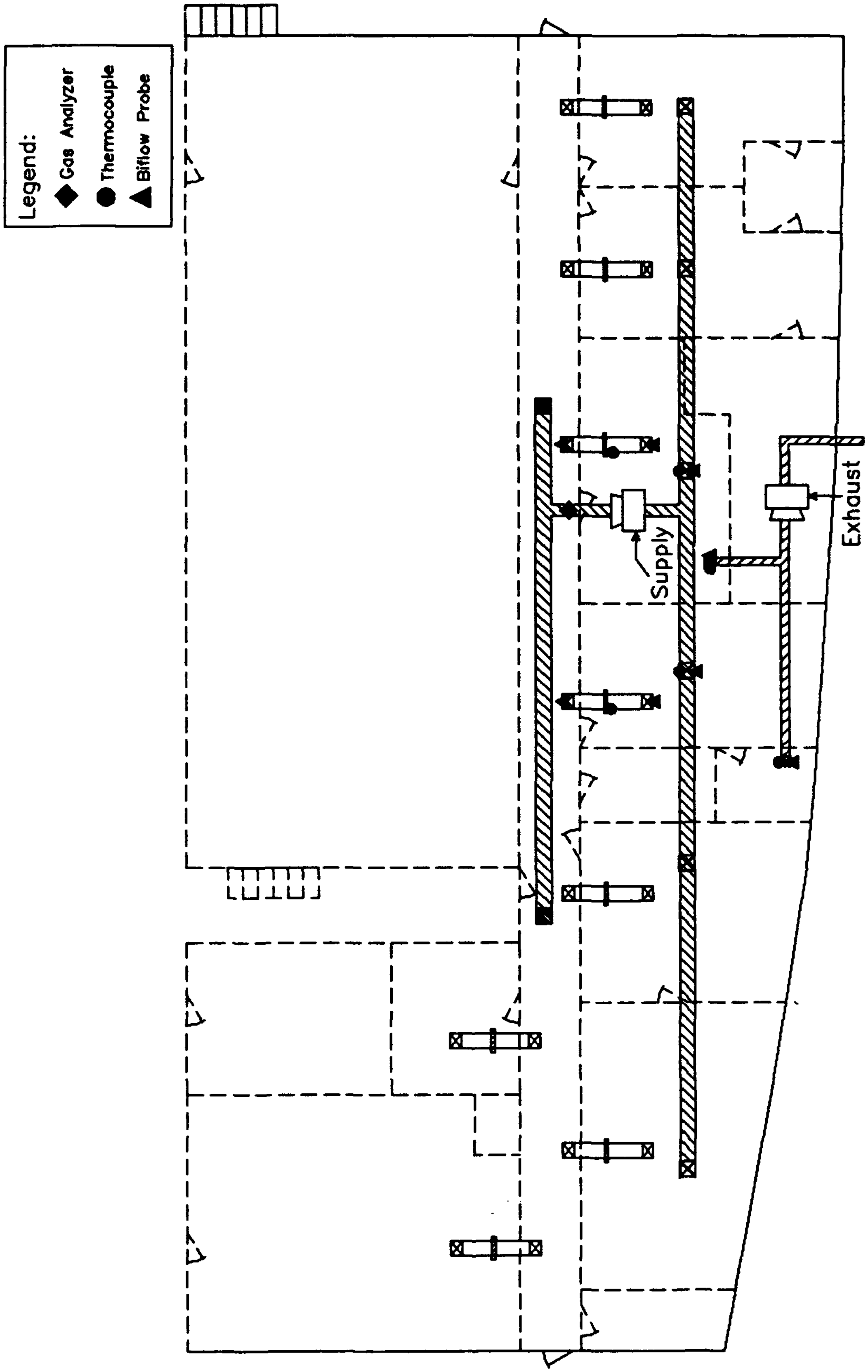
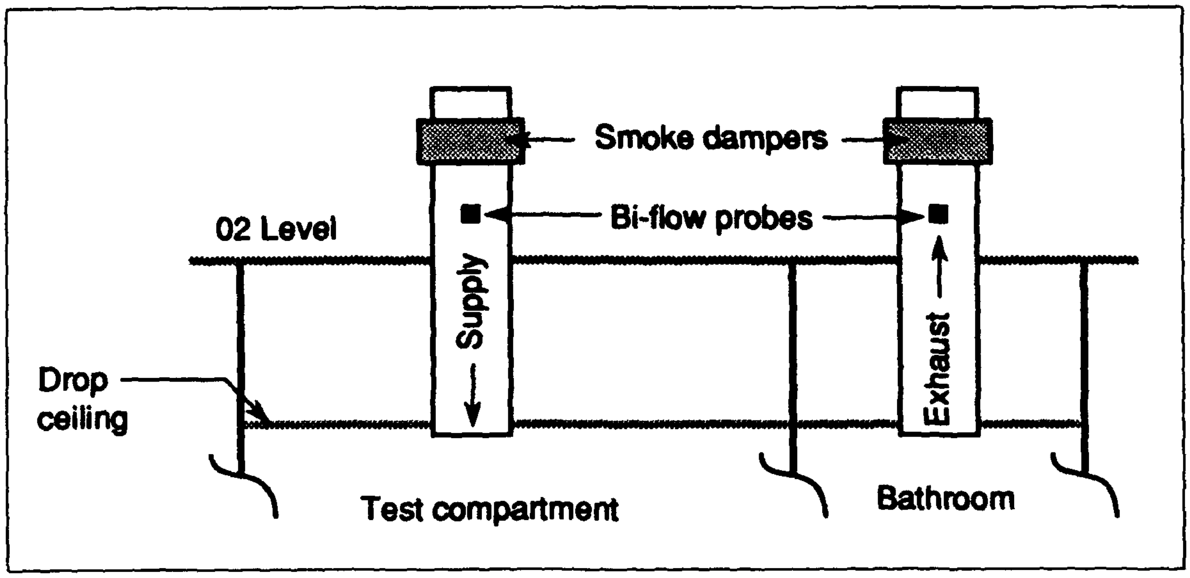
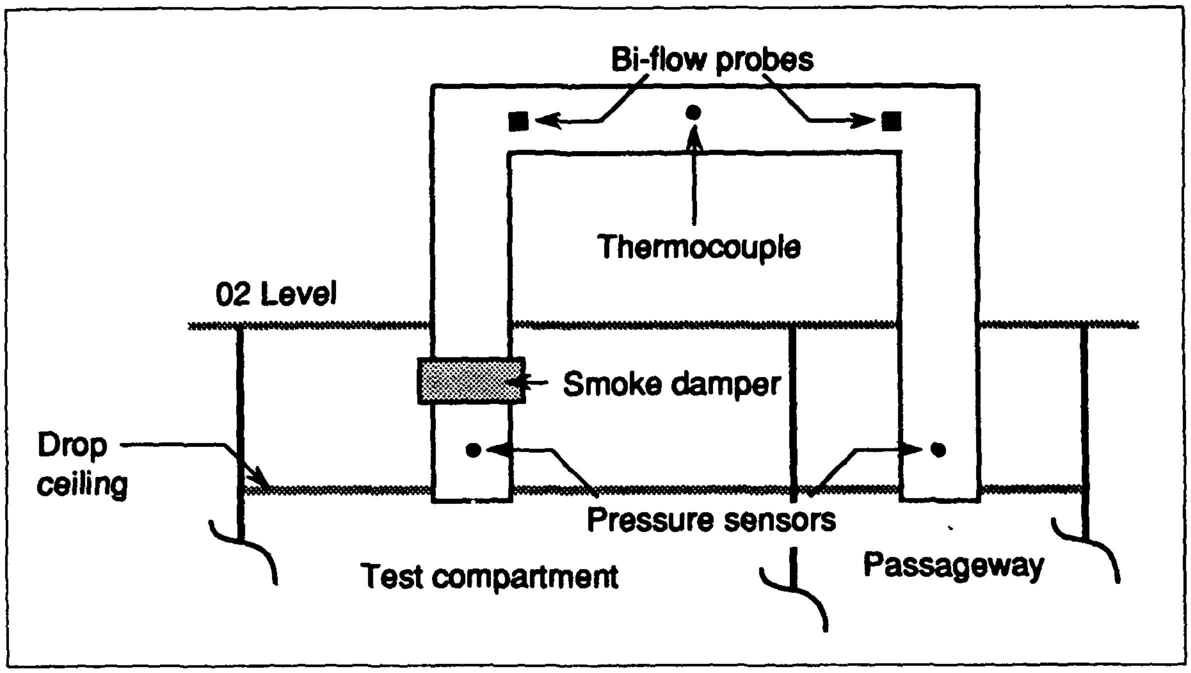


Figure 3-10 Test Area Ventilation System

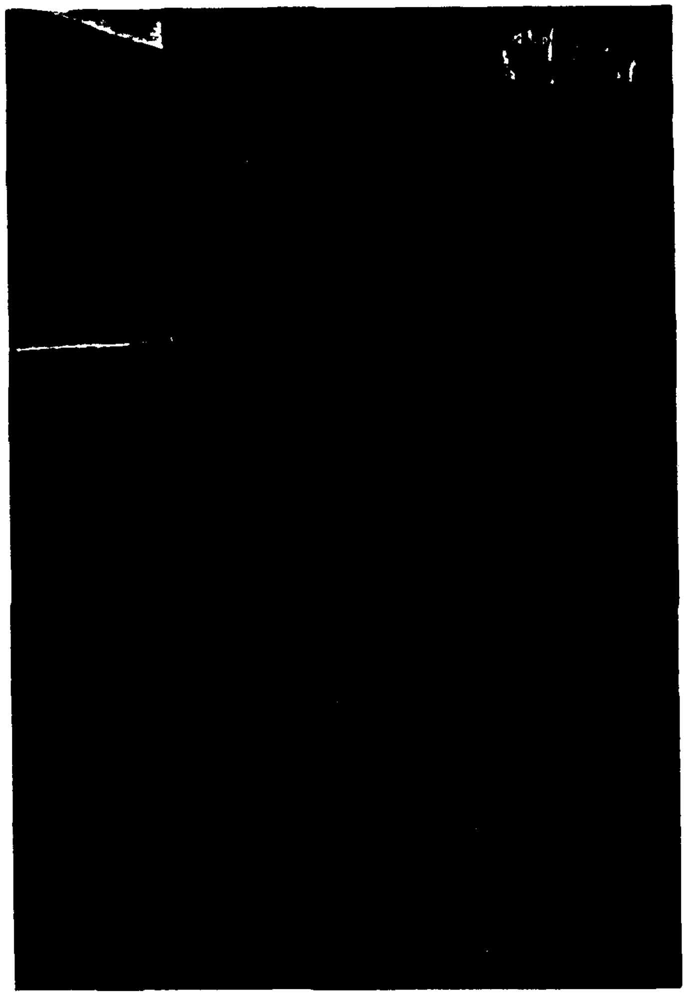


Ventilation Ducts



Balancing Ducts

Figure 3-11 Ventilation Instrumentation



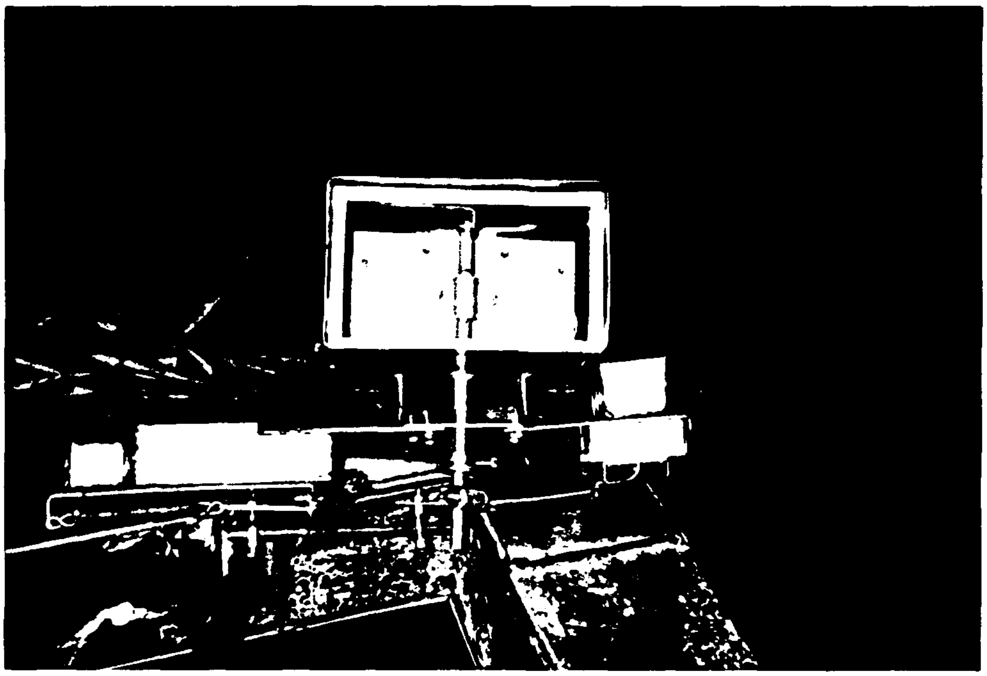
A. Bi-flow Probe on door vent

Figure 3-12 Door Vent Bi-flow Probes

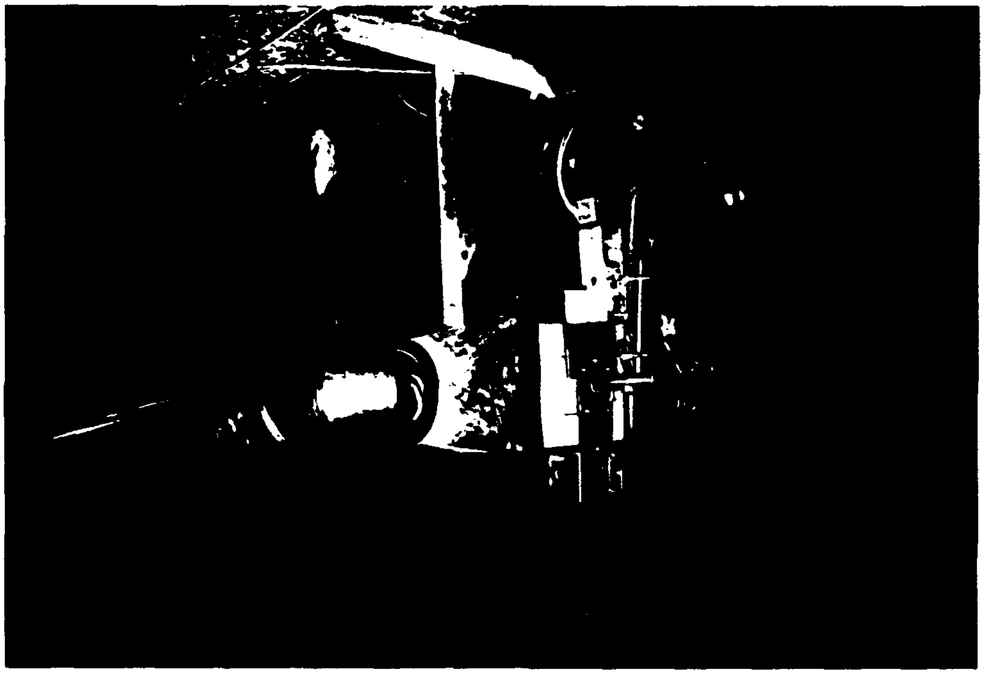
B. Bi-flow probes in use during test of configuration 1

C. Bi-flow probes moved out of the way during test of configuration 2

Figure 3-12 Door Vent Bi-flow Probes

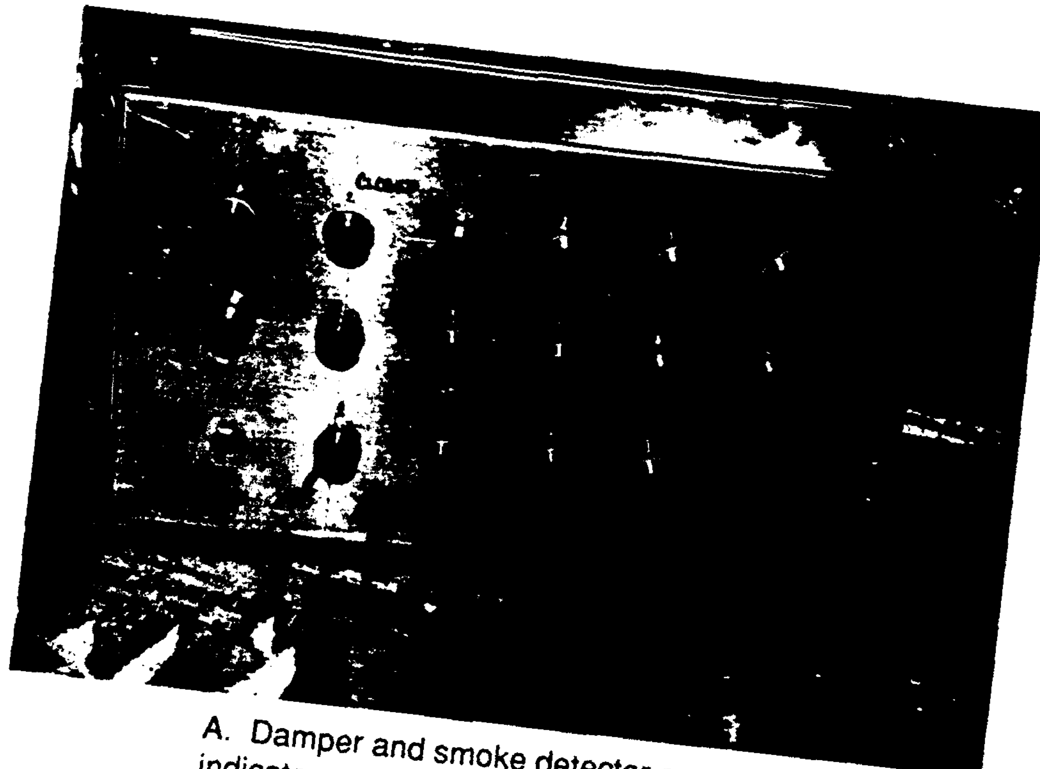


A. Electrically-operated smoke damper

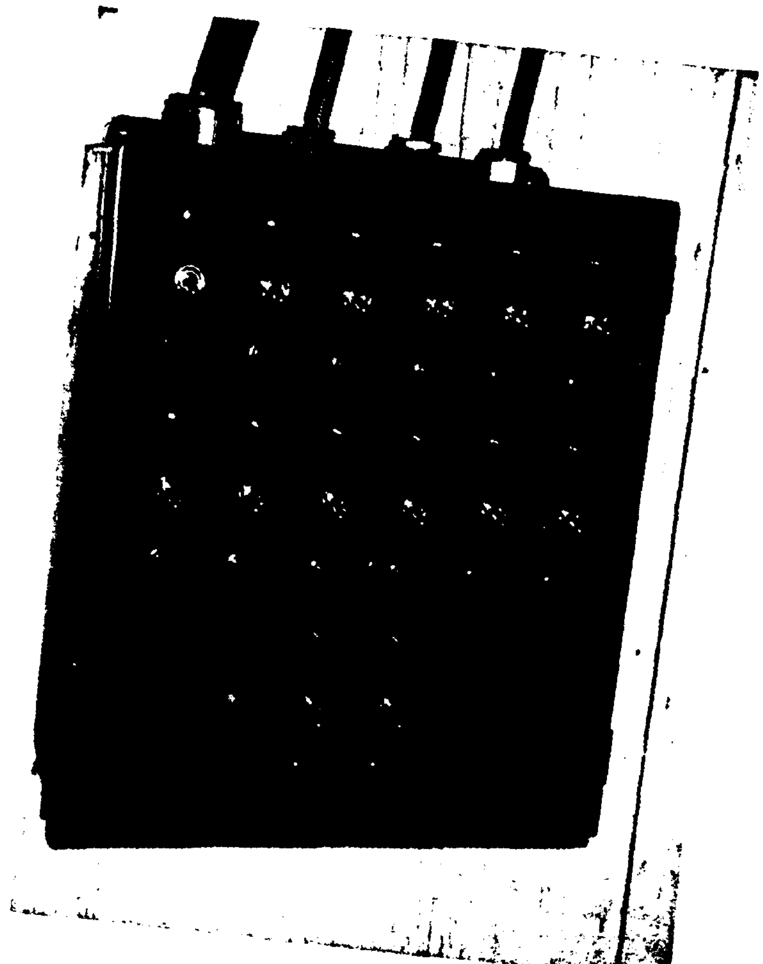


B. Smoke damper installed in a supply ventilation duct

Figure 3-13 Smoke Dampers



A. Damper and smoke detector operation indicator panel.



B. Damper Operation Panel

Figure 3-14 Operation/Indicator Panels

Prior to the start of each test, the data acquisition system was activated for at least five minutes. All channels were monitored in this "background" condition to determine if the pre-test readings were within normal ranges. This procedure provided two very necessary pieces of data: (1) a baseline for average ambient conditions, and (2) highlighted those sensors or analyzers in need of adjustment. As the test series proceeded, especially as there were more than one test per day, the ambient conditions would vary from test to test. Additionally, equipment often required adjustments of sensitivity due to accumulation of dirt and soot, or simply due to wear. For either case, the background time provided a common reference point to allow for the comparison of data from the individual tests in the series. Though video recording is considered part of the data acquisition system, the video cameras were not actuated until approximately 20 to 30 seconds before test initiation. This was done simply to reduce the amount of video tape required for the test series. The date/time generators for the cameras, and the initial data point for each channel, was automatically set to zero by the computer system upon initiation of the test.

Prior to the start of each test, the weight of the individual items used as the fuel source were recorded. During the few tests where the fire consisted of a single piece of furniture, this step was unnecessary. However, when multiple items were placed on the load cell (figure 2-7), individual weights were recorded. By subsequently weighing the items upon completion of the test, the amount of each item consumed was determined. When using diesel fuel as part of the fuel package, the level of fuel was measured before and after each test to determine the total consumed.

3.3 Test Procedures

Upon completion of the items discussed in Section 3.2, each test would be initiated by the simultaneous lighting of the test fire and activation of the data acquisition system. Typically, the test compartment would be completely filled with smoke in about 2 or 3 minutes. At that time, the two cameras associated with the test compartment were secured. During the initial minutes of each test, the indicator panel (figure 3-14) in the control room was monitored to observe when the indicator lights for the smoke detectors illuminated. Based on the particular test scenario, the Test Director would make the appropriate changes to the ventilation system.

