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CHARACTERIZATION OF SECONDARY IGNITION SOURCES IN UNATTENDED COMPARTMENTS AND FULL-SCALE BASELINE TEST

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16. Abstract

This program identifies the characteristics of five fuel loads burned within a metal lavatory. In 15 of the tests the lavatory door remained closed for the 30-minute test period while in 15 additional tests the door was opened after the fire had developed. Upon completion of these tests the most severe source was selected for use in the baseline test. In the baseline test, the lavatory and adjacent panels, all of which were constructed of contemporary materials, were tested for a period of 1 hour. Thermal, environmental, and biological data were obtained for all fuel loads, door conditions, and the baseline test. All tests were conducted in the Douglas Cabin Fire Simulator (CFS) with separate ventilation of the cabin and lavatory representative of an inflight condition.

Results of the baseline test established that by using the most severe fuel source:

- The exposed animal subject survived without complications
- No toxic levels of gas within the cabin were detected
- A propagating fire did not develop in adjacent structures
- The lavatory containing the fire remained structurally intact
- Decomposition of portions of the lavatory did occur
- Cabin visibility would have presented a problem after 5 minutes.

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PREFACE

The major objectives of this program have been to:

a. Examine the thermal and environmental characteristics of three types of fuels burned in two quantities contained within a metal lavatory.

b. Determine the hazard experienced in opening the door of a lavatory containing a developed fire.

c. Select the most severe source fuel for use in a baseline test.

d. Evaluate the effect of the most severe source upon a lavatory constructed of contemporary materials. The results of this test will serve as a basis of comparison for future tests of new materials.

All tests in this program were conducted in the Douglas Cabin Fire Simulator (CFS) under typical in-flight ventilation conditions. Thirty tests were conducted of five fuel sources. In half of these tests, the door remained closed for the 30-minute test period. The door was opened 100 to 150 seconds after the fire had started in the remaining 15 tests. The baseline test was allowed to continue for a period of 1 hour. Data obtained during these tests included:

a. Heat flux and temperature profiles of the lavatory.

b. Cabin temperature variations.

c. Gas analysis for O_2, CO_2, CO, CH_4, HF, HCL, and HCN.

d. Respiration and electrocardiogram data on an instrumented rat subject exposed in the cabin.

e. Color motion pictures were made of the baseline and ten opened door tests.

The conclusions reached on the program are:

a. The maximum load of simulated airline trash resulted in the most severe fire threat.

b. Opening the door of an involved module would be inadvisable.

c. Contemporary materials exposed to the selected source provided remarkable protection; however, the improvement in fire resistance of specific materials is desirable.

d. The baseline fire resulted in a survivable cabin condition; however, occupants of the cabin would have been subjected to severe discomfort from smoke.

Recommendations for future investigations include:

a. A need has been established for a method of combating a fire within a module that does not necessitate opening of the module.

b. An effective fire-resistant substitute for the current edge closeout material used in panel construction needs to be developed.

c. The increase in fire resistance of all materials would be desirable. The degree of improvement needed in this area should be the subject of separate tests with a new baseline panel of contemporary materials which incorporates a more fire-resistant edge closeout.

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INTRODUCTION

This investigation identified the thermal, environmental, and biological hazards of five fuel loads burned within a metal lavatory under the two conditions of a closed lavatory door for the full 30-minute period and the condition of opening the door after the fire had developed. The objectives of these tests were to determine the most critical fuel load for use in the baseline test and to evaluate the hazard of opening the door of an involved module. Upon completion of 30 of these tests, the largest quantity of airline trash was selected for use in the baseline test. In the baseline test, the lavatory and adjacent panels were constructed of contemporary materials and instrumented the same as in the initial tests. This test was conducted for a period of 1 hour. The complete series of tests were conducted within the Douglas Cabin Fire Simulator (CFS), Figure 1. The CFS was configured to simulate an in-flight condition with a cabin ventilation airflow of 26,900 liters per minute (950 CFM). The lavatory was ventilated by aspirating 1699 liters per minute (60 CFM) of cabin air through the module and by introducing an additional 169.9 liters per minute (6 CFM) of air into the module to stimulate the flow of a convenience outlet. The volume of the CFS cabin is approximately 99.12 cubic meters (3500 ft^3) and that of the lavatory module is 1.72 cubic meters (60.59 ft^3).

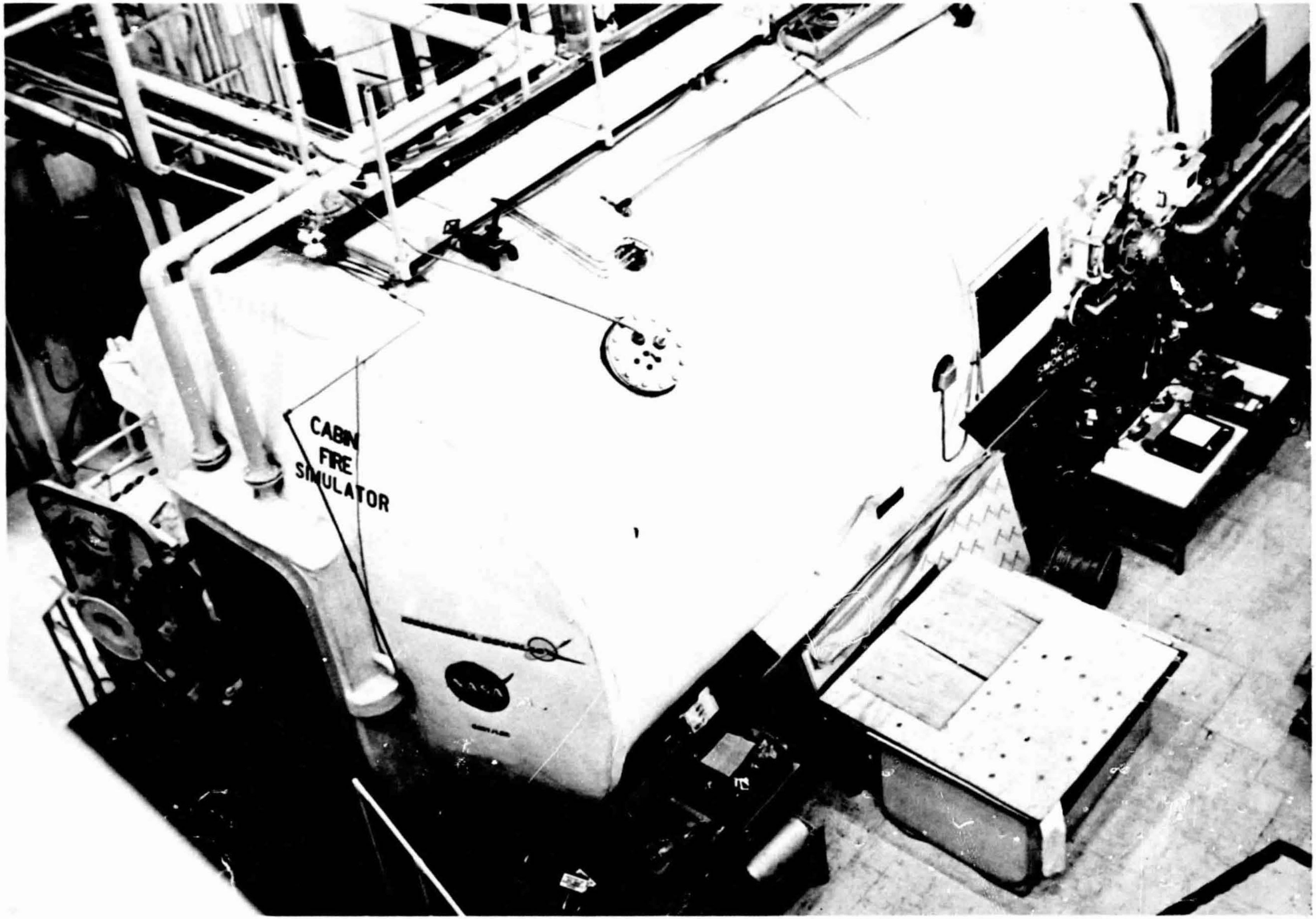

FIGURE 1. DOUGLAS CABIN FIRE SIMULATOR (CFS)

SECONDARY IGNITION SOURCE TESTS

Thirty tests were performed to investigate the effects of three types of fuel, in two quantities, burned within a stainless steel lavatory, Figure 2. In each test the fuel was ignited by a resistance coil energized by computer command. Ventilation typical of an in-flight condition was simulated. Each test period was of 30 minutes duration and in one-half of the tests the door of the lavatory was opened by computer command after the fire had developed. The time of door opening was 100 seconds for the arson attempt and 150 seconds in all other cases. Three tests of each fuel type, quantity, and door condition were made. The possible biological effects on the cabin environment were examined by 10 instrumented animal exposure tests, one for each test variable. In 15 tests, 6 bubbler samples, provided by a NASA-furnished system, were taken at 2-minute intervals of both the cabin air and the lavatory exhaust. These samples were analyzed for their content of HCN, HCL, and HF. Color motion pictures were made of 10 tests in which the lavatory door was opened. Visual observations were made from the CFS airlock viewing port and from two closed-circuit television viewing monitors. Recording of all thermal and real-time gas analysis was performed by the computer.