Depending on the speed at which the smoke propagated from the test compartment, the duration of each test was approximately 20 to 30 minutes. This provided ample time for the test fire to stabilize and provide sufficient data to compare the effects on the smoke movement when using either the door vent or the balancing duct. An installed CO_2 system was then activated to extinguish the fire. F&STD personnel were used to overhaul the fire and to evacuate the smoke from the test area.

Subsequent to the evacuation of the smoke from the test area, and prior to the start the following test, the test area was allowed to cool to ambient temperatures (or as nearly as time available would permit). During the cooling period, all instrumentation was checked, equipment was replaced and cleaned as required, and select bulkheads within the test area were given a new coat of white paint to aid in photograghic efforts.

4.0 TEST RESULTS

This section provides a brief summary of the data obtained for each of the test scenarios. The primary objective is to compile and analyze the performance data of the door vent and balancing duct configurations, subsequently referred to as Configurations 1 and 2 respectively, for each scenario. An attempt is made to determine what, if any, differences are discernible in the speed at which the smoke propagates into the passageway, or if there are any other differences that may make one configuration less desirable than the other.

The initial series of graphs, presented for each scenario, represent the data used in defining the fire for each test. To accurately compare the level of smoke propagation, it was necessary to ensure that similar fire parameters existed in each test, or that any variations between configurations were noted and taken into consideration. Subsequent to the initial three test scenarios, a standard fire was used in all tests. However, this did not guarantee that the fires would exhibit identical parameters in all tests. The graphs provided an easy reference from which to compare any differences in the parameters of the fires, or their coincident effects within the fire compartment. The following is a listing of the data provided for each test configuration:

Graph a: Heat Release Rate (Kw/m^2)
Graph b: Temperature (°C), above fire, 7 ft (2.1 m) level
Graph c: Temperature (°C), room, upper and lower levels [7 ft (2.1 m) and 3 ft (0.9 m)]

The second series of graphs provide data concerning the density of the smoke in the passageway, immediately adjacent to the test compartment. This data was used to provide a general comparison of the amount of smoke propagating into the passageway. The following is a listing of the data provided for each test configuration:

Graph a: % Transmittance, passageway (@ 6.5 ft (2 m) level)
Graph b: % Transmittance, passageway (@ 5.0 ft (1.5 m) level)
Graph c: % Transmittance, passageway (@ 3.5 ft (1.1 m) level)

It should be noted that the data presented on each graph has been electronically normalized, or "smoothed", by the computer data analysis program. The "raw" graphs contained many severe "spikes" that made analysis very difficult. The spikes are caused by "puffs" of smoke passing through the laser beams. These puffs of smoke can be much denser than that of the surrounding layer. As they pass through the laser beam, the % transmittance to the associated receiving unit drops dramatically for a short period of time (normally just a few seconds). Normalizing the graphs presents a better indication of the change in the % transmittance with respect to time.

Where multiple tests of one configuration were conducted, the resulting data of all tests (of similar configuration) are presented as averaged values.

4.1 Test Scenario No.'s 1, 2, and 3

- Basic ventilation system configuration (all systems on)
- No changes during test
- Test fire fuel: Scen. #1) sofa only
  Scen. #2) room fully furnished
  Scen. #3) crib/cushion/diesel fuel (standard test fire)

The first three test scenarios are addressed collectively. The only variation between these tests was the fuel used for the fire. However, the difference in the fuels did not appear to make an appreciable difference in the outcome of the tests. When actual furniture was used, the fire did not develop as quickly and the initial compartment temperatures were not quite as high as when using the cribs and cushions. This was expected. The porous nature of the cribs allowed for more efficient use of the initial oxygen available by exposing more fuel surface area and hence, more rapid combustion prior to the fire becoming oxygen controlled. Though a variety of fuels were used for the three scenarios, it was still possible to compare the results since both configurations were used in each scenario and averaging the data had no effect on the overall comparisons.

The graphs shown in figure 4-1 illustrate just how similar the fires were for the two configurations. Although the peak heat release rate was slightly higher for Configuration 2 (graph a), after approximately 3 minutes the two curves are essentially identical. Similarly, the temperatures above the fire and throughout the compartment (graphs b and c respectively) were nearly identical throughout the tests. The only other variable for these three scenarios was the total mass loss (wood and flexible polyurethane foam) during each test. Due to the variance of the fuels, a graph showing the average mass loss, over the duration of the tests, for each configuration was not plotted. However, an average value for the total mass (weight of wood and foam) consumed during the tests of each configuration was recorded:

- Configuration 1: 7.15 lbs (2.7 kg)
- Configuration 2: 6.98 lbs (2.6 kg)

As can be seen, the difference is minimal. Though the duration of some of the tests varied, as well as the total mass loss, the ratio of the amount of foam consumed to the amount of wood consumed remained fairly constant throughout all the tests.

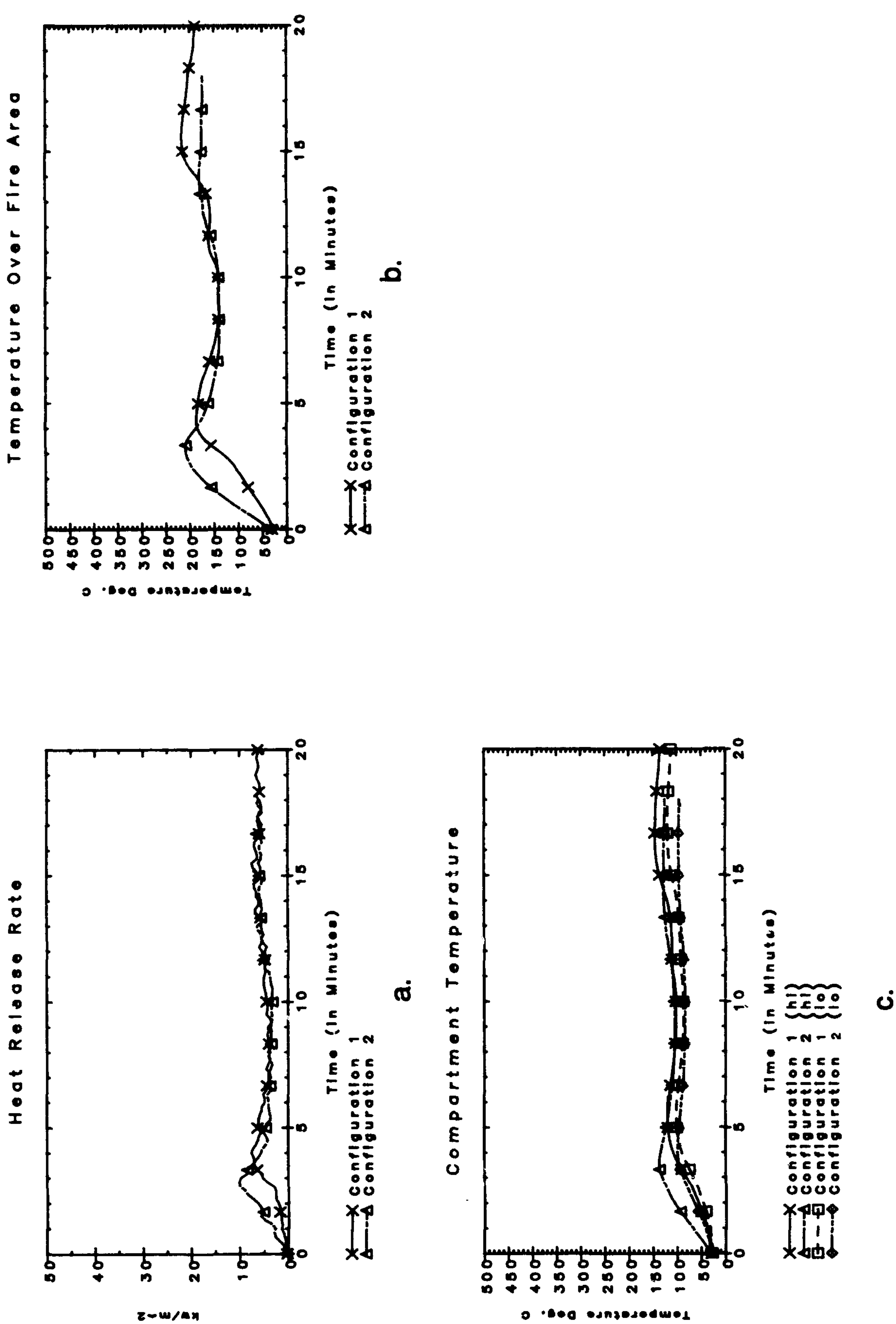


Figure 4-1 Heat Release & Temperature Data (avg.), Scenarios 1, 2, 3

A review of the data provided in the previous paragraphs, coupled with the data contained on the video recordings, confirmed that the test results for the two configurations were essentially equal. This fact provided a basis for comparisons between the performances of the door vent and balancing duct configurations in subsequent tests. The average values for the % transmittance for each configuration are presented in figure 4-2. As can be seen, there is very little difference in the performances of the two configurations. On the average, the balancing duct configuration (#2) appeared to allow slightly less smoke propagation into the passageway than did the door vent configuration.

4.2 Test Scenario No. 4

- Shut-down ventilation systems upon actuation of the passageway smoke detector

This scenario represents the procedures that are normally followed on passenger vessels. Current practice is to secure the ventilation systems (supply and exhaust) for the affected area of the ship when a passageway smoke detector is actuated. This is accomplished by personnel on the bridge of the vessel after they have an indication of detector actuation on their alarm panel. During this series of tests, the ventilation systems were secured immediately upon indication of a passageway detector actuating. This simulated a scenario where the detector automatically secures the ventilation systems, or the bridge crew is very quick in responding.

Although the standard fire was used for all tests in this scenario, review of figure 4-3a indicates a disparity in the average heat release rates for the fires of the two configurations. For Configuration 2, the fires exhibited a strong "surge" during the initial minutes of the tests. This surge was common to the majority of the tests in this test series regardless of the configuration. Though no definitive explanation can be given for the absence of the surge during the tests of Configuration 1, the most likely cause might be that the diesel fuel pan was not placed completely under the wood crib. This would decrease the fuel (crib & cushion) surface area that was exposed to the flames at the start of the tests, thereby slowing the speed at which the fire would grow. The surge is a result of the fire experiencing normal, rapid growth prior to becoming oxygen-controlled. After consuming the oxygen that is initially available, the fires attained a reduced level of steady, oxygen-controlled burning. The fact that no surge was evident during Configuration 1 had an impact on the amount of smoke that propagated into the passageway. Approximately 7 minutes elapsed before the fires of the two configurations exhibited similar heat release rates. Coincident with the rapid rise in the rate of heat release, was a significant drop in the values for % transmittance (figure 4-4) for Configuration 2. The

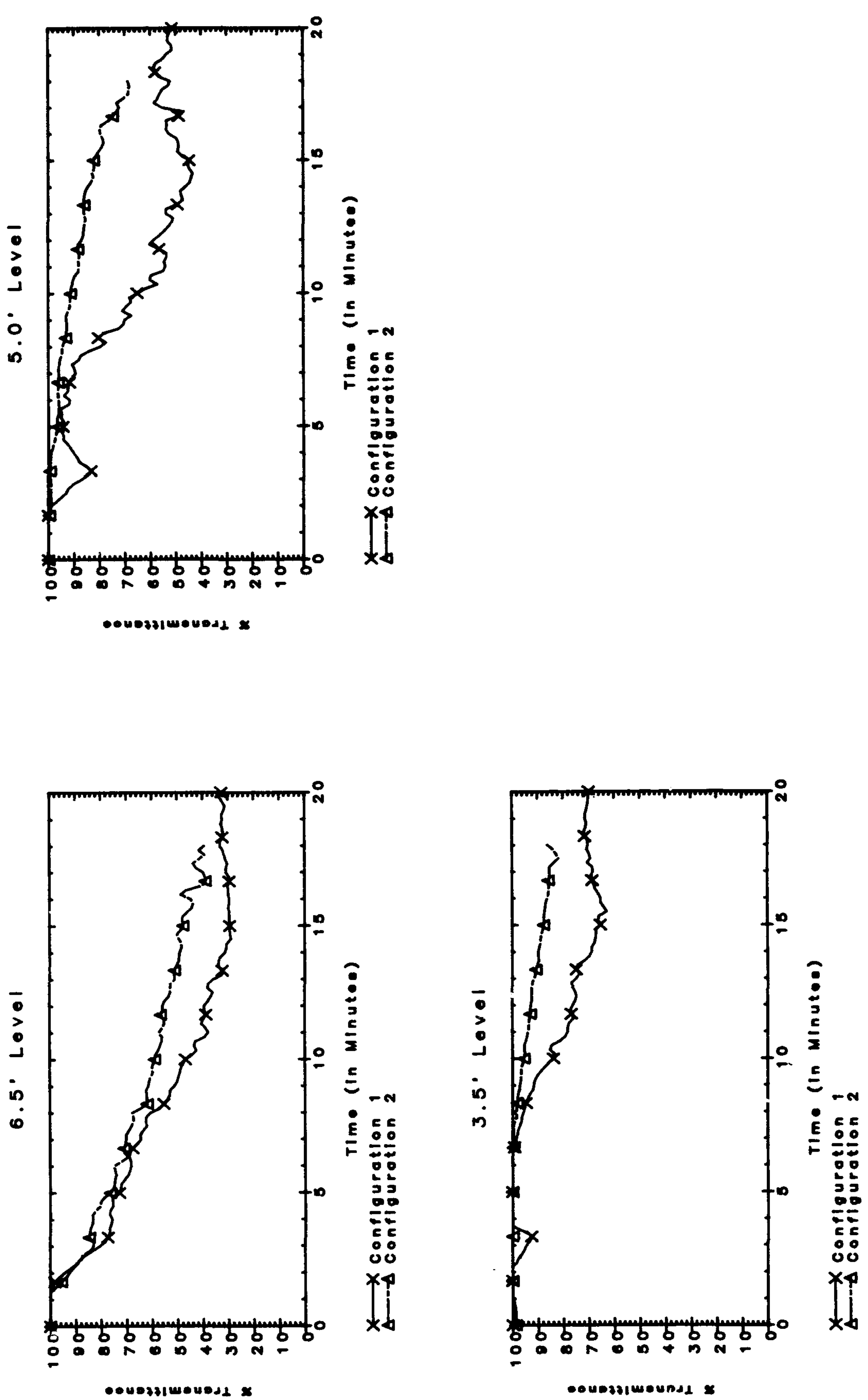


Figure 4-2 Transmittance Data, Scenarios 1, 2, 3 (avg)

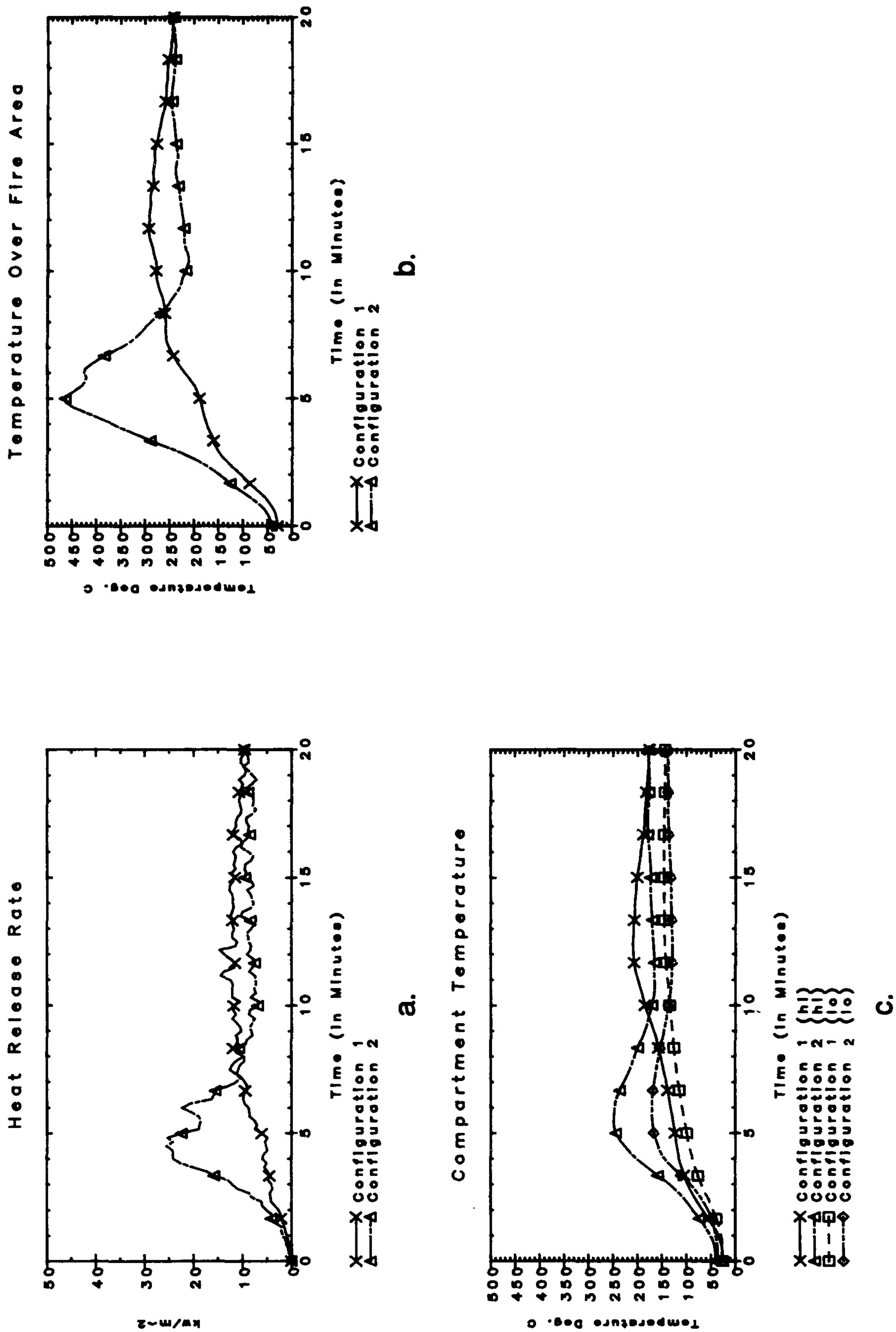


Figure 4-3 Heat Release & Temperature Data, Scenario 4

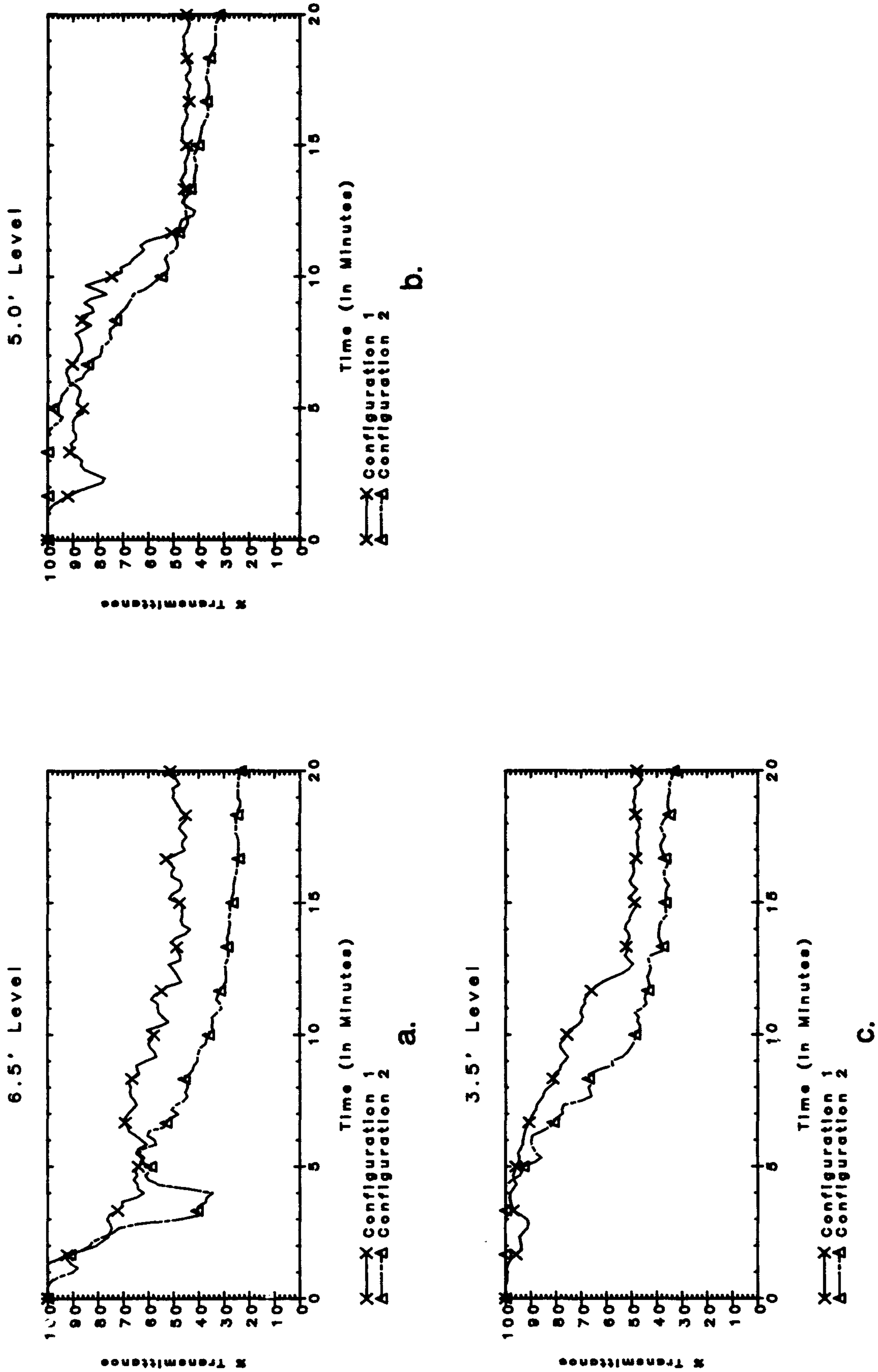


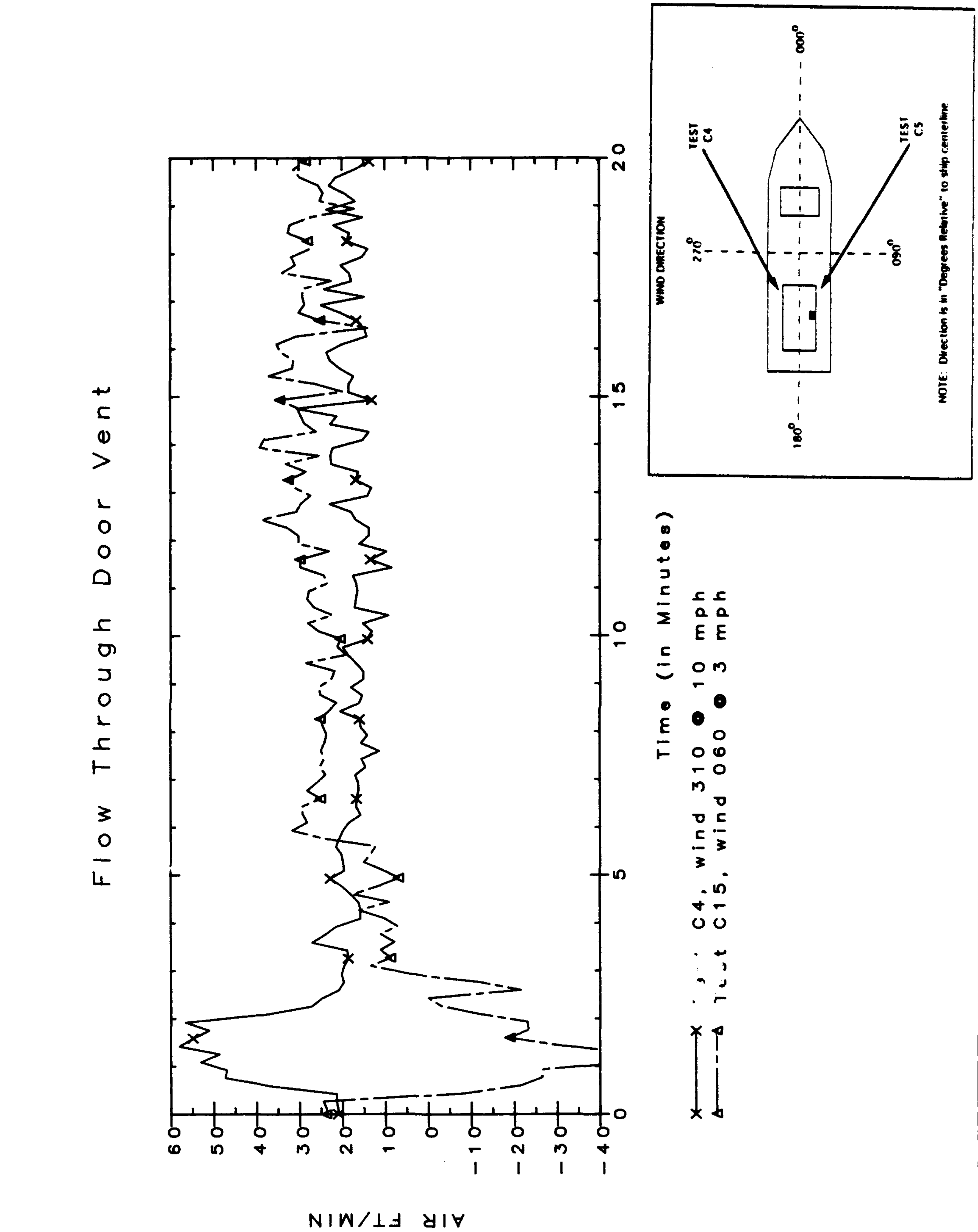
Figure 4-4 Transmittance Data, Scenario 4