SECONDARY IGNITION SOURCES

Three types of fuel in two quantities were selected for these tests by mutual agreement of NASA and Douglas. These sources were:

a. Airline Trash — This fuel consisted of a mixture of paper towels, waxed paper cups, and polystyrene cups contained within polyvinyl trash bags. This source is a conservative dry simulation of typical maximum quantities of combustible materials found in common airline usage.

b. Shredded Paper — This fuel consisted of shredded, unused newspaper. This source has been used in many Douglas IRAD tests and was selected by Douglas for its uniformity and repeatability of results.

c. Arson Attempt — This fuel consisted of airline trash with the addition of a quantity of lighter fluid in a vinyl zip-lock bag.

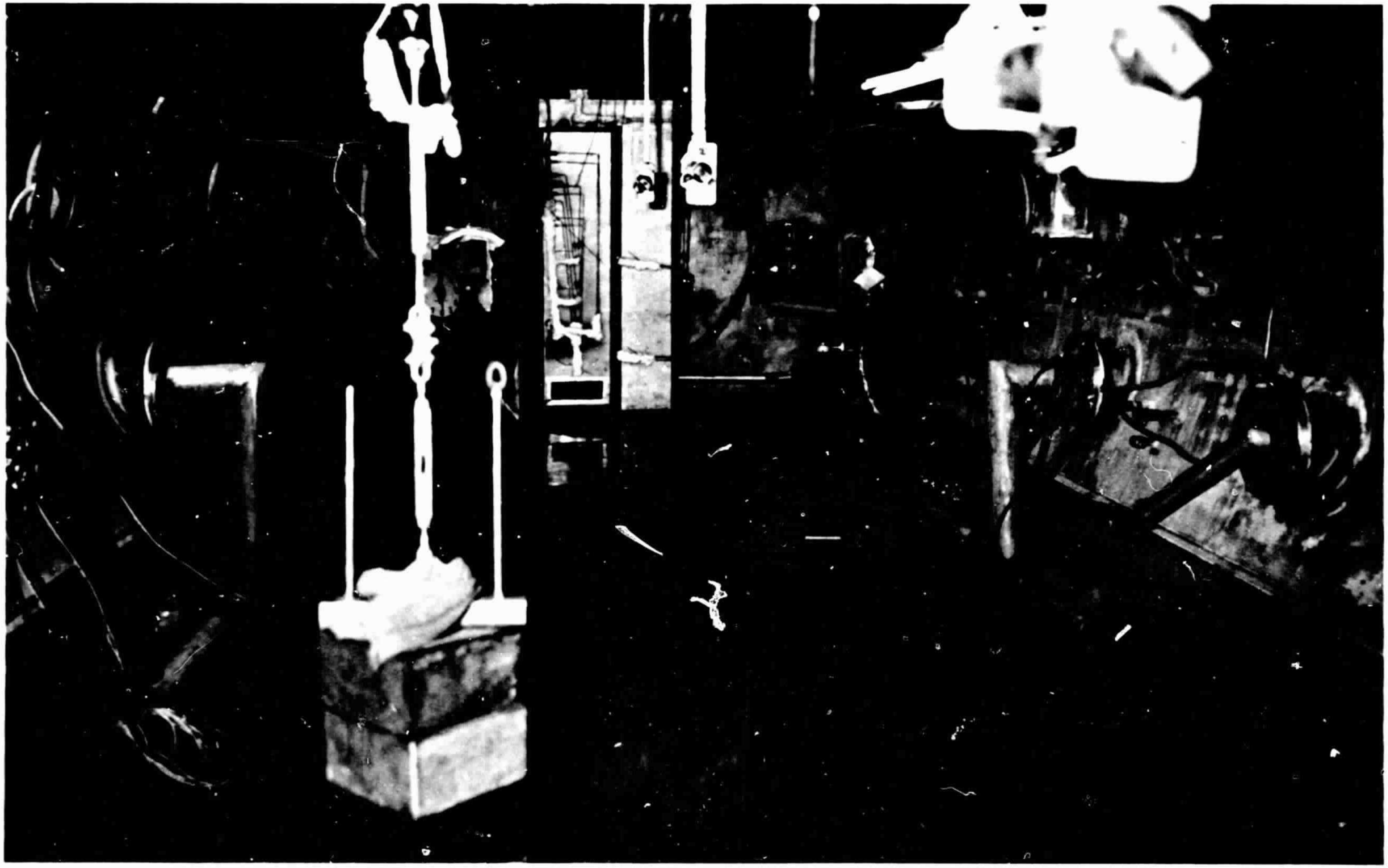

FIGURE 2. INTERIOR OF CFS AS CONFIGURED FOR IGNITION SOURCE TESTS

The airline trash and shredded paper fuel were used in two quantities while only one quantity of the arson attempt fuel was employed.

A simple code for identifying the fuel source, quantity used, and whether it was a closed door or an open door test was developed for identification purposes of the computer-printed data and will be used for all identification in this report.

AL	Fuel Type	AL = Airline Trash SP = Shredded Paper AA = Arson Attempt
I	Specific Test	if a digit $\bar{x}$ average of tests performed
B	Quantity	A = minimum tested B = maximum
C	Door Condition	C = Closed O = Open

AL I B C

This example indicates the first test of the largest quantity of airline trash conducted with the door closed for the entire test.

For the Airline Trash (AL) test the fuel consisted of two bags quantity (A) or four bags quantity (B). The contents of each bag consisted of:

Paper towels (crumpled)	0.907 kg (2 pounds)
Waxed paper cups	0.045 kg (0.1 pound)
Polystyrene cups	0.181 kg (0.4 pound)
Polyethylene trash bag	0.064 kg (0.14 pound)
Total per bag	1.197 kg (2.64 pounds)

For the Shredded Paper test, the fuel consisted of quantity (A) 2.268 kg (5 pounds) and quantity (B) 4.536 kg (10 pounds) of unused shredded newspaper placed in one and two expanded metal baskets respectively.