initial, rapid decrease in % transmittance is primarily evident at the 6½-foot level and is very short-lived. The % transmittance values (figure 4-4a) for Configuration 2 do, ultimately, attain a slope similar to that exhibited by the values for Configuration 1. They do, however, tend to remain at levels below those of Configuration 1. This is likely caused by the heavier influx of smoke into the passageway during the initial phase of the fires for Configuration 2.

A general comparison of the two configurations, using the amount of smoke propagating into the passageway (% transmittance data), would indicate that Configuration 1 performed slightly better than did Configuration 2. When the differences in the test fires are taken into account, the performances of the two configurations are essentially identical.

Visual observations during the tests, as well as subsequent analyses of the resulting test data, brought to light several additional anomalies that need to be addressed. One area of interest was the actual point of emission for the majority of the smoke escaping the test compartment. Based on visual observations, it appeared that most of the smoke emanating from the test compartment was coming from around the upper half of the door jamb. As was seen in figure 3-12c, black, horizontal streaks of soot were evident on the upper left portion of the compartment door. There was no evidence of smoke coming from the right side (hinge side) of the door. The door and frame installed in the test compartment were considered representative of an actual shipboard installation. Therefore, the smoke movement around the door (between the door and frame) is also considered representative of an actual shipboard fire scenario. Though not always occurring during the same timeframe for each of the tests, smoke was observed at this location at some time during all tests, regardless of the configuration. For the majority of the tests, smoke flow from this location would begin shortly after the smoke layer descended below the level of the top of the door. Typically, a steady flow would continue for the remainder of the test, with the intensity varying with the heat release rate of the fire.

A steady flow of smoke, for the duration of the tests, was not observed from either the door vent or the balancing duct. During tests of Configuration 1, smoke flow from the door vent was very inconsistent. In fact, this is an area where analyses of the test data revealed some interesting occurrences. Figure 4-5 represents flow data through the test compartment's door vent for the two tests of Configuration 1 in this scenario (Test No.'s C4 and C15). As can be seen, shortly after ignition of the fire, flow through the vent changes dramatically. However, for the two "similar" tests, the initial flows through the vent are in opposite directions. Review of the heat release data for these two tests indicates that during the initial minutes of the tests, both fires exhibited comparable rates of heat release. Based on this data, it was expected that flow patterns within the test



NOTE: POSITIVE VALUES INDICATE FLOW <u>OUT</u> OF THE TEST COMPARTMENT

Figure 4-5 Door Vent Air Flow, Scenario 4 compartment would be similar. Visual observations of the tests revealed that test C15 (initial flow <u>into</u> the compartment) exhibited heavy smoke flow from the upper half of the door jamb starting very early in the test. During test C4, flow from around the door jamb did not start until after the ventilation fans were secured, approximately 2 minutes into the test. It was at this point where the <u>outward</u> flow from the door vent began to decrease. The initial surges in flow through the door vent (in both directions) for the two tests were less than 3 minutes in duration. Subsequent to the "surge" period, flows through the vent became irregular pulses or "puffs".

To definitively determine the cause for the opposite flows through the door vent during the initial minutes of the two tests, additional testing will be required. The instrumentation used during these tests was not set to provide the level of sensitivity necessary to make highly accurate measurements of flows and pressures within the test compartment and passageway. The main function of the instrumentation used during this test series was to record the parameters of the fire and to identify general trends in the test compartment and surrounding areas. The levels of flows and pressure differences between the test compartment and passageway were small enough to fall below the range of accuracy of the instrumentation used. Though possible to identify relative trends and magnitudes, in many cases it was very difficult to identify "true" values versus background noise. The only factor that consistently varied with the different directions of initial vent flows was the relative wind direction. In each case when the initial vent flow was <u>out</u> of the compartment, the relative wind was off the port side of the test vessel. When the initial vent flow was <u>into</u> the test compartment, the wind was always off the starboard side of the test vessel. It is well documented that the direction and velocity of external winds can have a significant impact on an internal fire due to changes in pressures as the wind travels through and around a structure. Yet, without instrumentation installed to specifically quantify the impact of the wind, it is impossible to provide definitive conclusions concerning its impact on the vent flows in these tests.

Regardless of the direction of the initial surge, subsequent flow through the door vent was very sporadic and irregular. The visual and electronic data confirm this fact. Upon subsidence of the initial surge, an erratic pulsing of smoke from the door vent was observed. It appeared that during this phase of the test, flow through the door vent was alternately supplying air (oxygen) to the test compartment (fire) and releasing pressure when the differential became great enough. Throughout this process, smoke flow from the upper half of the door jamb remained relatively steady and constant.

Tests of Configuration 2 did not provide any of the conflicting or confusing data evident with tests of Configuration 1. Flow through the balancing duct was consistent with expectations. Figure 4-6 provides representative flow data for the balancing duct. Shortly after ignition of the fire there is an initial increase in flow through the duct. The increasing flow lasts for approximately 2 to 3 minutes before dropping back to a lower, albeit higher than the initial flow, relatively steady flow for the remainder of the tests. Based on visual observations, it appeared that the amount of smoke propagating through the balancing duct contributed less to the overall smoke concentration in the passageway than did the smoke escaping from around the door jamb. It must also be noted that subsequent to the formation of the initial smoke layer in the passageway, the view of the balancing duct terminal was obscured. This prevented further visual observation of smoke exiting the terminal. However, the constant flow values shown in figure 4-6 tend to indicate (barring a significant increase in species concentration) that the relative contribution to passageway smoke density made by the balancing duct did not change.

This test scenario also provided an alternate flow path for the smoke exiting the test compartment in addition to those mentioned above; door vent, balancing duct, and around the door jamb. Upon securing the ventilation fans, the ventilation ducting became an additional path for smoke propagation from the test compartment. Figure 4-7 is provided as an example of the flow data recorded in the supply air ventilation duct. For this example, the ventilation system fans were started approximately 1 minute prior to the start of the test and were secured approximately 1 minute into the test (upon actuation of a passageway smoke detector). It can be seen that upon securing the supply fan, the flow values for the supply duct quickly drop to zero and then become negative. The negative flow values indicate flow out of the test compartment. The smoke that entered the supply ventilation system spread in two directions. Some flow disseminated throughout the supply system and into the surrounding compartments and the remaining smoke exhausted out the make-up air intake. The configuration of the ventilation system was such that the intake for the make-up fresh air was the highest point in the system. Additionally, the proximity of the fresh air intake to the test compartment was such that it most likely provided the path of least resistance to the escaping smoke. Therefore, during the last half of the test series, in all tests that required the securing of the ventilation systems, the damper in the fresh air intake was closed simultaneously with the securing of the supply ventilation fan. This prevented the smoke from escaping directly to the atmosphere and forced it to exit through the return air terminals. It was felt that this would provide an indication of what would likely occur when the fan room and associated fresh air intake are on the same level as the compartments being served. When the intake damper was closed, a significant increase in the amount of smoke entering the passageway was observed. This increase was due to smoke flow through the return air ducting. Smoke flow from the return air ducts was much heavier than flow from either the door vent or

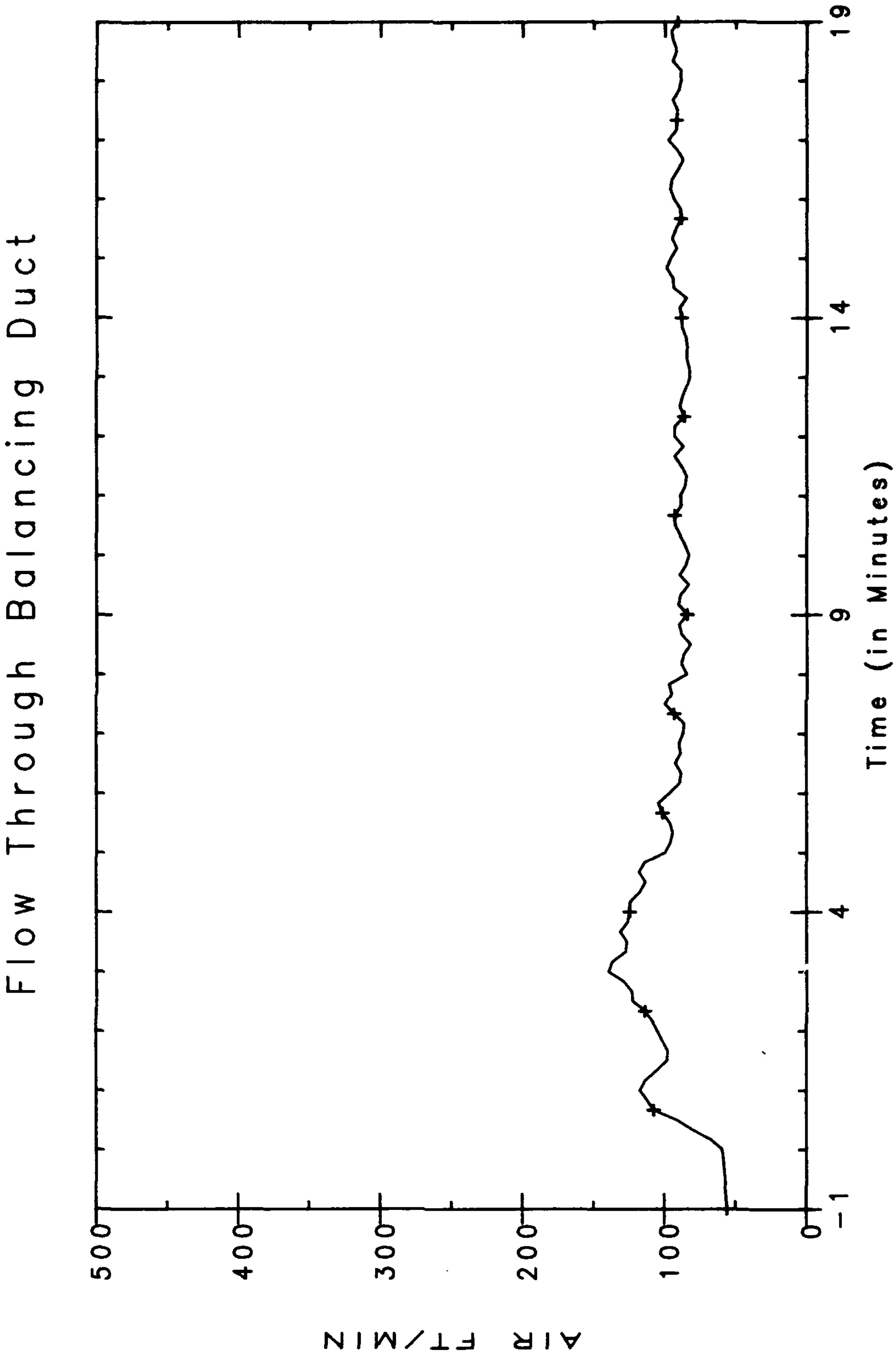


Figure 4-6 Balancing Duct Air Flow, Scenario 4

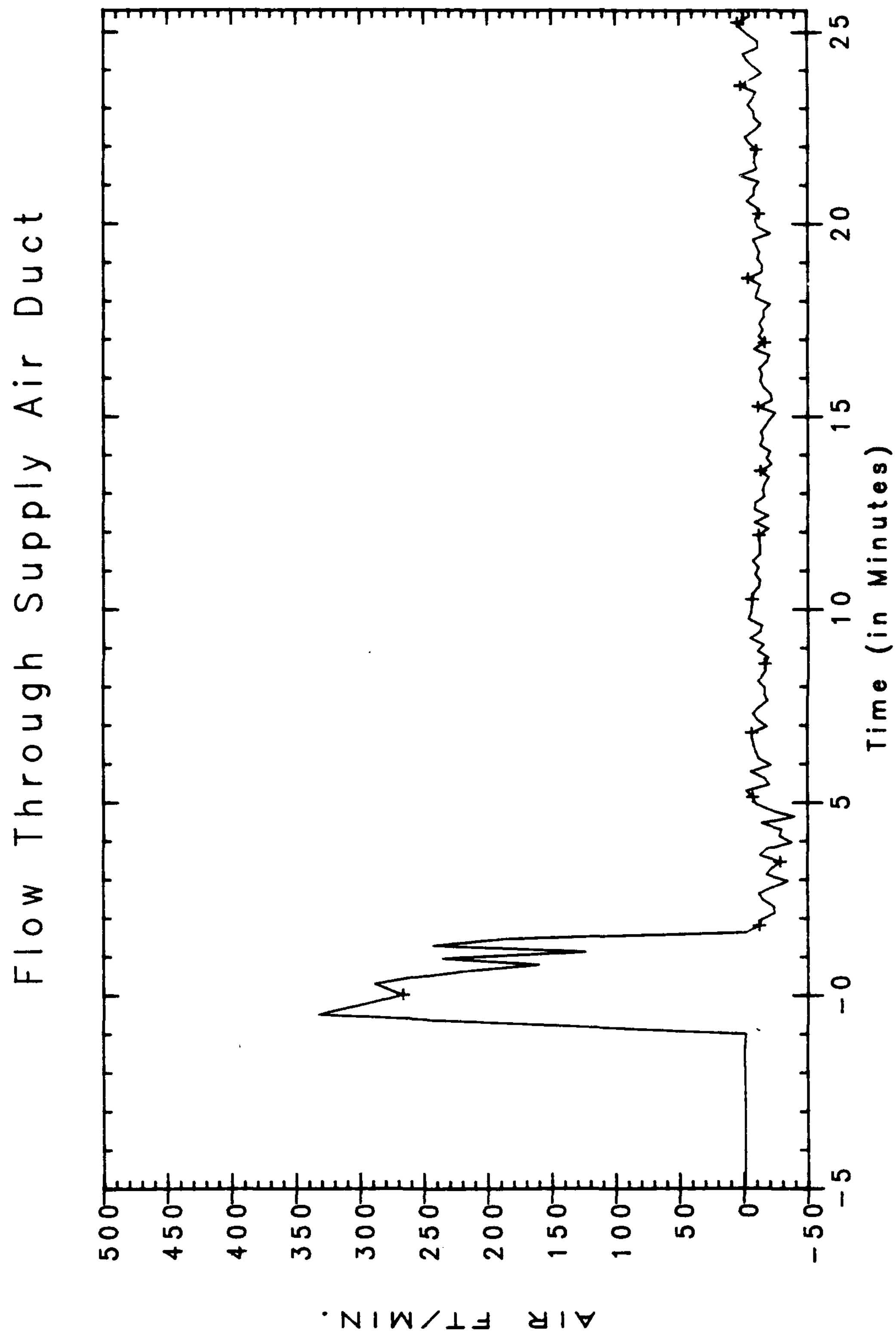


Figure 4-7 Flow Through Supply Duct

the balancing duct. In some instances the smoke flow was heavier than that from around the door jamb. The main factors for the greater smoke flow from the return air vents, with respect to both the door vent and balancing duct, are as follows:

1) The location of the return air ducting high in the overhead, with respect to the door vent, provided a more likely flow path for the hot smoke.

2) The size of the return air ducting is much larger than the balancing duct (approximately 3 times larger). This provided for much more flow area and fewer friction losses.

It should be noted that although more smoke appeared to be entering the passageway during a shorter timeframe (visual observation), this fact is not reflected in the % transmittance data recorded by the laser obscuration meters. Figure 4-8 represents % transmittance data (at the 6½-foot level) from two tests of identical configuration. During test C15 the fresh air intake damper was closed upon securing of the ventilation fan. In test C4 the damper remained open. This data does not appear to confirm that which was recorded visually. The data seems to indicate that closing the damper did not make any difference in the smoke density in the passageway. However, this data is representative of the smoke density only at the location of the lasers. Smoke, in the absence of other forces (i.e.; air movement and temperature variations), will act similar to a thick liquid with a very high viscosity. Figure 4-9 represents a sketch of the expected smoke movement. Though the volume of smoke entering the passageway may more than double when the fresh air intake damper is closed, the laser obscuration meters do not reflect this fact because of their location away from the second source of smoke. Future tests will require additional laser units located along the length of the passageway to record the speed at which the smoke spreads horizontally as well as vertically.

The amount of smoke entering the supply ventilation ducting and spreading into the surrounding compartments was very slight. Smoke detector actuation times in Area #3 ranged from 7 to 15 minutes. At no time during the four tests in this scenario did the concentration of smoke in Area #3 become great enough to make the compartment untenable.

It must be stressed that the results of this test series are very specific to the ventilation configuration used. Changes to the configuration and location of the fan room and ventilation ducting will very likely have a significant impact on the way smoke propagates through the ducting and surrounding areas.