The fuel for the Arson Attempt consisted of two bags of airline trash and only one quantity (A) was used. A quantity of lighter fluid, 0.212 kg (0.47 pound) in a sealed, vinyl zip-lock bag, was placed in the top of each of the two trash bags prior to ignition.

CFS CONFIGURATION AND INSTRUMENTATION

The CFS was configured and instrumented as shown in Figure 3, with a metal ceiling tangent to the cabin air distribution duct outlet located on centerline of the cabin. Cabin air was exhausted from two ducts at floor level that extended the full length of the cabin. The lavatory for this series was constructed with 0.406-mm (0.016-inch) thick type 321 stainless steel walls and instrumented as shown in Figure 4. For these tests, an unsuccessful attempt was made to accurately determine the weight loss of the fuel as it burned. The relatively small weight loss per unit time together with the lift effects of the heated air, friction effects, and the differential thermal expansion of the suspension system resulted in a problem for which a solution was beyond the scope of the program. In an attempt to better understand this problem, Thermocouple No. 23 in Figure 3 was attached to the cable that suspends the lavatory.

BIOLOGICAL EXPERIMENT

Instrumented animal subjects (rats) were exposed in 10 of the source fire tests which included one of each fuel type, quantity, and door condition. The subjects were instrumented for electrocardiogram (ECG) and respiration, with an electrode belt containing two ECG electrodes and a respiration sensor. The experiment was conducted using the method developed under Contract No. NAS 2-8668 for NASA ARC (Reference 1). The cage containing a subject, Figure 5, was placed on a portable stand at a height of 10.2 cm (4 ft) off the floor, at a distance of 10.2 cm (4 ft) away from the door of the lavatory, and at an angle of approximately 30 degrees from the hinged side of the door. The cage was shielded from direct heat radiating from the lavatory with Fiberfrax which covered the top and two sides of the cage nearest the lavatory. The remaining sides were open to the cabin atmosphere. The subject's electrode belt was attached to an umbilical cord plugged into a receptacle in the top of the cage. The cord extended through a sealed port leading to the monitoring and recording station.

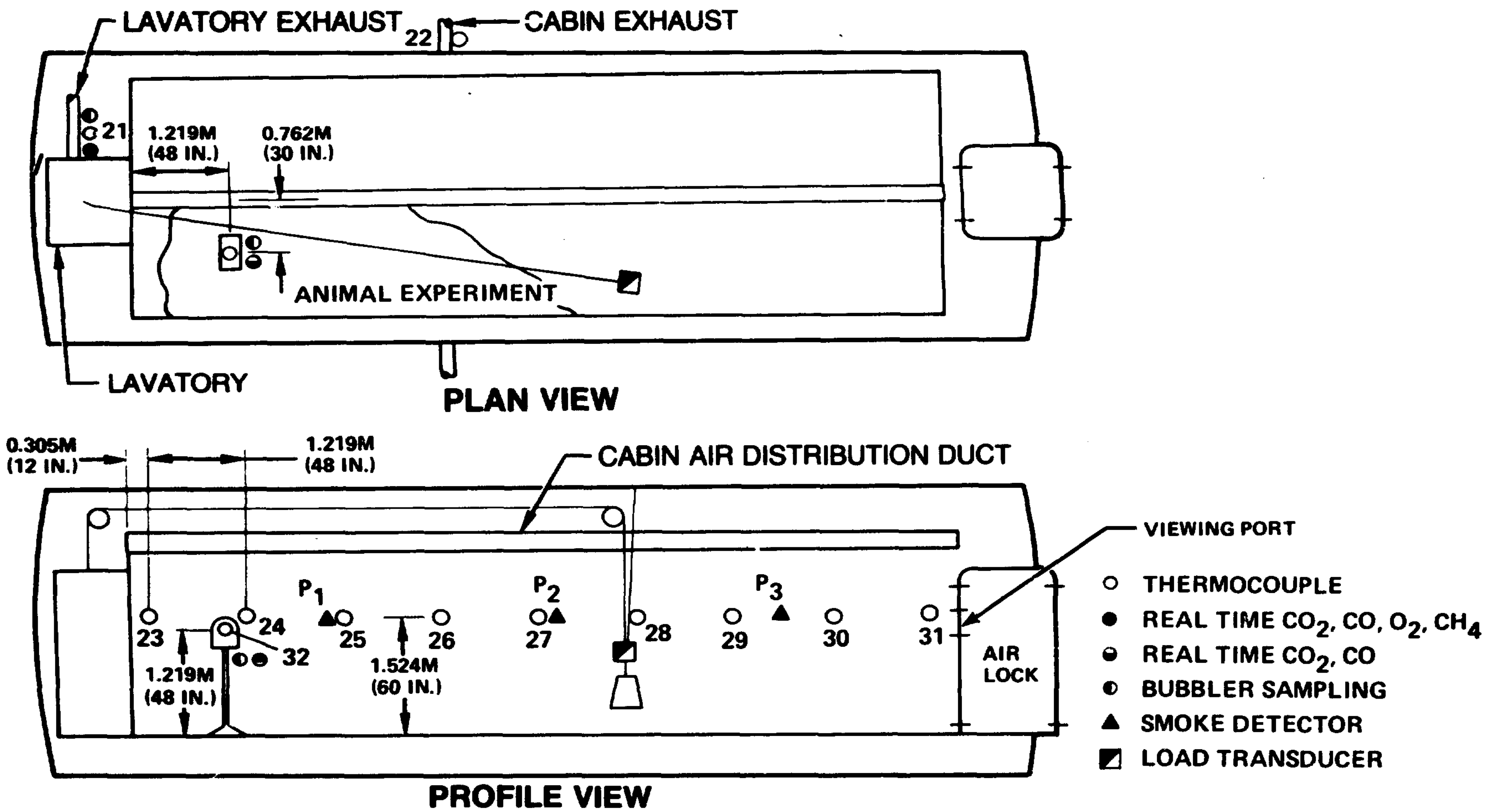

FIGURE 3. CABIN INSTRUMENTATION

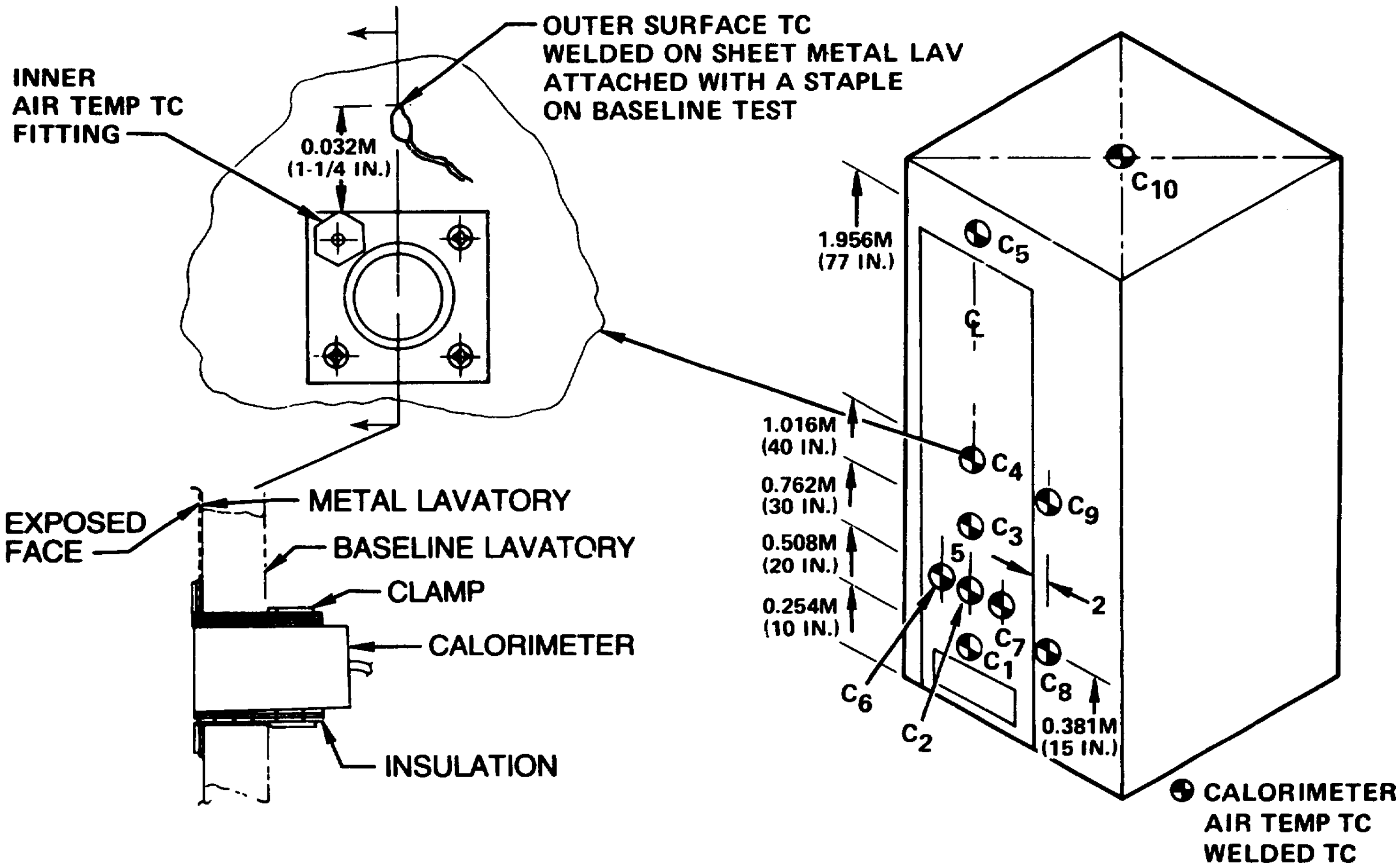

FIGURE 4. LAVATORY INSTRUMENTATION

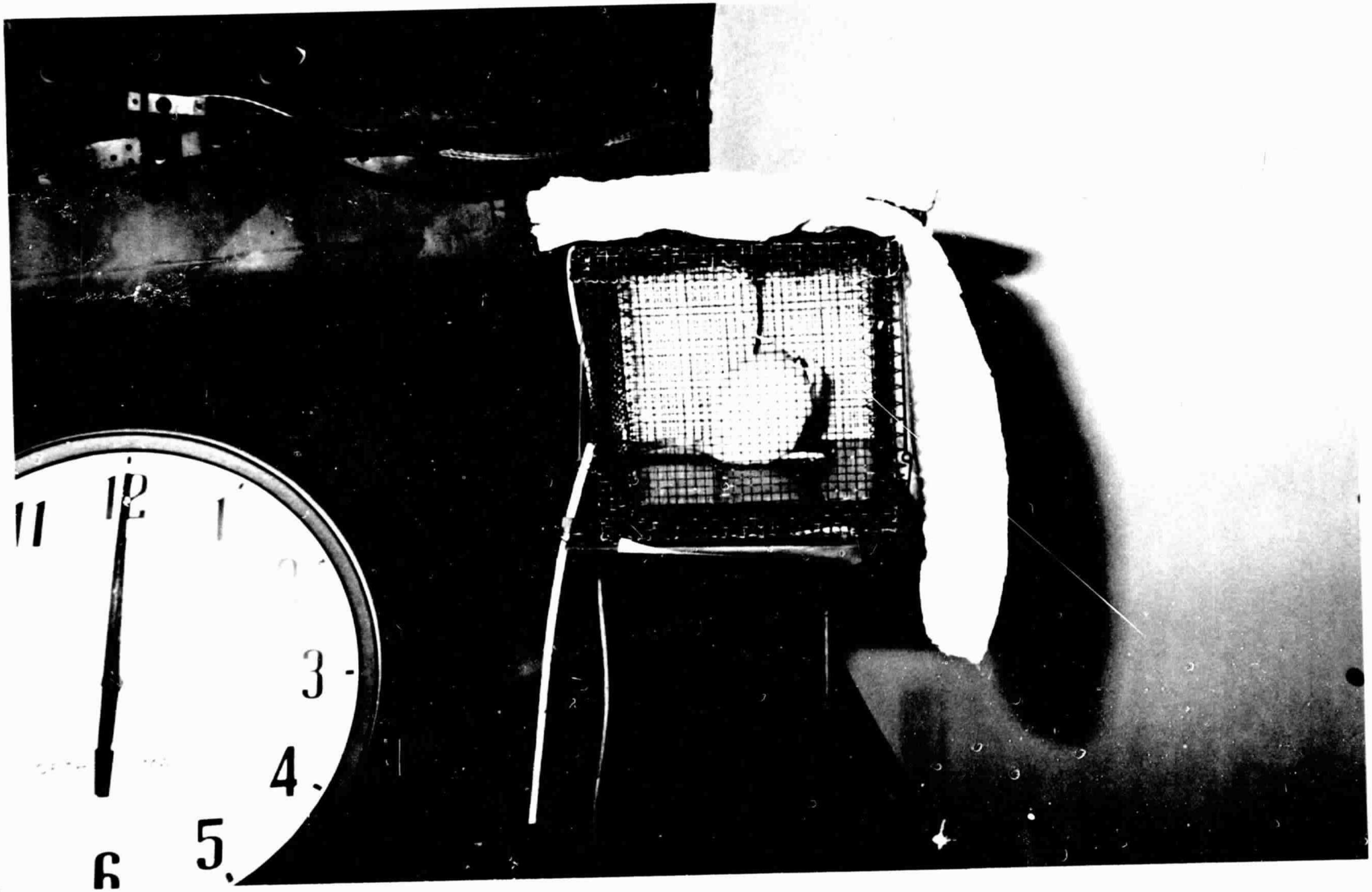

FIGURE 5. INSTRUMENTED ANIMAL SUBJECT

Recording was accomplished using the Portable Animal Recording Test System (PARTS) as shown in Figure 6 and developed under Douglas IRAD programs (Reference 2). One of the monitors of the closed-circuit television system was available for visual observation of the subject's behavior.

GAS ANALYSIS