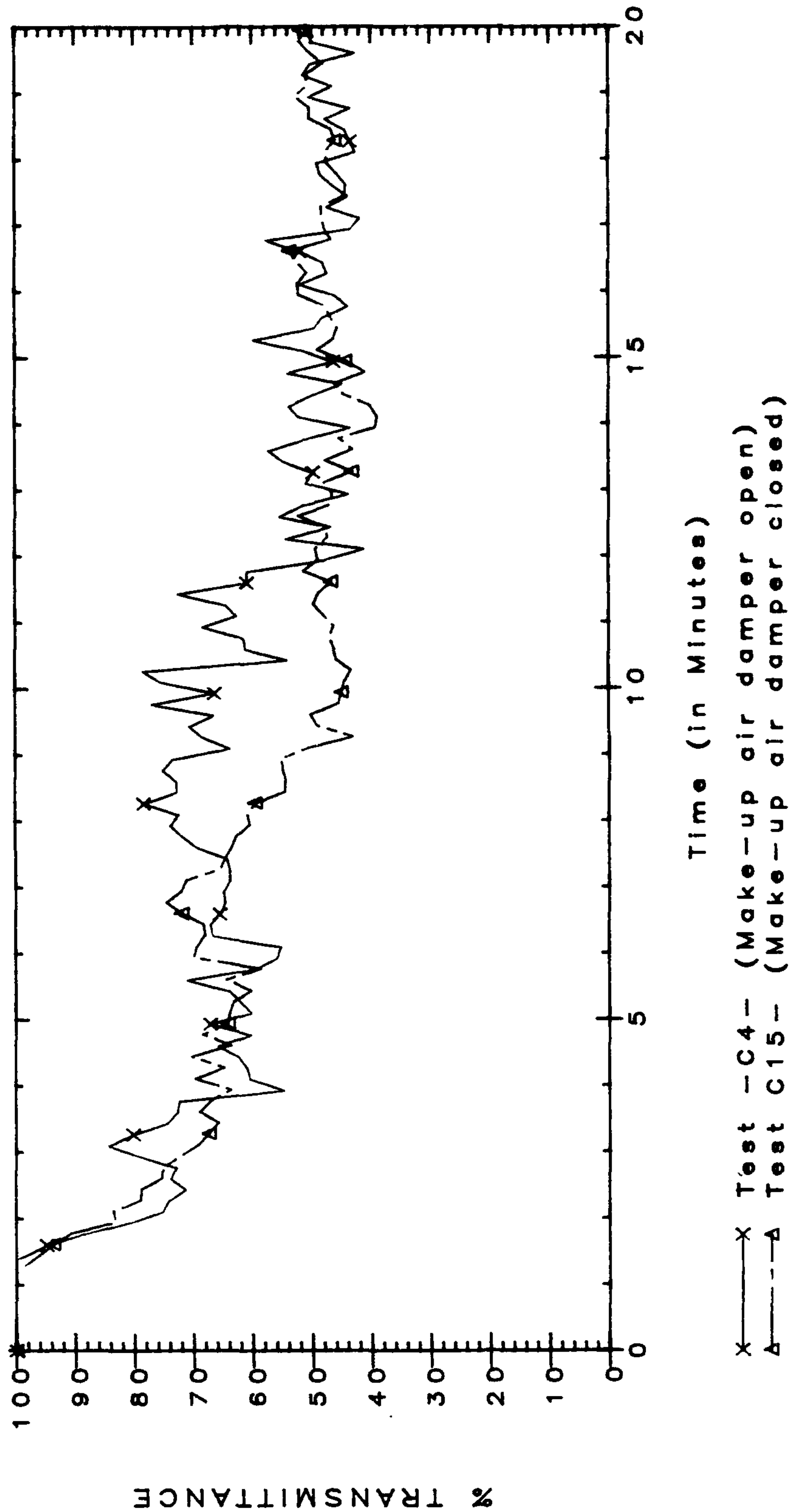


Figure 4-8 Passageway Transmittance Data (6.5'), Scenario 4

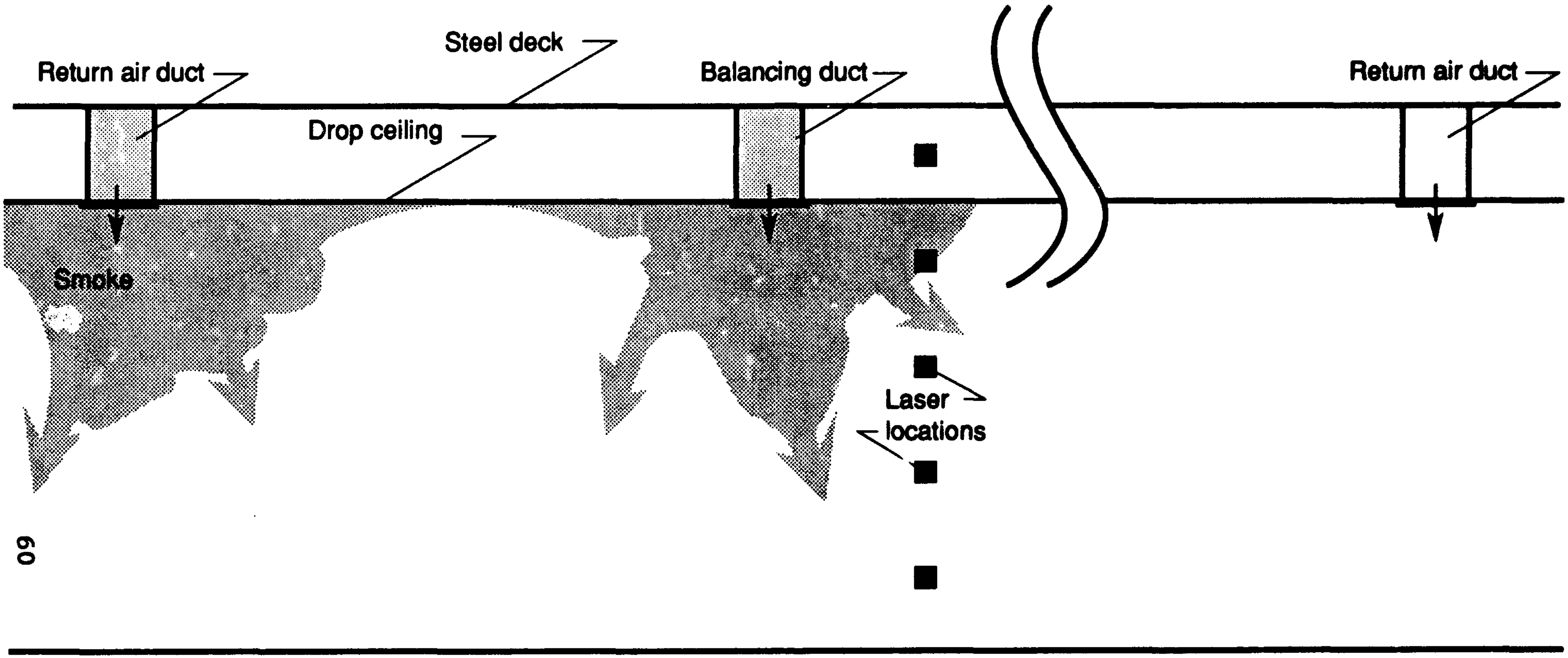


Figure 4-9 Smoke Dispersal within Passageway

4.3 Test Scenario No. 5

- Shut-down ventilation systems upon actuation of the test compartment smoke detector

This scenario is identical to Scenario #4, except that the smoke detector in the test compartment (stateroom) is used as the signal to secure the ventilation system fans. This situation simulates a configuration where the detectors for a specific section of a ship are wired in series such that a signal from any detector in that zone will cause the ventilation systems to secure. The main purpose of this scenario is to compare the resulting data to that of Scenario #4. This comparison will indicate whether the shorter detection time, and subsequently earlier time of ventilation system shut-down, will have a significant impact on the amount of smoke escaping the test compartment.

Similar to Scenario #4, the initial average heat release rates and temperatures (figure 4-10) of the fires for Configuration 2 were much higher than those for Configuration 1. Again, these factors were taken into consideration when comparing the results of the two configurations.

Comparing the results of the two configurations, % transmittance data reveals that Configuration 2 did not perform as well as Configuration 1. Based on the initial surge by the fires for Configuration 2, this is not unexpected. However, unlike Scenario #4, the graphs of the two configurations never attain similar slopes (figure 4-11). The values for Configuration 2 continue to decrease at a greater rate than those for Configuration 1 until approximately 14½ minutes. This indicates a higher rate of smoke infiltration into the passageway. After 14½ minutes, a comparison of the transmittance data for the two configurations is no longer valid. During one of the tests for Configuration 1, the test compartment door was opened. This was done to provide an indication of the response by the fire and smoke. As expected, the output of the fire in the test compartment and the density of the smoke in the passageway immediately increased. During the other test of Configuration 1, it was noted visually that very little smoke was emanating from around the compartment door. There was the familiar puffing of smoke from the door vent, but the normally steady flow of smoke from the upper half of the door jamb was absent. In this test the fresh air intake damper was closed and heavy amounts of smoke were seen coming from the return air terminals in the passageway. The fresh air intake damper was closed 20 seconds after ignition, coincident with the actuation of the stateroom smoke detector. Flow back through the supply vent and into the return air ducting was established very early in the development of the fire. This may account for the absence of smoke flow from around the door and the higher % transmittance values (i.e., less smoke at the location of the lasers). As mentioned earlier, additional laser

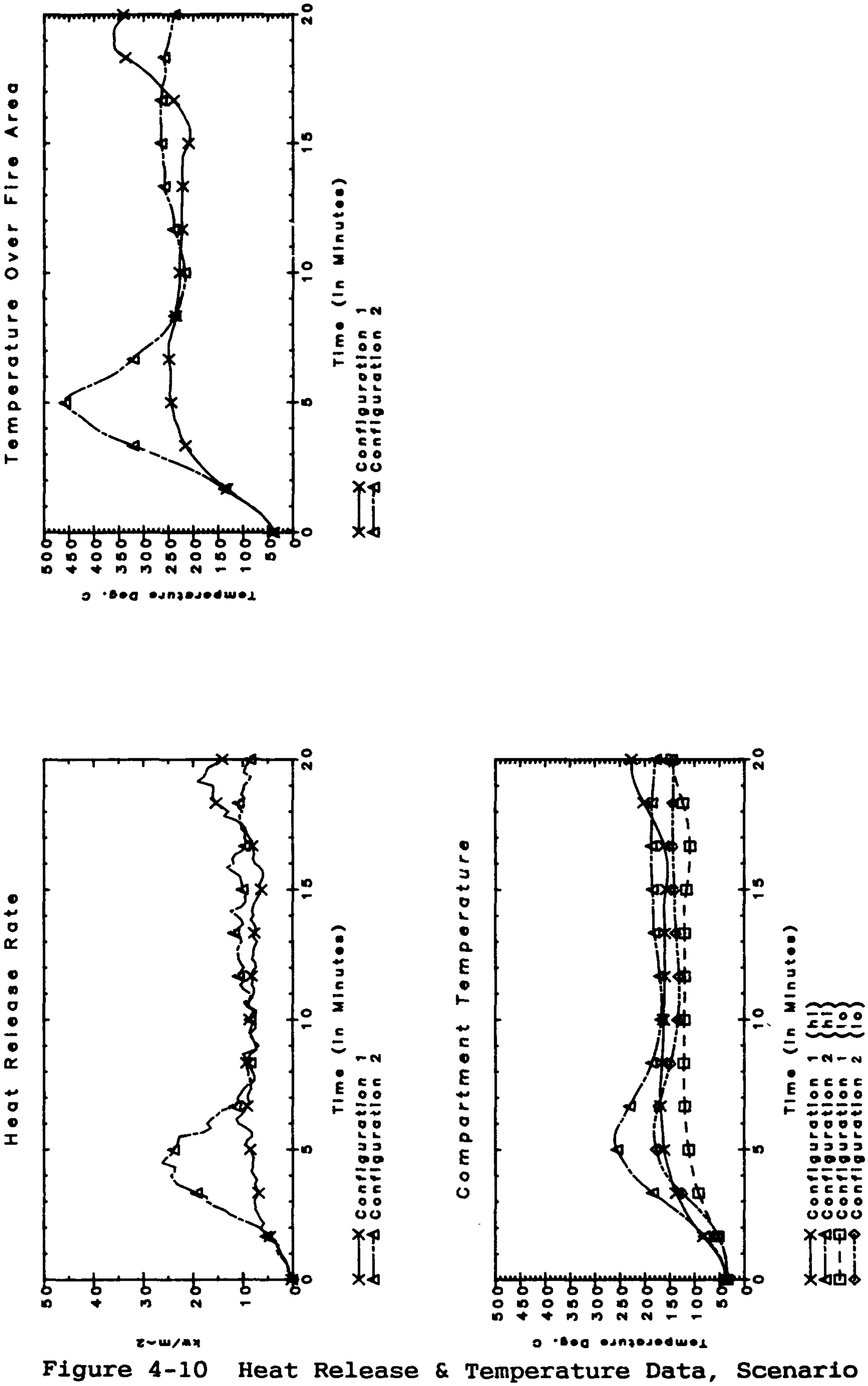


Figure 4-10 Heat Release & Temperature Data, Scenario 5

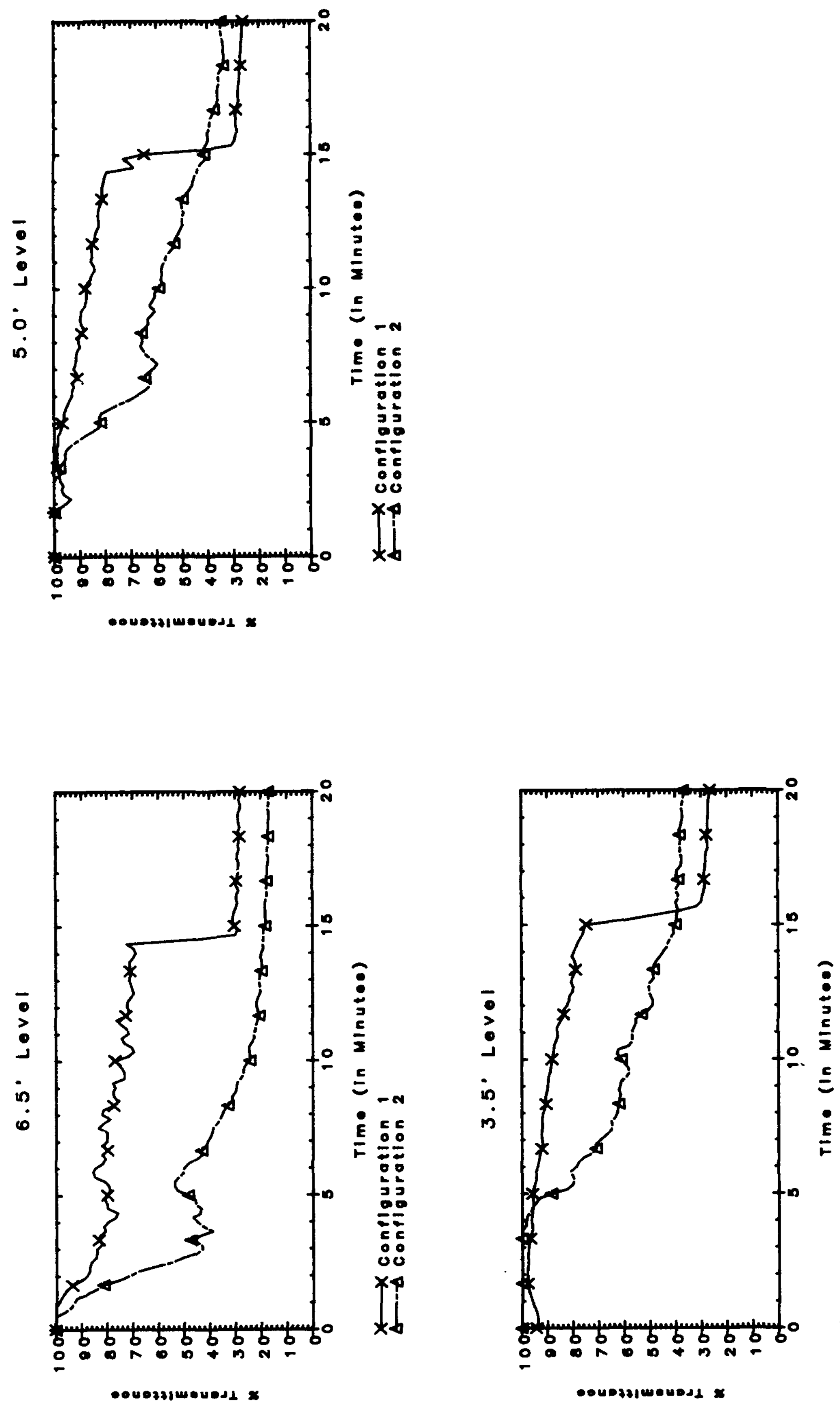


Figure 4-11 Transmittance Data, Scenario 5

units located along the length of the passageway will be required to get a true indication of the amounts of smoke throughout the entire passageway.

Visual records of the tests of Configuration 2 confirm the higher rate of smoke infiltration into the passageway. During the initial test (fresh air intake damper open), steady smoke flow was observed from the balancing duct terminal and around the test compartment's door jamb. The second test, where the fresh air intake damper was closed 38 seconds into the test, exhibited a steady flow of smoke from both the balancing duct and return air duct terminals. An irregular flow of smoke (puffing) was noticed emanating from the upper half of the door jamb. Again, this indicates that the location and configuration of the ventilation system ducting may have a significant impact on the propagation of smoke from the compartment. Figure 4-12 represents the level of CO_2 present in the return air duct. CO_2 is used only as an indicator of the level of combustion by-products in order to compare the two tests. It can be seen that the level of CO_2 is much lower for test C7 (damper open) than for test C20 (damper closed). Therefore, it is expected that the concentration of smoke moving through the return air duct is greater for test C20 than for test C7. Though the transit time for the gas sample has already been compensated for, there is still a lengthy delay before the first traces of CO_2 begin to register. This delay can be accounted for by considering the delay in securing the ventilation fans, the time required for buoyancy to overcome the weakening dynamic air pressure caused by the fans, and the normal time for the smoke to transit the ducting and reach the analyzer sampling point. The difference in the data highlighted in figure 4-12 is indicative of the typical values seen in all tests where the damper was open for one and closed for the next.

All other data are essentially identical to those exhibited in Scenario #4. The time saved (30 seconds to a couple of minutes, depending on the specific test and configuration) in securing the ventilation fans had very little impact on the overall amount of smoke that propagated into the passageway. The main benefit of the earlier alert is the time saved in warning the passengers and crew of the hazard that may exist. This scenario would simply provide more time for evacuation and for the crew to react and possibly prevent a serious fire.

4.4 Test Scenario No. 6

- Shut-down ventilation systems and close balancing duct damper upon actuation of the test compartment smoke detector

This scenario is identical to Scenario #5 except that in addition to the ventilation systems being secured, the damper installed in the balancing duct is also closed when the stateroom smoke detector is actuated. Since the door vent is not applicable to this scenario, Configuration 1 was not used.

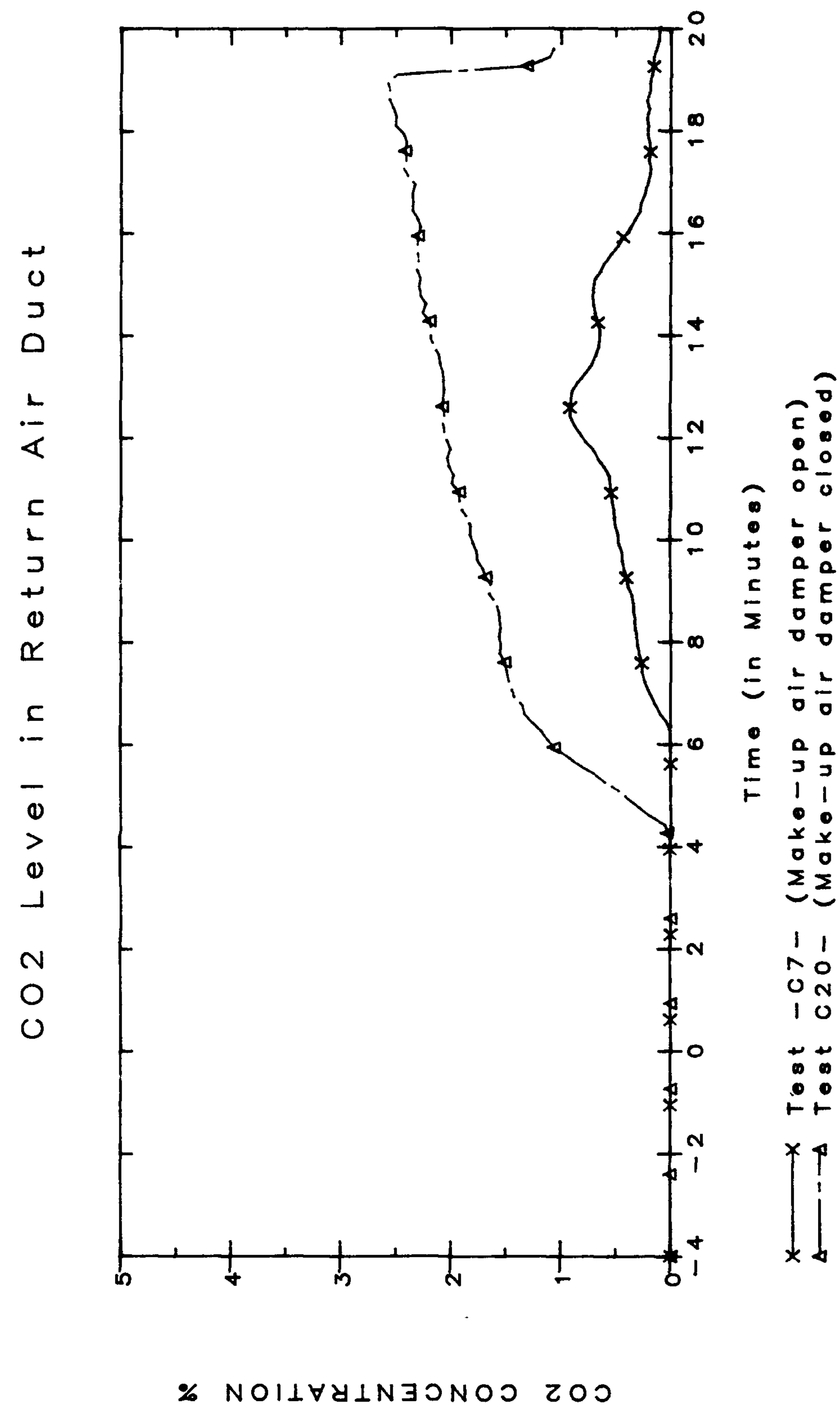


Figure 4-12 Return Air Duct CO_2 Concentration, Scenario 5

The fires used in this scenario did not exhibit the initial surge seen in many of the previous tests. The fire gradually increased in size for approximately five minutes before reaching a steady, oxygen-controlled level of burning. The average temperatures for the fire and the upper and lower regions of the compartment are comparable to previous tests (figure 4-13).

Review of figure 4-14 tends to indicate that the closing of the balancing duct damper had a significant impact on the amount of smoke propagating into the passageway. The data presented in figure 4-14 must be tempered. The balancing duct and door vent represent two of the three main sources of smoke that appear to have the most impact on the values recorded by the installed laser obscuration meters. If both of these sources are removed, it is likely that the % transmittance values will be lower. This does not necessarily mean that less smoke is present in the passageway. Smoke entering the passageway at other locations may not be readily reflected in the obscuration data.

The third major source of smoke having a direct impact on the values recorded by the obscuration meters is the area around the compartment's door jamb. During this scenario, the door jamb did not appear to yield the amounts of smoke as noted in previous tests. During the initial test of this configuration, very little smoke propagated into the passageway. The small amount entering the passageway did so from around the upper half of the door jamb. At no time during this test did the visibility ever deteriorate to the point that movement through the passageway would be impeded. It must be noted that during this test the fresh air intake damper was open.

During the second test, the fresh air intake damper was closed and the results were somewhat different. Initially the tests were quite similar with respect to the smoke propagation. Approximately 5 minutes after ignition, smoke flow from the passageway return air terminal was noted. Flow from the terminal was steady and the smoke density in the passageway appeared heavier than that of the first test. The location of the return air terminal away from the laser obscuration meters prevented the smoke from having a significant impact on the recorded % transmittance values. Again, the visibility was not reduced to the point where movement through the passageway would be impeded. Looking at the gas concentrations revealed the fact that the CO_2 level remained around 0.5% and the CO level never exceeded 0.25%.

The amount of smoke observed in Area 3 was slight for both tests. Toxicity factors aside, the concentration of smoke was not sufficient to hinder the escape of the occupants. As an indicator, at no time during the tests did the CO_2 level in Area 3 ever rise above 0.5%.

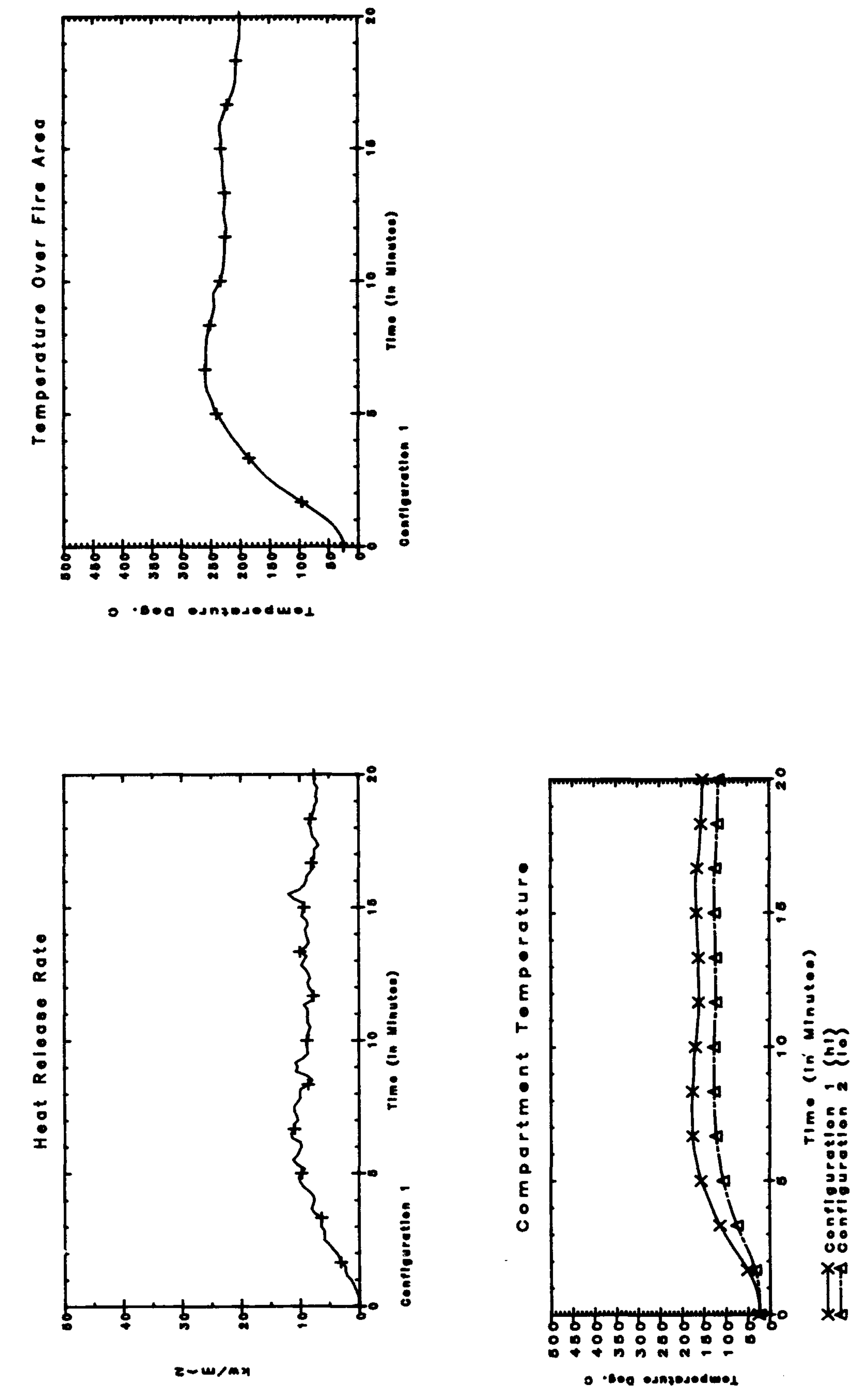


Figure 4-13 Heat Release & Temperature Data, Scenario 6

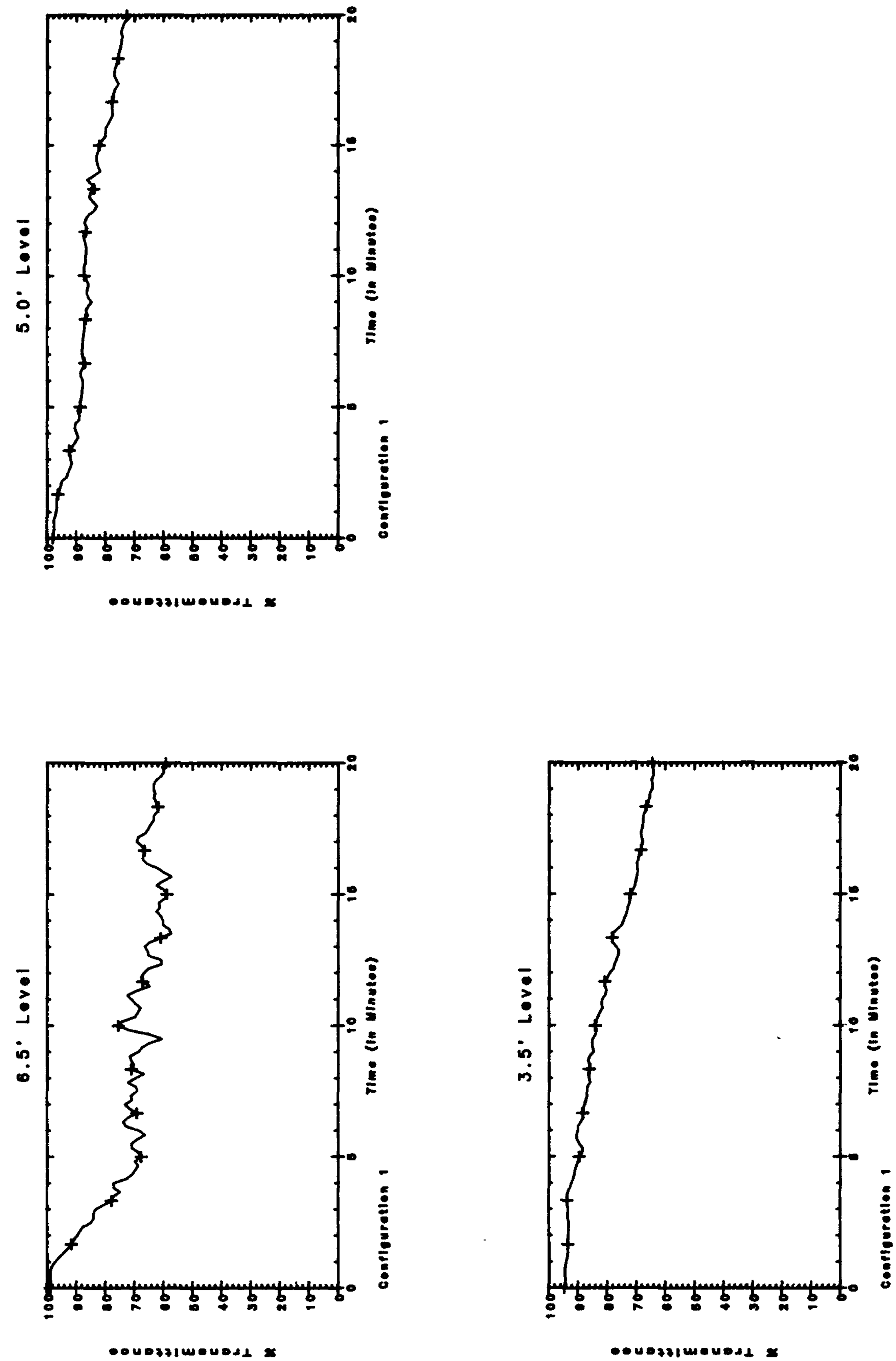


Figure 4-14 Transmittance Data, Scenario 6

4.5 Test Scenario No. 7

- Shut down only the supply fan upon actuation of the passageway smoke detector.

The purpose of this scenario is to determine what, if any, impact is realized by securing only the supply ventilation fan and allowing the exhaust ventilation fan to continue to operate. This will provide information concerning the amount of smoke removed by the exhaust system and whether it is sufficient to make a noticeable reduction on the smoke entering the passageway.

An initial comparison of the performances of Configurations 1 and 2 indicated results similar to previous tests. In this scenario the average values of heat release and temperatures are slightly higher for Configuration 1 (figure 4-15). However, in this case the transmittance data slightly favors Configuration 1 in spite of the hotter fires (figure 4-16). In past tests, the hotter fires normally produced slightly lower % transmittance values (higher % obscuration). However, when considering the level of precision inherent with a test such as this, the two configurations are considered to have performed essentially the same.

Comparing test data from this scenario to that of the scenarios when the exhaust system was secured (e.g., scenario #4), reveals no discernible differences in the level of smoke entering the passageway. Two factors appear to influence this outcome:

1) The exhaust vent is located in the bathroom, behind a closed door. The smoke must descend to the level of the door, leak around the door, and migrate to the exhaust vent.

2) The amount of air exhausted from the bathroom, approximately 70 cfm, is insufficient to make any difference when compared to the amount of smoke being generated by the fire.

All other results from this scenario are comparable to those of previous scenarios and will not be presented.

4.6 Test Scenario No. 8

- Set-up is identical to Scenario No. 7, except that this scenario will additionally close the balancing duct damper and uses the stateroom smoke detector as the initiating source. (Configuration 1 is not used in this scenario.)

The purpose of this scenario was simply to determine if the closing of the balancing duct damper had an impact on the amount of smoke entering the passageway. (NOTE: Figure 4-17 is provided for reference only.)

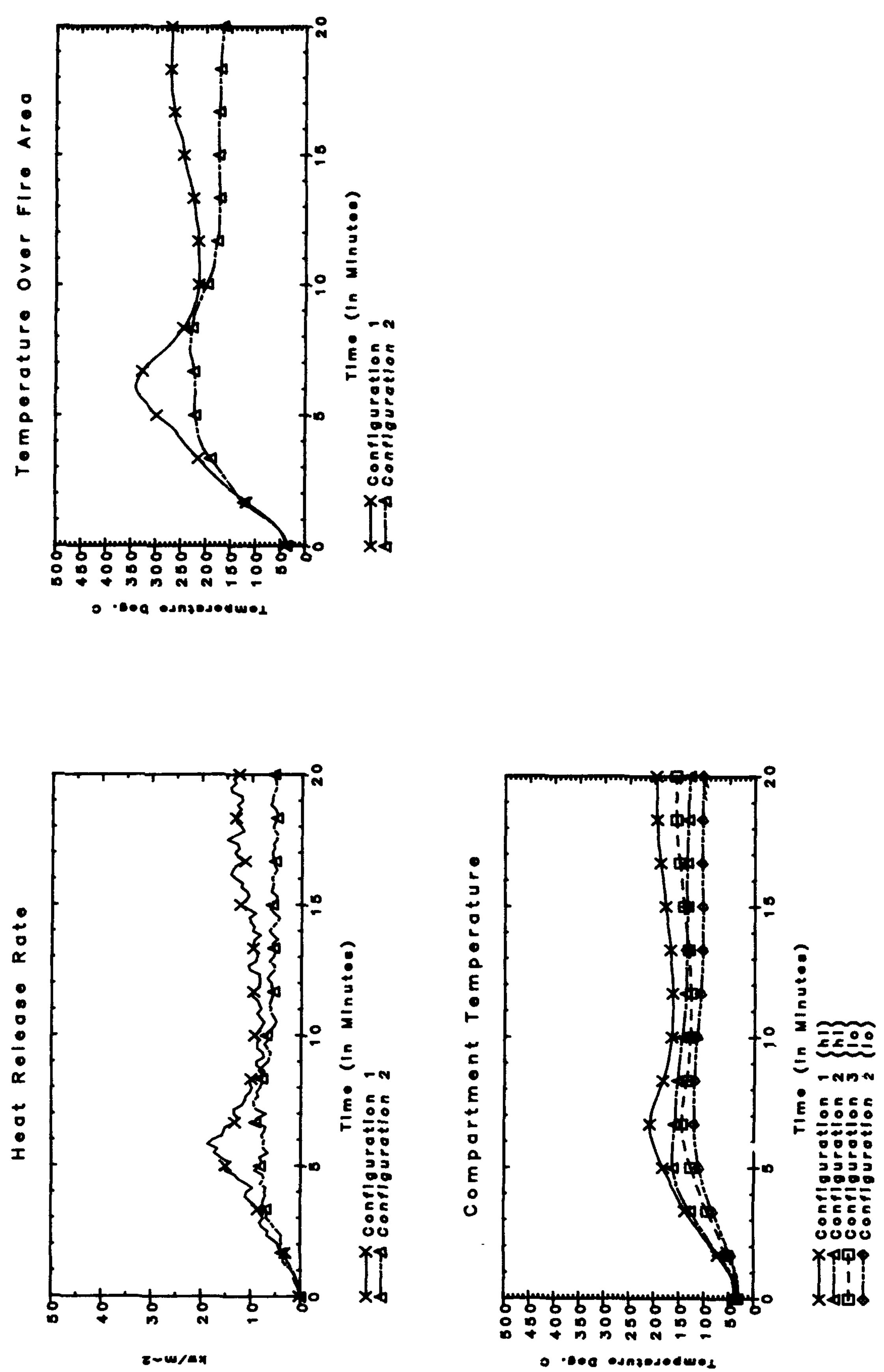


Figure 4-15 Heat Release & Temperature Data, Scenario 7

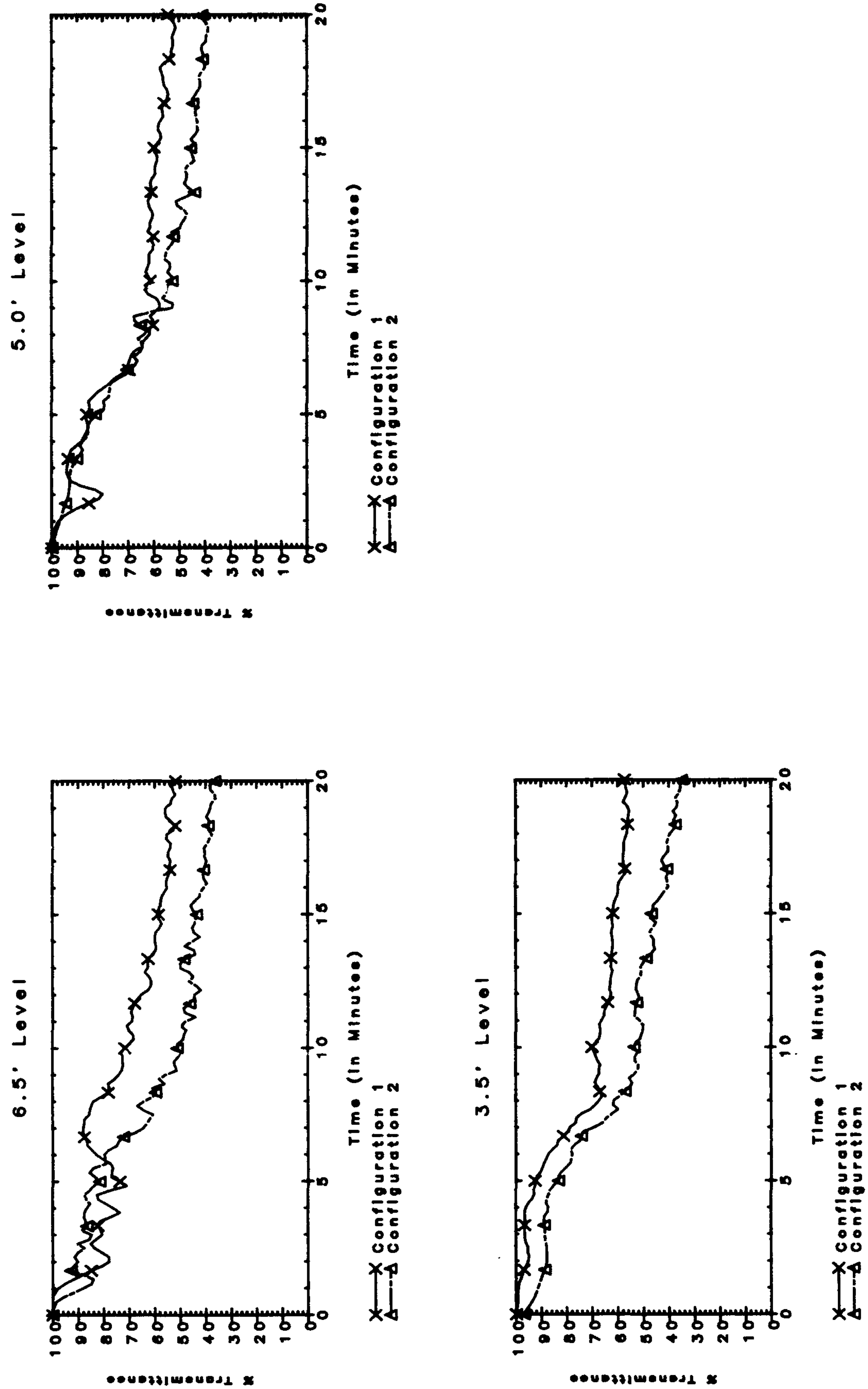


Figure 4-16 Transmittance Data, Scenario 7

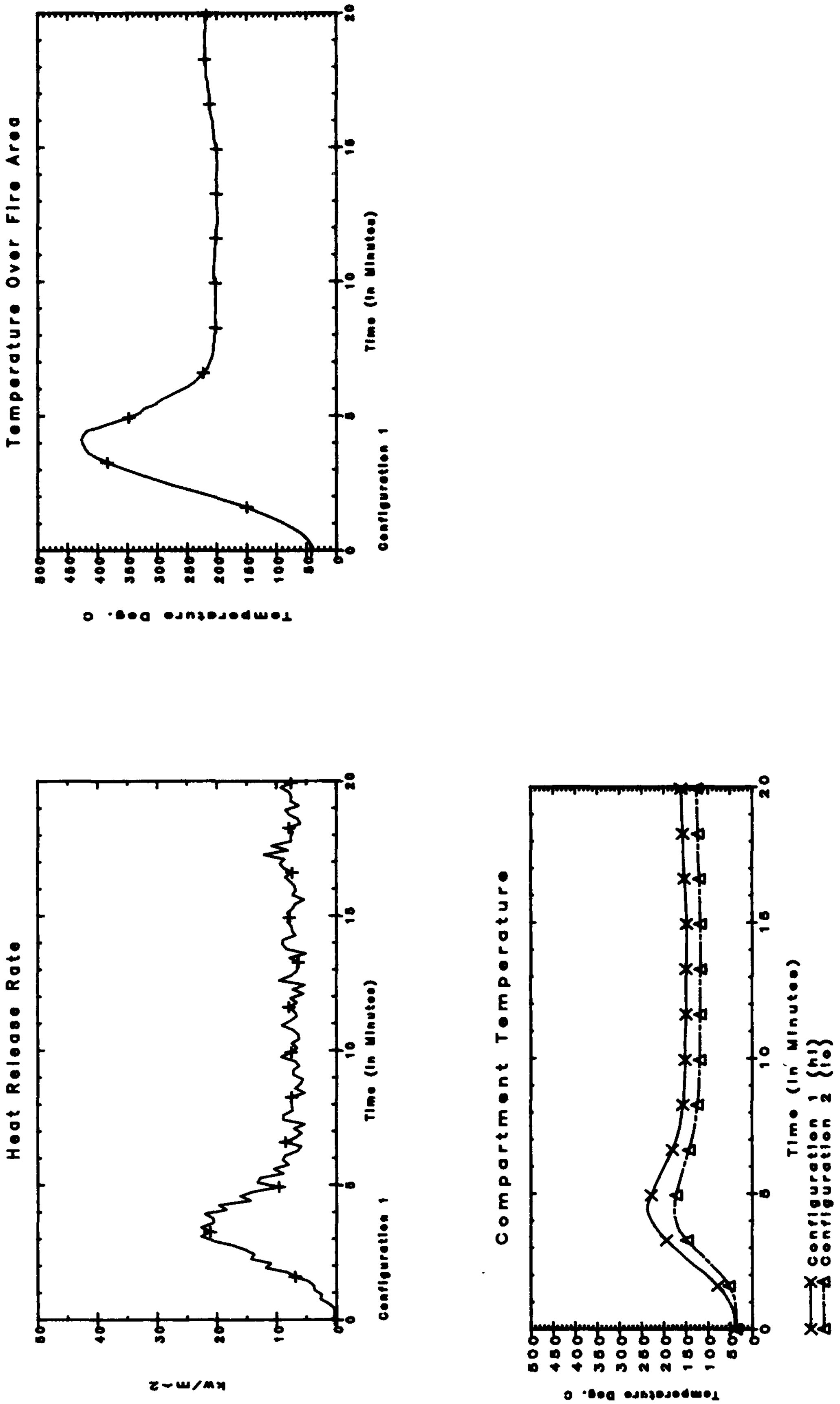


Figure 4-17 Heat Release & Temperature Data, Scenario 8

As can be seen in figure 4-18, very little smoke entered the passageway during the course of this test. This data was compared to that collected in both Scenarios 6 and 7. It appears that this configuration performed substantially better than similar configurations in either of the two previous scenarios. As mentioned in section 4.4, it is expected that by closing the balancing duct, which terminates close to the laser obscuration meters, a significant reduction in smoke passing through the laser beams will be realized. However, visual observation of this scenario did confirm that less smoke appeared to be present throughout the passageway.

A significant difference can be seen in the % transmittance data for Scenarios 6 and 8. The only apparent difference between the two scenarios is that the passageway smoke detector was used as the initiating source in Scenario No. 6. However, the data used in Scenario No. 6 represents the average of two tests. One in which the fresh air intake damper was open, and one in which it was closed. The data for Scenario No. 8 represents the results of only one test, where the fresh air intake damper was open. It has been seen in previous tests that by closing this damper, a source of significant smoke leakage, smoke is then forced back into the return air duct and eventually enters the passageway. During the second test of this scenario, a problem was encountered with the test equipment and the data from this test is considered unreliable. Without the expected lower % transmittance values from this second test (damper closed) to average with the first test (damper open), it is not surprising that Scenario No. 8 appears to perform better.

4.7 Test Scenario No. 9

- Ventilation systems remain running throughout the test.
- Close stateroom supply ventilation damper (and balancing duct damper for Configuration 2) upon actuation of stateroom smoke detector.

The purpose of this scenario was to observe the effects of allowing the ventilation systems to continue to operate while isolating the stateroom containing the fire. For this scenario, exhaust ventilation from the bathroom of the test compartment remained active and only the damper in the supply duct was closed. It was anticipated that by continuing to supply air to the surrounding staterooms, thus creating a slight over-pressure, this would help prevent the infiltration of smoke into the other areas. The main concern with this procedure is the possibility of greater smoke infiltration into the passageway (egress route) due to the possibility of it being under slightly less pressure. Additionally it was hoped that by isolating a source of oxygen, the supply vent, the fire would be further restricted in its ability to grow.