In each test the atmosphere of the lavatory exhaust and the cabin was monitored by the equipment shown in Figure 7, and the results were computer-recorded. The lavatory exhaust was examined for its content of CO, CO_2, O_2, and total hydrocarbons as CH_4 equivalents, while CO and CO_2 were measured in the cabin at the subject's cage. The equipment used for determining the content of these gases included:

Lavatory Exhaust Analysis

Gas	Analyzer	Range	Sample Flow Rate
Carbon Monoxide	MSA Model 303	0-10%	1 lpm
Carbon Dioxide	Beckman Model 864	0-20%	1 lpm
Oxygen	MSA Model 802	0-25%	2 lpm
Total Hydrocarbons	MSA Model 200	0-20%	2 lpm

Cabin Atmosphere Analysis

Gas	Analyzer	Range	Sample Flow Rate
Carbon Monoxide	MSA Model 303	0-5000 ppm	1 lpm
Carbon Dioxide	MSA Model 303	0-2.5%	1 lpm

The sampling lines leading to the analysis equipment were 1/4-inch O.D. stainless-steel tubing. Before analysis, the sample was filtered with a Pall Epocel 3 cartridge, zinc dust, and calcium sulphate to remove particulates, acid gases, and water respectively. Hydrocarbons were sampled using a heated line. Delay time between the event and its measurement was between 30 and 60 seconds.