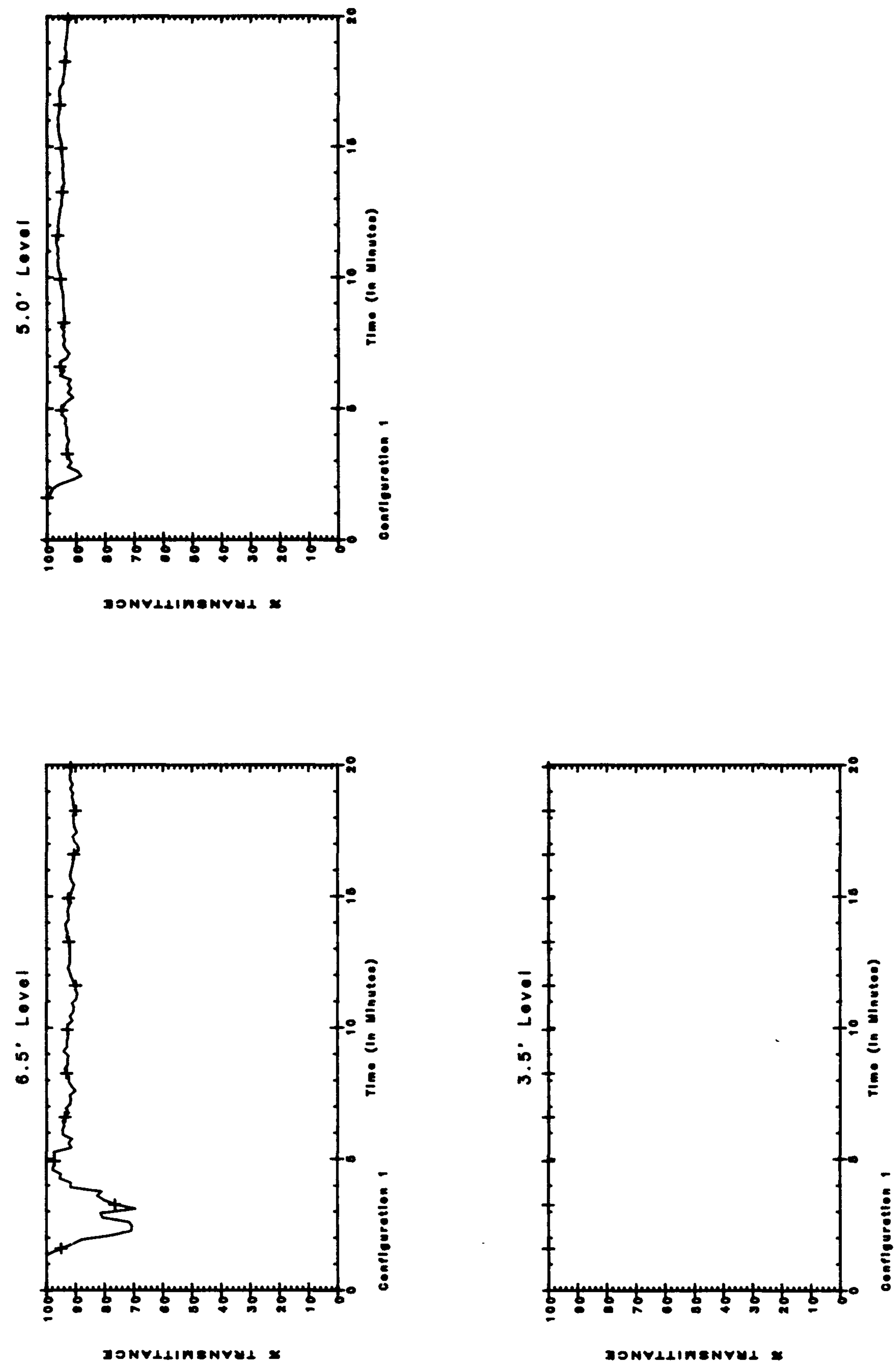


Figure 4-18 Transmittance Data, Scenario 8

For Configuration 1, the supply damper was closed 25 seconds after the start of the test. (It must be noted that there was a slight delay in the ignition of the fire and hence a concurrent delay in the actuation of the smoke detector.) Shortly after the smoke layer descended to the level of the door vent, smoke was observed "puffing" from the vent. Smoke was also observed emanating from around the door jamb. However, as is readily apparent from figure 4-19, the smoke entering the passageway was significantly less than what had been observed in previous tests. This fact is even more apparent when reviewing the results of the test of Configuration 2. There was less of a drop in the % transmittance data for the balancing duct configuration than for the door vent configuration. Both configurations represent a significant improvement over previous scenarios.

Review of figure 4-20 may provide some insight as to the reduced infiltration of smoke into the passageway and surrounding compartments. In addition to the surrounding compartments remaining under a slight over-pressure condition, the isolation of the supply air duct appears to have had an impact on the size and smoke generation capabilities of the fires. It can be seen that the fires exhibited a slight surge during the initial minutes of the tests and then experienced the normal drop in their heat release rates as the available oxygen was consumed. This phenomenon has been a standard throughout all the previous tests. However, the fires in this scenario never achieved levels of heat release rates demonstrated by the majority of the previous tests. Additionally, the steady state heat release rates finally achieved by the fires were lower than the levels noted in most of the previous fires. The fires were generating less smoke, and the supply/return air ducts were no longer available to transport smoke away from the test compartment.

Although the smoke detector never actuated in Area 3, light smoke was observed in this compartment. Throughout this test series, the reliability of the smoke detectors was suspect. The detectors were cleaned and replaced as necessary after each test, yet correct operation appeared sporadic. Allowing the ventilation systems to remain in operation did appear to prevent the infiltration of smoke from the passageway into the surrounding compartments, but did allow smoke to enter through the return air system. The design of this particular ventilation system utilizes the passageway as the main source of the return air. Therefore, once smoke infiltrated into the passageway, a percentage was being drawn into the return air system and distributed throughout the surrounding compartments. At no time did the level of smoke in the surrounding compartments ever reach a point where it would have been detrimental to personnel or restrict their movement.

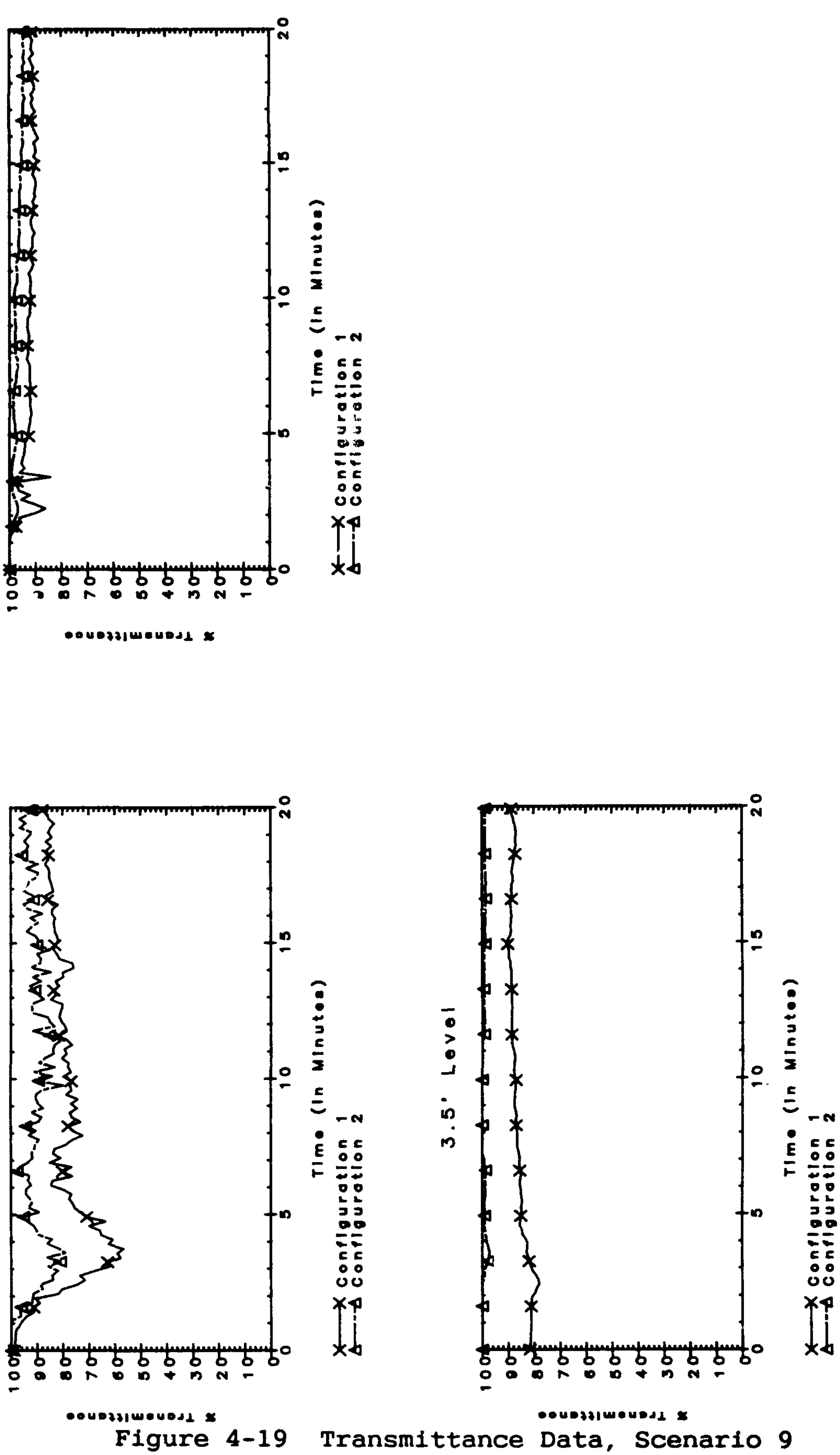


Figure 4-19 Transmittance Data, Scenario 9

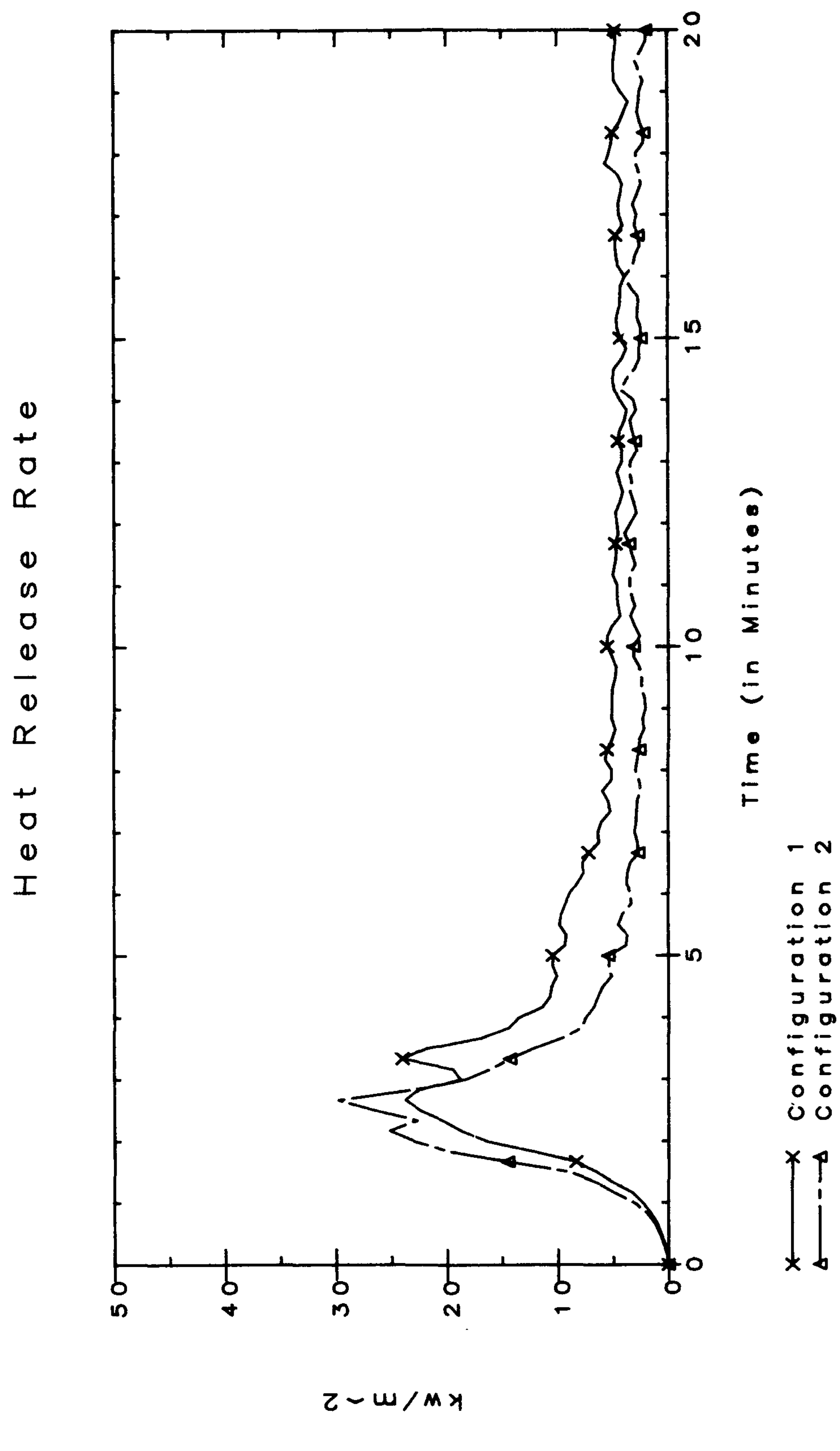


Figure 4-20 Heat Release Data, Scenario 9

4.8 Test Scenario No. 10

- Similar to Scenario No. 9, except that both supply and exhaust duct dampers for the test compartment were closed.

- Configuration 1 was not used for this scenario, and the balancing duct damper was also closed when the smoke detector actuated.

The purpose of this scenario was simply to assist in defining the contribution made by the exhaust system in removing smoke from the test compartment.

When comparing the lower % transmittance values exhibited in figure 4-21 to those of Scenario No. 9 (figure 4-19), initial impressions are that allowing the exhaust system to remain active in removing smoke from the test compartment did make a difference in the amount of smoke entering the passageway. This conflicts with earlier test data where the status of the exhaust system made no appreciable difference on the smoke infiltrating the passageway. A partial explanation for the increased amount of smoke in the passageway during this scenario can be found by comparing the heat release data (figures 4-20 & 4-22a) for each scenario. The % transmittance data for this scenario more closely matches that of Configuration 1 of Scenario No. 9. Review of their respective heat release rates also reveals a very close match. Although the data represents different configurations, past analyses of the two configurations have shown that the % transmittance data has been comparable when all other factors have been similar.

Certainly there is no detrimental effect associated with allowing the exhaust system to continue to operate. Also, there does not appear to be any substantial benefit either. It must be noted that this may only be true for the scenario of a bathroom exhaust and a stateroom. In a scenario where there are no segregating doors to filter through and the exhaust system is sized to accommodate a higher flow, the results may be quite different.

4.9 Test Scenario No. 11

- Basic ventilation system configurations.

- Close supply ventilation damper (and balancing duct damper for Configuration 2) upon actuation of the stateroom fire detector.

- Open port hole to simulate breaking. (Opened at time of peak heat release.)

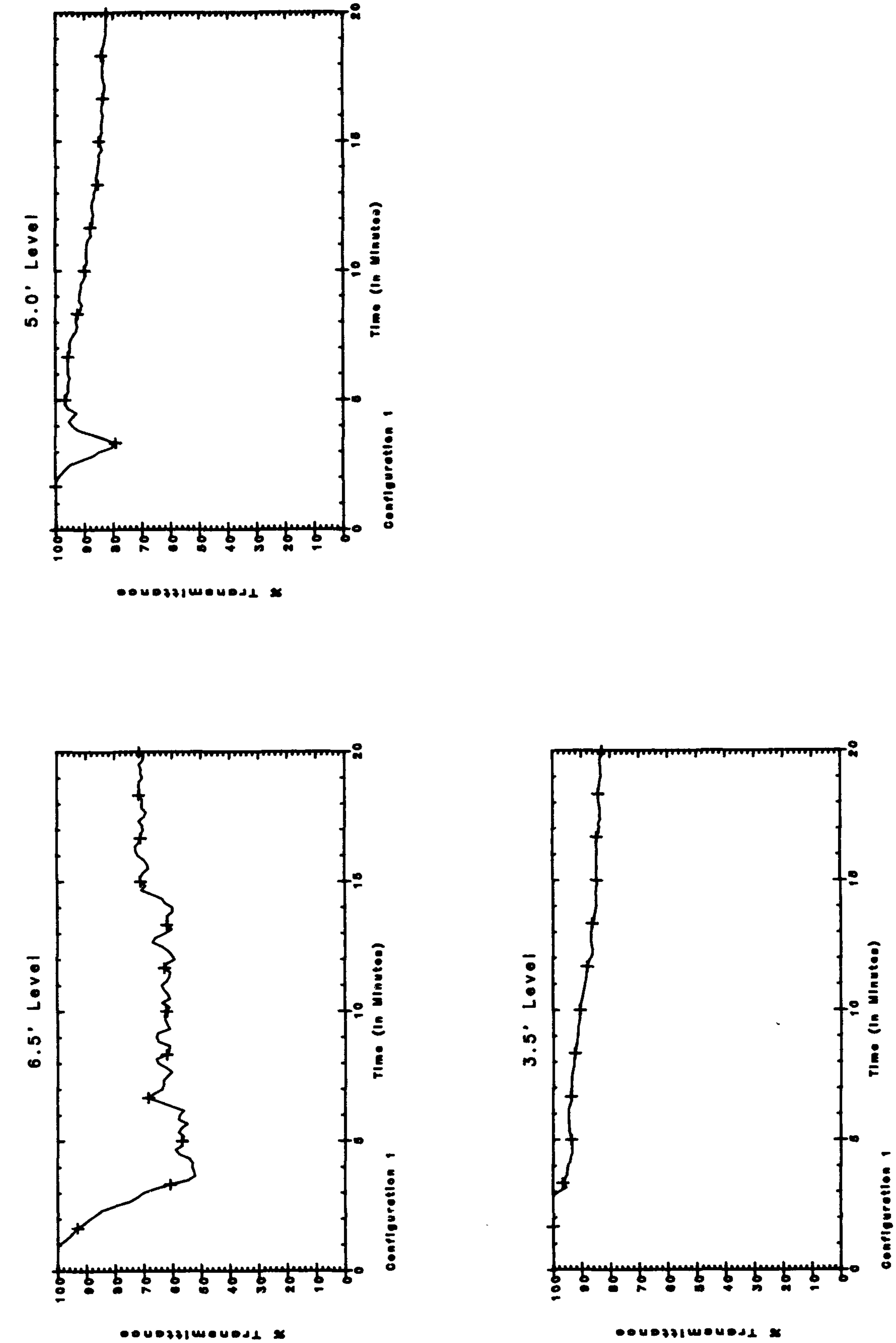


Figure 4-21 Transmittance Data, Scenario 10

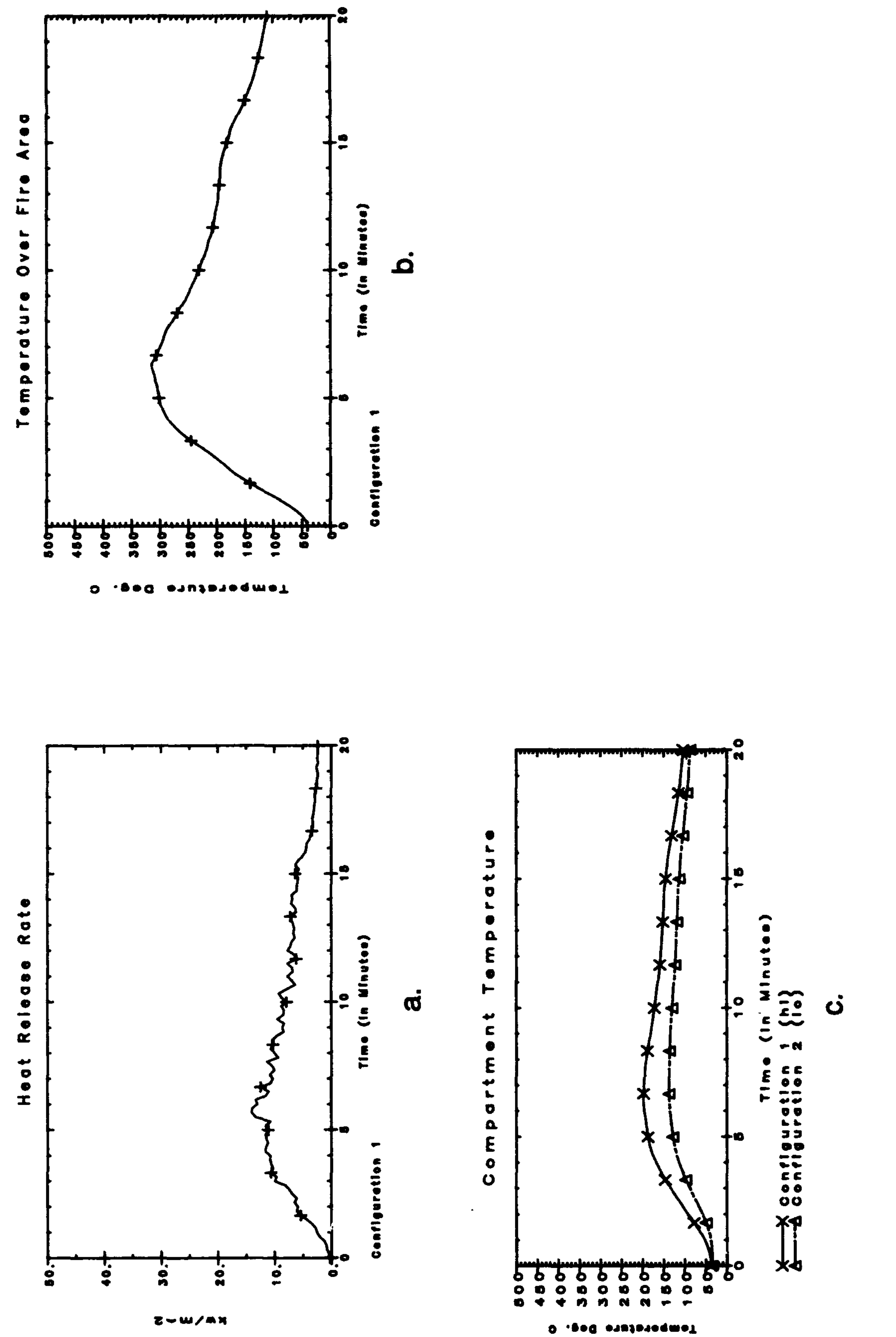


Figure 4-22 Heat Release & Temperature Data, Scenario 10

This scenario was not part of the original Test Plan. However, because of the lack of standards regulating the type of windows being installed in staterooms (from a fire resistance point of view) and the potential impact on the fire that the loss of the window might have, it was considered prudent to investigate this aspect. The purpose of this scenario was to simulate, as close as possible, a situation where the glass in a window shattered due to a fire in the stateroom. Unfortunately, the port hole installed in the test compartment was not truly representative of what is being installed in today's cruise ships and merchant vessels. The port hole was only ten inches (0.54 ft^2 or 0.051 m^2) in diameter . Vessels built in recent years normally incorporate a window of much larger proportions, possibly 4 to 9 square feet (0.4 - 0.8 m^2). Therefore, chances are very good that the impact on the fire in this test scenario may vary greatly from what might occur if a larger window were installed.

To achieve temperatures that might realistically be expected to cause failure of glass windows, the test fire was configured slightly differently from previous tests. The fire load remained the same, but the diesel fuel pan was placed completely beneath the crib and cushion so that more fuel would become involved at a faster rate. Figure 4-23 is evidence that the heat release rates and temperatures exhibited for this scenario were significantly greater than those of previous scenarios. The port hole of the test compartment was opened at the point during the test when the temperature, above the fire, appeared to peak. This was simply to ensure that the highest room temperatures were achieved.

The heat release rate and temperature profiles for the two configurations were very similar. In both instances the fires grew quickly during the initial three minutes of the tests, and subsequently exhibited a very dramatic drop in output. Since the port hole was open at the approximate time of peak temperature, the initial drop in the fires' output coincides with the opening. What is interesting to note is the degree to which the heat release values subside. Unlike previous tests, the fires in this scenario appear to be barely sustaining combustion subsequent to the peak values. Previous tests have all exhibited a rapid decrease in the output of the fire once the initial oxygen supply was depleted. In the previous tests however, the fires attained a level of steady combustion several times the size of the fires in this scenario. Initial predictions were that the additional source of oxygen would increase the level of sustained combustion. However, the data gathered from this scenario tends to suggest that opening the port hole was detrimental, rather than beneficial, to the fire's ability to sustain combustion.

An explanation for this unexpected development may be found in the flow patterns of the air inside the test compartment. Prior to opening the port hole, the fire was utilizing the oxygen initially available in the test compartment

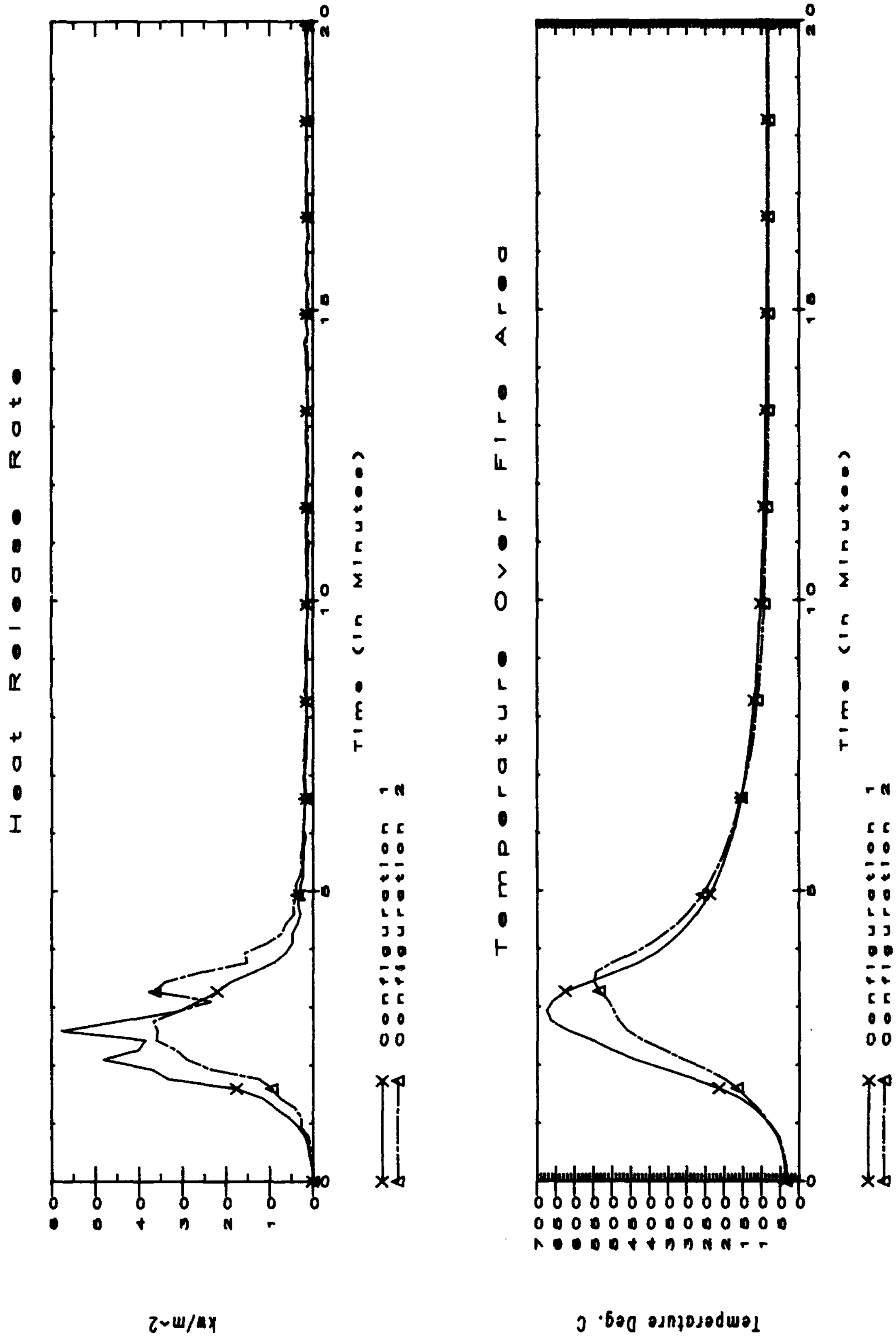


Figure 4-23 Heat Release & Temperature Data, Scenario 11

and that which could be drawn through/around the compartment door. The supply ventilation damper was closed after approximately 20 seconds, so this was not considered a source of oxygen. Upon opening the port hole it was observed that this immediately became a source of oxygen, with all flow through the opening going into the compartment. The opening of the port hole did not appear to have any significant impact on the results (smoke concentration in the passageway) of the test of Configuration 2. The same can not be said of the results for Configuration 1. As seen in figure 4-24, the % transmittance data for both configurations exhibit an initial, significant drop during the initial minutes of the tests. This can be attributed mainly to the initial size (output) of the fires. For Configuration 1, the % transmittance values take a second downward trend shortly after the time when the port hole is opened. This coincides with visual observations that indicated a significant increase in the amount of smoke emanating from the door vent. Prior to the port hole being opened, smoke flow from the door vent was of a puffing nature, as demonstrated in previous tests. The puffing has been explained as the alternating in-flow of oxygen and out-flow of smoke once the internal pressure was significant enough to cause the reversal of flow. By providing an alternate source of oxygen, the door vent was no longer utilized as an oxygen source and all subsequent flow was out the vent. It appears that by opening the port hole, air flow patterns inside the test compartment were altered, thus causing the increased smoke flow through the door vent. A similar occurrence was not evidenced by the test results from Configuration 2. Once the fire began its dramatic drop in output, the % transmittance values for Configuration 2 began to rise significantly as the smoke flow from the compartment lessened and the smoke in the passageway began to disperse away from the laser obscuration meters.

A change in the air flow patterns within the test compartment also appeared to be the cause for the dramatic decrease in the output of the fire. The port hole was located in the starboard bulkhead, at a point slightly above and aft (figure 4-25) of the location of the fire (fuel). The configuration of the fuel was such that it was "stacked" in a vertical configuration (figure 2-7). Inspection of the fuels subsequent to each test revealed a change in the pattern of fuel consumption. In all prior tests, the consumption of the three fuels (cushion, wood crib, and diesel fuel) had been relatively similar in the distribution of percentage of mass loss. In most tests, with an average burn time of 22 minutes, the 1 inch (2.54 cm) of diesel fuel in the pan was completely consumed. Additionally, the mass loss of the cushion would generally account for approximately 25% of the total mass loss recorded by the load cell. The total weight of fuel consumed (crib & cushion) for previous tests averaged approximately 11 lbs (4.1 kg). During this scenario, the total weight loss averaged approximately 8 lbs (3 kg), and the cushion accounted for approximately 75% of this total. Additionally, barely ¼ inch

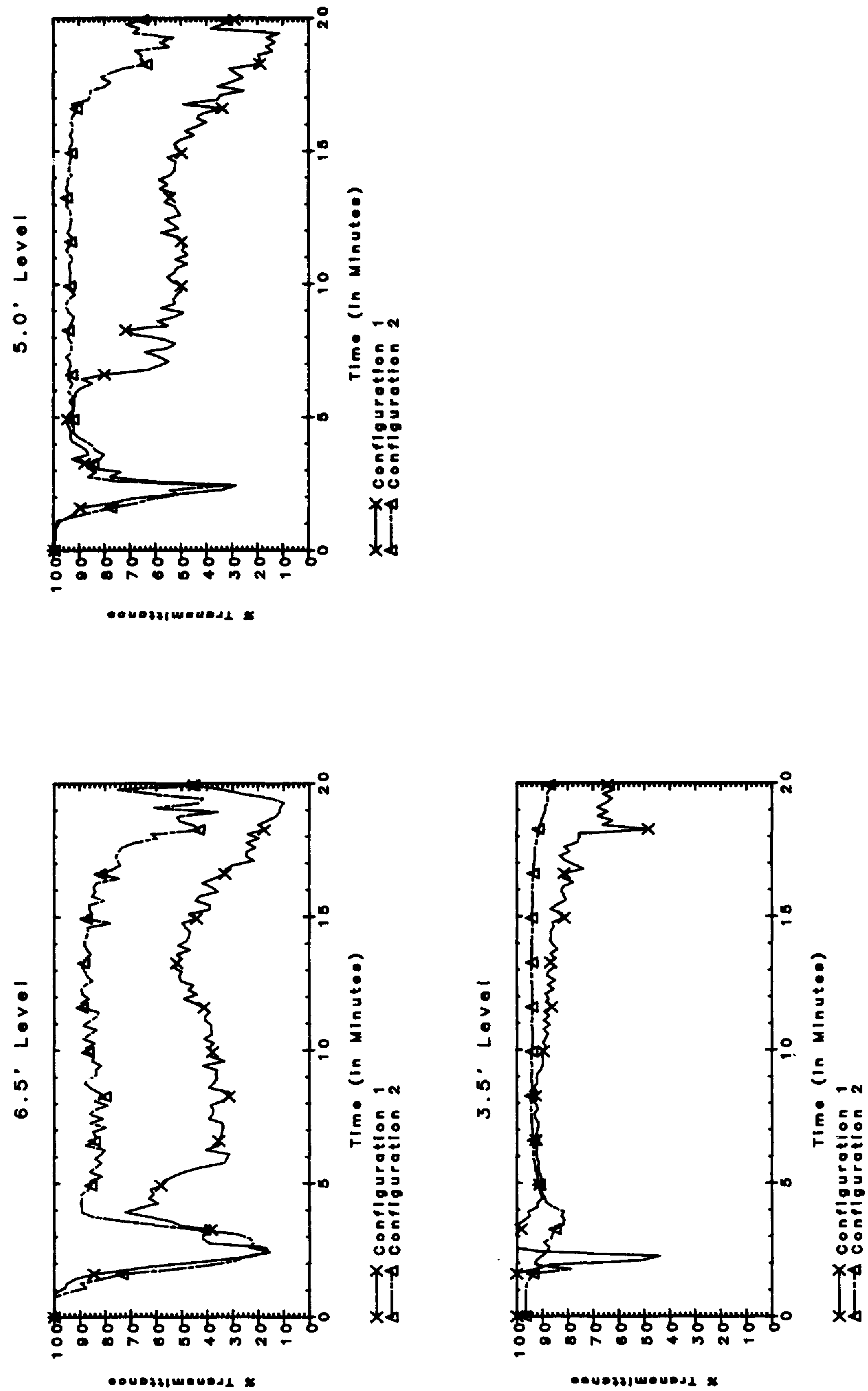
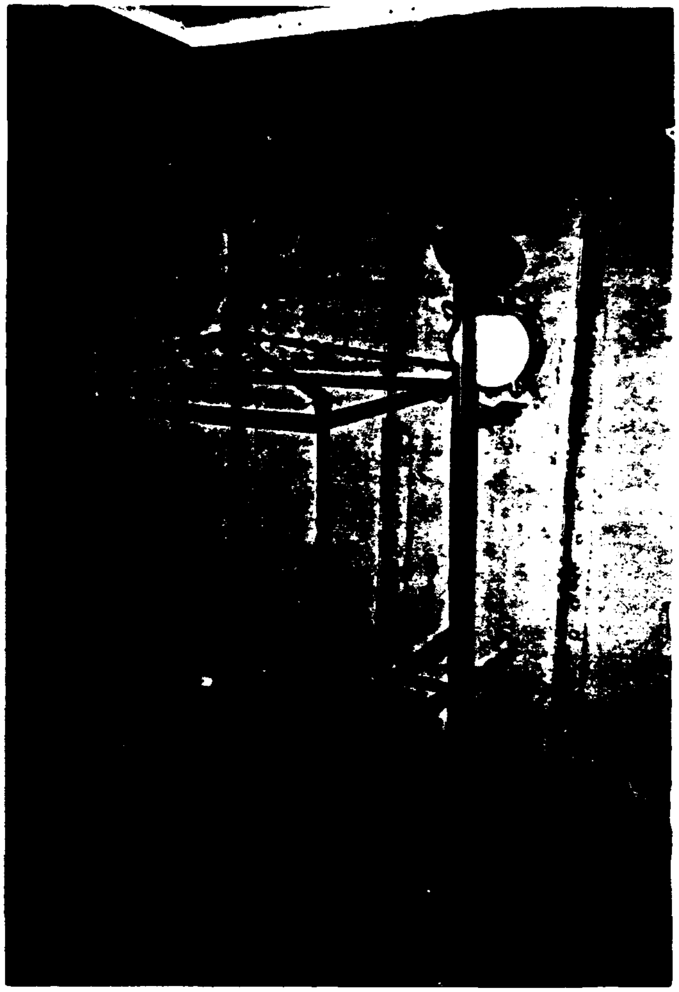


Figure 4-24 Transmittance Data, Scenario 11



Location of port hole with respect to
load cell cradle

Figure 4-25 Port Hole

(0.63 cm) of the diesel fuel was consumed. This data, as well as post-test visual inspections of the fuels, tends to indicate that combustion of the diesel fuel and crib was essentially extinguished subsequent to the port hole being opened. The air flow pattern through the port hole may have been such that air was immediately entrained in the upper region of the test fire, with minimal oxygen available at the lower regions.

The results of this scenario are very specific to the use of a small port hole. If a larger window were installed, it is possible that a "classic" smoke layer might develop in the compartment. In this scenario, the fire would continue to burn much hotter, a distinct smoke layer would likely develop, and flow through the window would be bi-directional; hot gases and smoke flowing out through the upper portion and fresh air flowing in through the lower portion. Due to the increased temperatures involved, this situation has the potential to be very damaging to the vessel as well as hazardous to personnel on the weather decks depending on the location of the stateroom.

4.10 Test Scenario No. 12

- Basic ventilation systems configuration, no change in status of fans or dampers.
- Both door vent and balancing duct are open.

The purpose of this test scenario was to determine if the combined use of a door vent and balancing duct exhibited any unique results that might warrant further study. There are design situations where it is possible to see the two used in tandem. The most common situation is in a large room where the allowable size of the door vent is insufficient to handle all the required return air flow. Instead of "ducting" all the return air to the passageway, a smaller duct is used in conjunction with door vents to accommodate the required flow.

This scenario definitely produced a significant amount of smoke in the passageway. Additionally, more smoke was observed in Area 3 than in past tests. As evidenced by figure 4-26, the volume of smoke emanating from the passageway terminal of the balancing duct was a significant increase over what had been witnessed in previous tests. Although the smoke did not appear to propagate down, vertically, at any greater rate as compared to previous tests, it did quickly distribute throughout the length of the passageway. Subsequently, the smoke was quickly pulled into the return air ducting and distributed to the surrounding compartments by the supply system. The volume of smoke in the surrounding compartments rapidly became much heavier than in any of the previous scenarios. One possible explanation for the lack of downward smoke propagation in the passageway may be that a significant amount of smoke was being removed by the return air system.

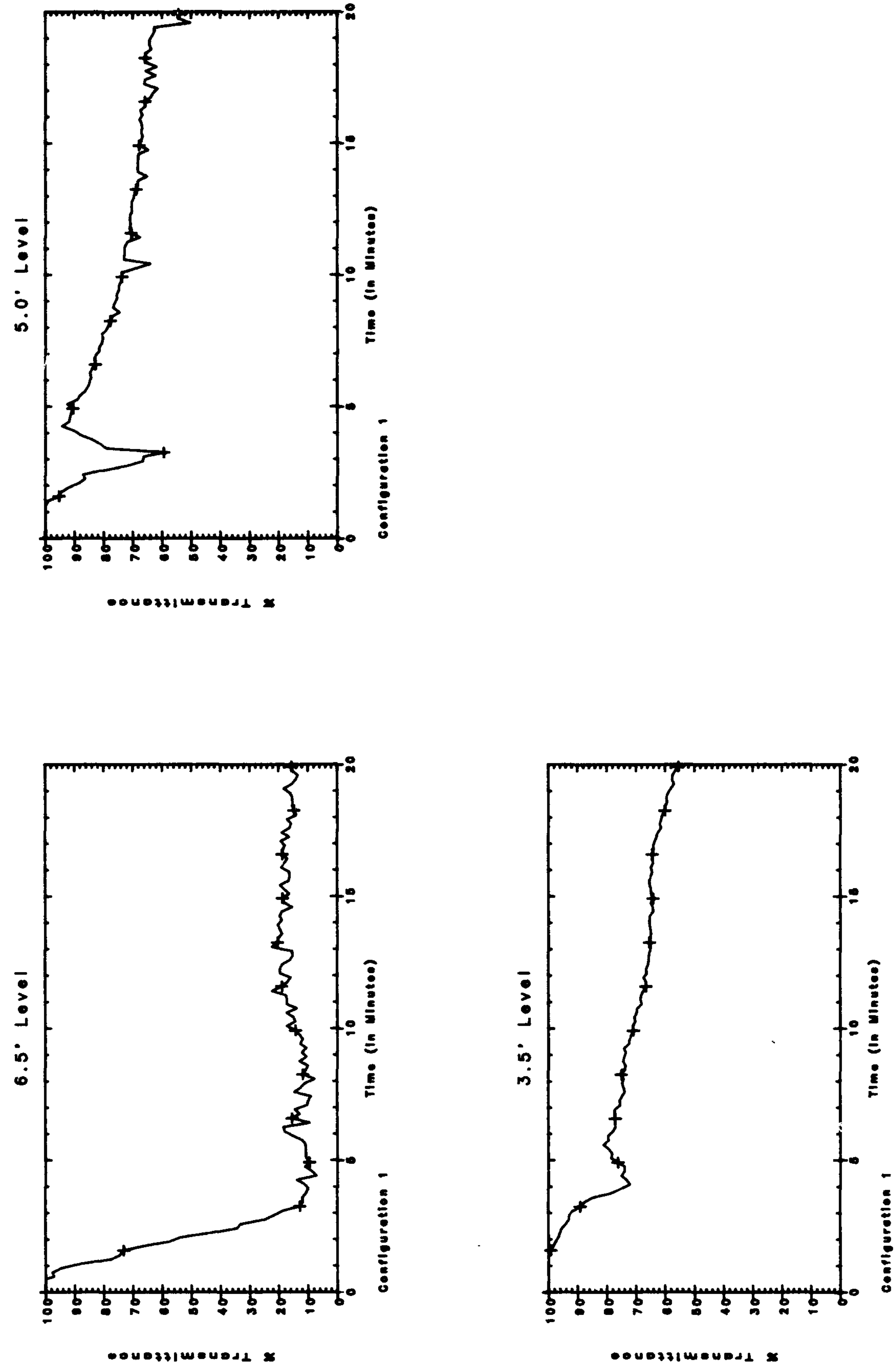


Figure 4-26 Transmittance Data, Scenario 12

The increased volume of smoke observed in the passageway can not be attributed to the size of the fire. As seen in figure 4-27, the heat output of the fire in this scenario was, if anything, slightly less than the average exhibited throughout this test series. Additionally, data of the flow through the balancing duct for this scenario exhibited values identical to those of other scenarios where the configuration of the ventilation systems were similar. Therefore, it was concluded that the increase in the volume of smoke was due to the additive nature of having two vents connecting the passageway to the test compartment. A steady flow of smoke was observed emanating from the door vent from the time the smoke layer (inside the test compartment) reached the level of the vent, until approximately time 3:15. This time coincides with the point at which the fire began to subside; i.e., the excess oxygen had been depleted and the fire was now oxygen-controlled. At this time, smoke flow from the door vent began to exhibit the "puffing" phenomenon seen in previous tests. However, as evidenced by figure 4-26, the smoke concentration in the passageway, after 4 or 5 minutes, was much greater than in previous tests.

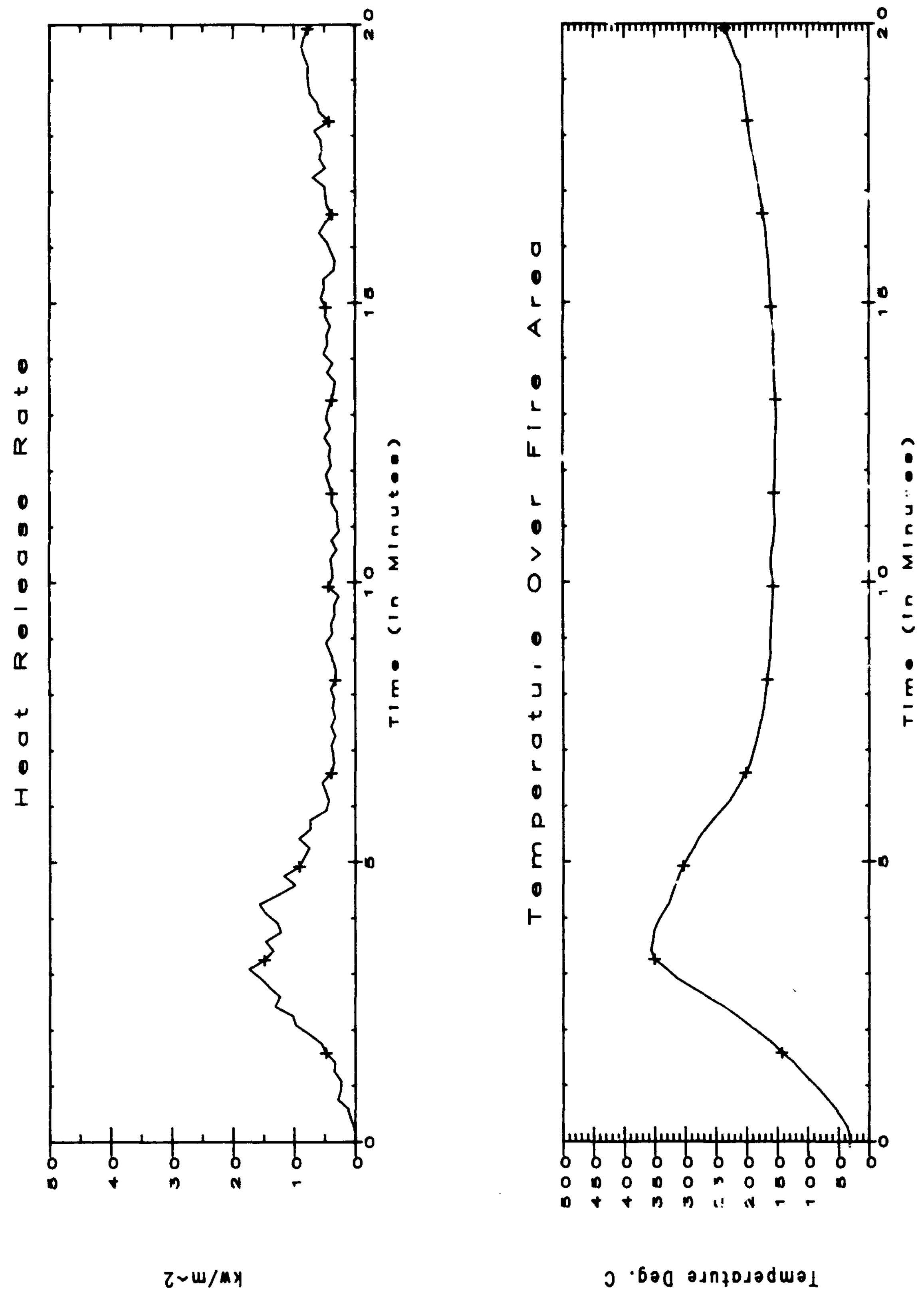


Figure 4-27 Heat Release & Temperature Data, Scenario 12

5.0 COMPARISON OF RESULTS

The primary purpose of this test series was to provide a comparison between door vents and balancing ducts. Through the use of multiple test scenarios it was hoped that, coincidentally, additional information could be obtained to further improve other aspects of shipboard smoke control or at least identify areas requiring further study. This section provides a brief comparison of Configuration 1 (door vents) and 2 (balancing ducts), as well as comparisons of the various scenarios outlined in Section 4. This section identifies those changes that appeared to contribute to containing the smoke within the test compartment.

5.1 Door Vents vs Balancing Ducts

Throughout the analyses of the individual scenarios (Section 4) it became apparent that no significant differences existed between the performances of the door vent and balancing duct configurations. Regardless of the changes between scenarios, the data resulting for each configuration was comparable. This is not to say that no differences existed. Definite nuances were noted that were unique to each configuration, yet they had little or no effect on the overall results of the tests. The primary difference between the two configurations was that initial traces of smoke were detected earlier in the passageway when using the balancing duct. Depending on the specifics of each vessel's detection systems, this may or may not be of benefit. For instance, the most common detection system design currently being utilized has smoke detectors installed in the passageways and not in the individual staterooms. In this situation, infiltration of the smoke into the passageway sooner in the development of the fire may be considered a plus due to earlier actuation of the smoke alarms. Thus alerting the crew and possibly providing the opportunity to extinguish the fire earlier in its developmental stage. After the first minute or so following ignition, the volume of smoke in the passageway appeared to be approximately equal when comparing the performance of the door vent and balancing duct for each scenario.

5.2 Scenario vs Scenario

Unlike the basic comparison of the door vent to the balancing duct, significant differences were noted between tests of some of the various scenarios. Changes in the configuration of the ventilation systems had, in some instances, significant impacts on the amount of smoke propagating from the test compartment to the passageway and surrounding compartments. As mentioned previously, the main factor used in the comparisons was the relative amounts of smoke observed/recorded in the passageway and Area 3. The laser obscuration meters were used as one source of data for comparing each scenario. The obscuration meters provided good data, albeit very localized and not representative of the entire test area. As such, many conclusions from this test series are based heavily on visual observations (to include the video recordings). Because instrumentation was not available to monitor the entire test area, it was necessary to make periodic visual observations during the course of each test to verify the actual dispersal of the smoke within the entire test area. Smoke density within a multi-compartmented test area can be a very difficult parameter to define. Many factors affect its movements. Any subtle, seemingly insignificant change in one of these factors may cause a significant change in the way the smoke propagates throughout the test area. For example; Section 4.2 discusses the apparent effects of a change in wind direction on the initial direction of flow through the door vent. To identify subtle changes, it was equally necessary to utilize the electronically-recorded data (to as great a degree as possible) to confirm/explain much of what was seen visually. Through the coupling of the visual and electronic data, it was possible to compare the different scenarios and develop general impressions as to which scenarios offered the best results in terms of personnel safety and available egress time.

Many of the questions raised in Section 4 as a result of apparently conflicting data remain unanswered due to the time constraints of this test series and the inability to run several tests of each configuration and scenario. However, the majority of the conflicting data was associated with areas of interest not directly related to the comparison of the door vents and balancing ducts and will not affect the results of the primary comparisons. Further, detailed studies will be required to answer these remaining questions.

Variations between the different scenarios consisted mainly of changes to the ventilation systems. An effort was made to keep the modifications simple to reflect possible (realistic) options for ship owners/designers that would be easy to implement and not be cost prohibitive. Most scenario variations reflect only a change in the status of the ventilation system fan(s) and/or the isolation of the fire compartment through the use of smoke dampers. Both these options provide the ability to use either manual or automatic actuators, and would not be difficult to install (backfit).

The first three scenarios were used simply as a baseline for the test series and to define the specifics of the test fire. Basic data was also obtained concerning comparison values for the door vents and balancing ducts. Only the fuel was varied to determine if it would have a significant impact on the test results; it did not. In the next two scenarios (4 & 5), the ventilation systems (supply and exhaust) were secured upon actuation of the smoke detector in either the stateroom or the passageway. Essentially no difference in smoke propagation, with respect to time, could be seen when comparing these two scenarios. Both of these scenarios exhibited transmittance values slightly worse than the average values of the three previous scenarios. This is to be expected since the return air system was removing some of the smoke from the passageway during the initial scenarios. The only difference noted between Scenarios 4 and 5 was that the smoke was detected one to two minutes earlier when using the stateroom smoke detector, as compared to when the passageway detector was used.

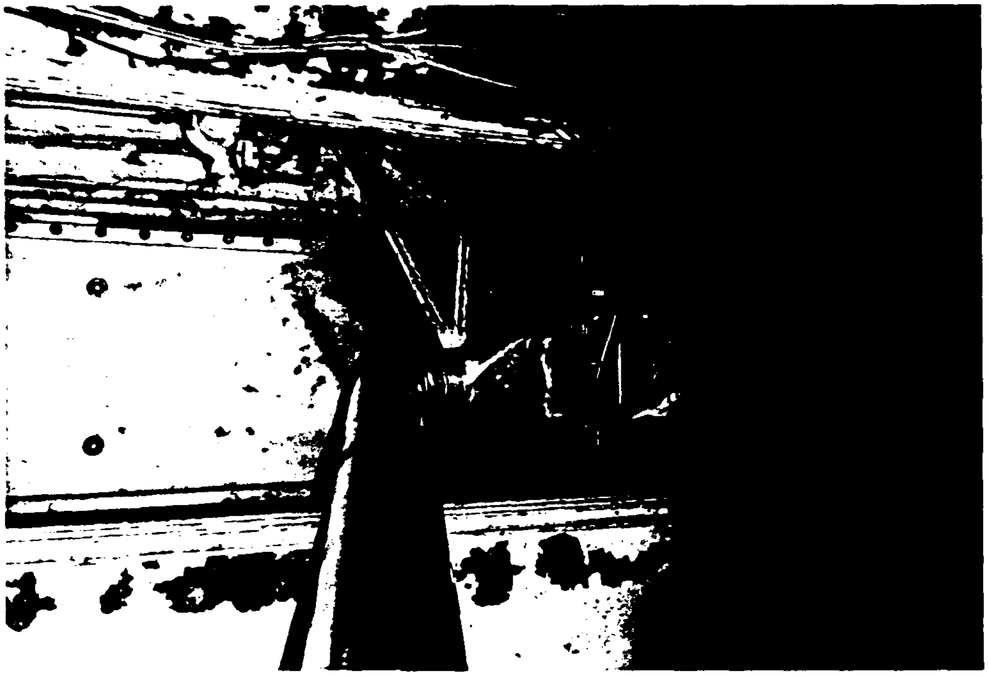
Scenario 6 was identical to Scenario 5, except that the damper in the balancing duct was also closed when the systems were secured. (Only Configuration 2 was used for this scenario.) The results of this test were much better than any seen thus far. The % transmittance values, at the 6.5-foot level, had not dropped below 60% by the end of the test, as compared to 20% to 30% values for the previous tests. It was confirmed visually that this change in the system configuration did appear to improve the tenability time for the passageway. Throughout the length of the passageway, visibility was never reduced to the point that movement would have been hampered (possible toxic effects not taken into account).

Scenarios 7 and 8 investigated the impact of allowing the exhaust fan to continue to operate throughout the test. The difference between these two scenarios was that in Scenario 7 the passageway smoke detector was used as the indicator for shutting down the supply ventilation system. In Scenario 8, the stateroom detector was used and the balancing duct damper was also closed during the tests of Configuration 2. The results of Scenario 7 did not show any improvement over most of the previous scenarios. It did not perform as well as Scenario 6 and the final % transmittance values of 30% to 40% were about the average of the previous tests. Based on this information, it appears that the exhaust fan did not have much effect on the amount of smoke propagating into the passageway. Again, this was somewhat expected due to the size (approx. 70 cfm) and location of the exhaust. The exhaust system is simply too small, with respect to the smoke generation rate, to have any significant impact. The results of Scenario 8, however, were much different. As evidenced by figure 4-18, very little smoke propagated into the passageway. Based on the results of Scenario 7, it is felt the improved performance of Scenario 8 is more a function of the closed balancing duct damper than the effects of allowing the exhaust fan to continue to operate.

In Scenarios 4 through 8, the supply and exhaust ventilation systems (one or both) were simply secured, with no efforts made to isolate the ventilation ducting supplying the test compartment. In each of these five scenarios, smoke propagation through the ventilation ducting to the surrounding compartments was noted. The actual volume of smoke varied with each test, but in no case did the smoke concentration ever reach levels that would have posed an immediate threat to personnel safety or evacuation efforts. This fact is a function of several key variables specific to this test series. Should the size of the fire, the size of the test compartment, or the size and configuration of the ventilation systems change, there would likely be a change in the amount of smoke propagating through the ducting to the surrounding areas. Scenarios 9 and 10 were developed to ascertain the effects of isolating the test compartment from the ventilation systems without securing the ventilation system fans. This was accomplished through the use of smoke dampers located in the risers for the supply and exhaust ducts (figure 5-1). For Scenario 9, only the damper in the supply vent was closed. In Scenario 10 the dampers in both the supply and exhaust vents were closed. For both these scenarios the stateroom's smoke detector was the simulated actuator for the smoke dampers. The smoke damper located in the balancing duct was also closed during tests with Configuration 2. Review of the transmittance data for Scenario 9 reveals that both configurations appeared to perform quite well. However, it must be noted that one contributing factor to the improved % transmittance values does have a detrimental side effect. Since the ventilation systems continued to operate, return air was being removed from the passageway and hence, some of the smoke entering the passageway was being siphoned back into the return air system. The fact that smoke was being removed from the upper layer in the passageway most likely contributed to the lower % transmittance values demonstrated by these two scenarios. The smoke, mixed with fresh air, was then distributed throughout the other compartments in the test area. Similar to Scenarios 4 through 8, where the smoke moved through the ventilation ducting due to natural buoyancy effects, the concentration of smoke in the surrounding compartments was very slight. Again, the severity of this event is a factor of the specific configuration of the ventilation systems. Also, in scenarios 9 and 10, depending on the concentration of the smoke in the adjacent compartments and the sensitivity of the smoke detectors, the applicable smoke dampers were shut if smoke was detected in the adjacent compartments (Area 3). This prevented further intrusion of smoke into that compartment through the ventilation ducting.

The % transmittance values for the tests of Scenario 10, although lower than previous scenarios, were significantly greater than those of Scenario 9. The only (apparent) difference between these scenarios was that the exhaust duct damper was not closed during tests of Scenario 9. During previous tests where the exhaust system was shut down, little difference could be distinguished in the comparison of % transmittance values of similar scenarios where the exhaust system continued to operate. Initial impressions were that the exhaust systems were too small, compared to the amounts of smoke being generated, to make any noticeable difference. The average values exhibited by the fires for Scenario 10 (temperature, heat release rates, etc.) were comparable to previous fires, so it is assumed that the smoke generation rate was also comparable. No other variances between

A. Smoke damper installed in supply ventilation duct riser



B. Smoke damper installed in exhaust ventilation duct rister

Figure 5-1 Ventilation System Smoke Dampers scenarios were noted that would account for the difference in the passageway smoke concentrations. This is an area where further investigation will be required.

Both Scenarios 11 and 12 represent areas of interest that were beyond the scope of the initial balancing duct/door vent comparison. Time was available at the end of the initial test series and these scenarios represented questions that were raised during the development of the overall smoke control program. Scenario 11 was developed to investigate the impact on the compartment fire should an installed window (port hole) fracture. This event would provide a new source of oxygen, as well as a vent for the smoke and combustion products. For this scenario it was assumed that the stateroom smoke detector would initiate closure of the supply damper, and the balancing duct damper for Configuration 2, and the ventilation systems remained active throughout the tests. The opening of the port hole did not appear to have a significant impact on the results of tests of Configuration 2. The results of these tests are comparable to those of Configuration 2 for Scenario 9. The initial "spike" seen in figure 4-24 is a result of the significant increase in the (initial) size of the compartment fire. The results of Configuration 1 are much worse than most of the previous scenarios. The fact that the fire had another source of oxygen meant that the "puffing" effect seen in previous tests, where flow through the door vent was intermittent in both directions, was replaced with a steady flow of smoke out the door vent.

Scenario 12 was added to this test series after learning that installations did exist where a combination of door vents and balancing ducts were being used. The basic ventilation system configuration was used for this scenario; ventilation systems remained active throughout the test and all dampers remained open. This scenario exhibited the worst results of all tests in this series. The combination of the door vent allowing air (oxygen) into the compartment and the balancing duct venting the combustion products, provided an ideal situation for the smoke to propagate into the passageway.

6.0 CONCLUSIONS

This test series was developed to evaluate the use of balancing ducts, and their relative performance as compared to that of door vents. Additionally, in light of the many questions that seem to be surfacing concerning the best means of controlling smoke movement in a large, multi-compartmented environment, the original test plan was modified to explore alternative smoke control measures.

Many interesting events were observed during this test series and although some questions remained answered, others surfaced. These new questions will need to be addressed in the follow-on efforts of the Coast Guard's Shipboard Smoke Control Program.

6.1 Balancing Duct vs Door Vent

The comparison of the balancing duct to the door vent provided indications that a balancing duct poses no greater hazard to personnel safety than do door vents. This fact may be applicable only to the scenarios/compartment configurations used during this test series. In fact, had the balancing duct been installed low, beneath the bathroom area, it is possible that this configuration may have provided even more favorable results. Equally, a change in the size or configuration of the compartment or test area may cause less favorable results.

Based on what was seen during this test series, the performances of both the door vent and the balancing duct were overshadowed by the amount of smoke escaping from around the door jams. The one major difference noted between the door vent and balancing duct is that the balancing duct lends itself more readily to the installation of a smoke damper. Utilization of a smoke damper did appear to further reduce the amount of smoke entering the passageway. The results of this test series tend to indicate that the use of balancing ducts may be no more hazardous than door vents. The majority of the smoke was observed to leak around the door. More study, using different scenarios, is warranted. If installed and utilized properly, balancing ducts could, foreseeably, be part of an overall, smoke-conscious, HVAC system.

To conduct the comparison of the door vent and balancing duct, it was necessary that the test compartment door remain closed. The fact that the door was closed had the greatest impact on restricting the size of the fire and the spread of smoke. Though not the primary focus of this test series, this fact will be addressed in the following section of this report.

6.2 Alternative Safety Measures

As mentioned previously, a variety of interesting events were noted during the course of this test series. The following paragraphs address those events, as well as possible changes that can be made to existing installations.

6.2.1 Compartment Openings: Two of the most notable facts that were brought to light as a result of this test series are not related to the balancing duct issue and are applicable for any scenario. These are:

1) if the compartment door is kept closed, the size of the fire (in a typically-configured/sized stateroom) will be severely restricted due to the lack of available oxygen.

2) the majority of the smoke exiting the test compartment did so from around the door's jamb and undercut.

It was seen throughout this test series that although plenty of fuel was available, as long as the compartment door remained closed the fire quickly became oxygen-controlled, thus restricting further growth and reducing the heat release and smoke generation rates to relatively low levels. The configuration of the compartment door used during this test series was typical for shipboard installations and the gaps between the door and jamb were considered normal. Based on the results obtained during this test series, two simple, non-cost-prohibitive methods of improving smoke containment come to light:

1) install self-closing mechanisms on all stateroom doors. This will assist in ensuring the door will be closed at the time of a fire and restrict the amount of oxygen available.

2) install gasket material around the door jamb. This will further restrict the amount of air flow into the compartment and greatly restrict the amount of smoke that can infiltrate the passageway as a result of seepage from around the door.

These methods will not reduce the risk of a fire occurring, but could greatly assist in restricting the fire's growth and spread, thereby restricting the fire damage and providing a safer environment for personnel egress.

6.2.2 Ventilation Systems: As seen in the details of the test results (Section 4) and briefly discussed in the summation (Section 5), many of the changes to the various scenarios did not make much difference in the amount of smoke infiltration into the passageway. However, a couple of changes did provide significant improvements in the tenability (toxicity not included) of the passageway. Normal practice is for the crew to secure the ventilation systems for the affected area when a smoke/fire alarm is actuated. Comparing the results of Scenarios 1 through 3 to those of Scenarios 4 through 6 show that this practice may do more harm than good. The final results will be dependent on the actual configuration of the ship and it's ventilation systems. One "given" is that by securing the ventilation system fans, smoke will now be able to enter and spread throughout the supply ducting. Essentially, the supply ducting is now acting like a balancing duct, connecting each stateroom to the next. The results of this test series showed that allowing the ventilation systems to remain active made little or no difference in the passageway smoke concentration. The air being supplied to the fire by the ventilation system made no discernible difference in the size of the post-oxygen-controlled fire. Although the active ventilation systems did not slow the infiltration of the smoke into the passageway, they did prevent the smoke from entering the adjacent staterooms. Only during Scenario 6, where in addition to securing the ventilation systems the damper in the balancing duct was also closed, was there a decrease in the passageway smoke concentration. Closing the damper dramatically reduced the ventilation area available for smoke propagation out of the test compartment and thus, reduced the amount of smoke present in the passageway. The test results of Configuration 2 in Scenario 6 can not be used when comparing the basic system configuration and the effects of securing the fans.

Based on the results of this test series, it can not be definitively said that the operation of the exhaust system does, or does not, have an impact on the amount of smoke propagating from the fire compartment into the adjacent areas. Too many variables exist that can change the test results. However, it can be said that in no case did the operation of the exhaust system exacerbate the situation. As long as the exhaust system terminates in an unconfined area outside the vessel, away from personnel, the operation of the system can only improve (no matter to what degree) the smoke control efforts.

The practice of securing the ventilation systems must be reviewed. If a system is to be secured, it should be based on a study of the specific design of the ship's ventilation systems. Whether or not the systems are to be secured should be a documented part of each ship's fire fighting procedures.

The use of smoke dampers in the ventilation systems is an area that warrants further consideration. Dampers are currently being used in existing shipboard HVAC systems to redirect air flow or change the mix of fresh and recirculated air. As evidenced by the results of this test series, prudent placing of smoke dampers in a ventilation system can have beneficial results, with respect to smoke control. **(NOTE: The smoke dampers discussed here are not to be confused with the fire dampers that are required when ventilation ducting penetrates specified horizontal and vertical boundaries.)** Isolation of the fire compartment by closing the dampers in the balancing duct and supply ventilation rises had significant impact on restricting smoke flow from the compartment. This fact must be tempered by the costs of requiring the installation of dampers throughout the accommodation areas of a cruise vessel. As stated earlier, each type of ventilation system should be reviewed, with respect to smoke control, individually. Smoke dampers could certainly be an effective part of a ventilation system's smoke control package.

Smoke detectors in individual staterooms did not have an impact on smoke movement during this test series. However, they did provide notification one to two minutes earlier than when using detectors in the passageway. It is recognized that false alarms are still a possibility in a scenario such as this, but the extra time provided for evacuation and fire party response is considered worth the nuisance.

Regardless of the HVAC system configuration, shipboard firefighting procedures should be reviewed to determine the best course of action for that system. Information obtained during this test series will be used in follow-on analyses and test efforts associated with the Shipboard Smoke Control Program. The goal of this effort is to provide a basic set of guidelines that can be used to develop smoke control measures for any ventilation system.