In one-third of the closed door tests and in two-thirds of the open door tests, the lavatory exhaust and the cabin air were sampled using two NASA JSC-furnished bubbler systems, as shown in Figure 8.

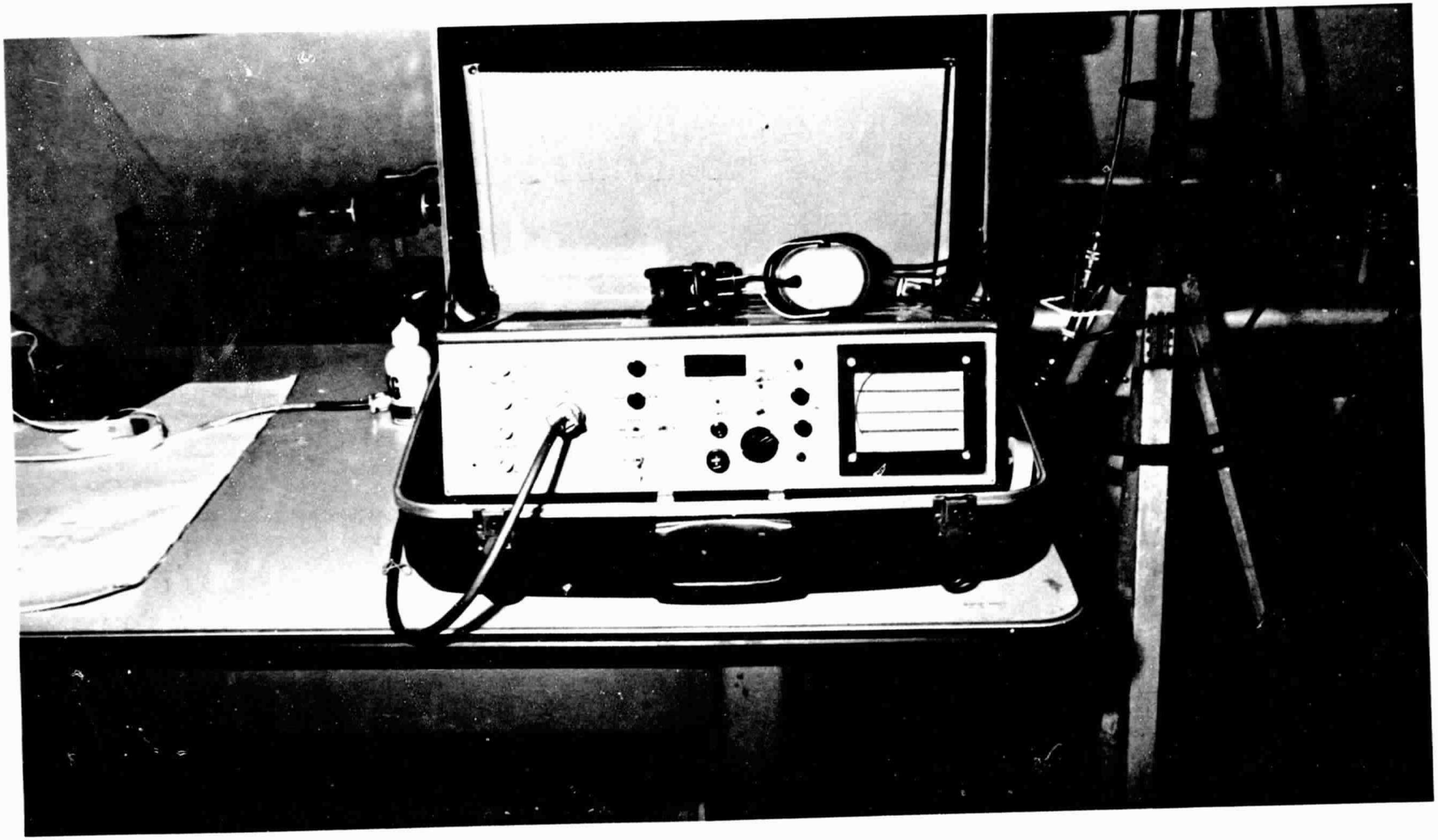

FIGURE 6. PORTABLE ANIMAL RECORDING TEST SYSTEM (PARTS)

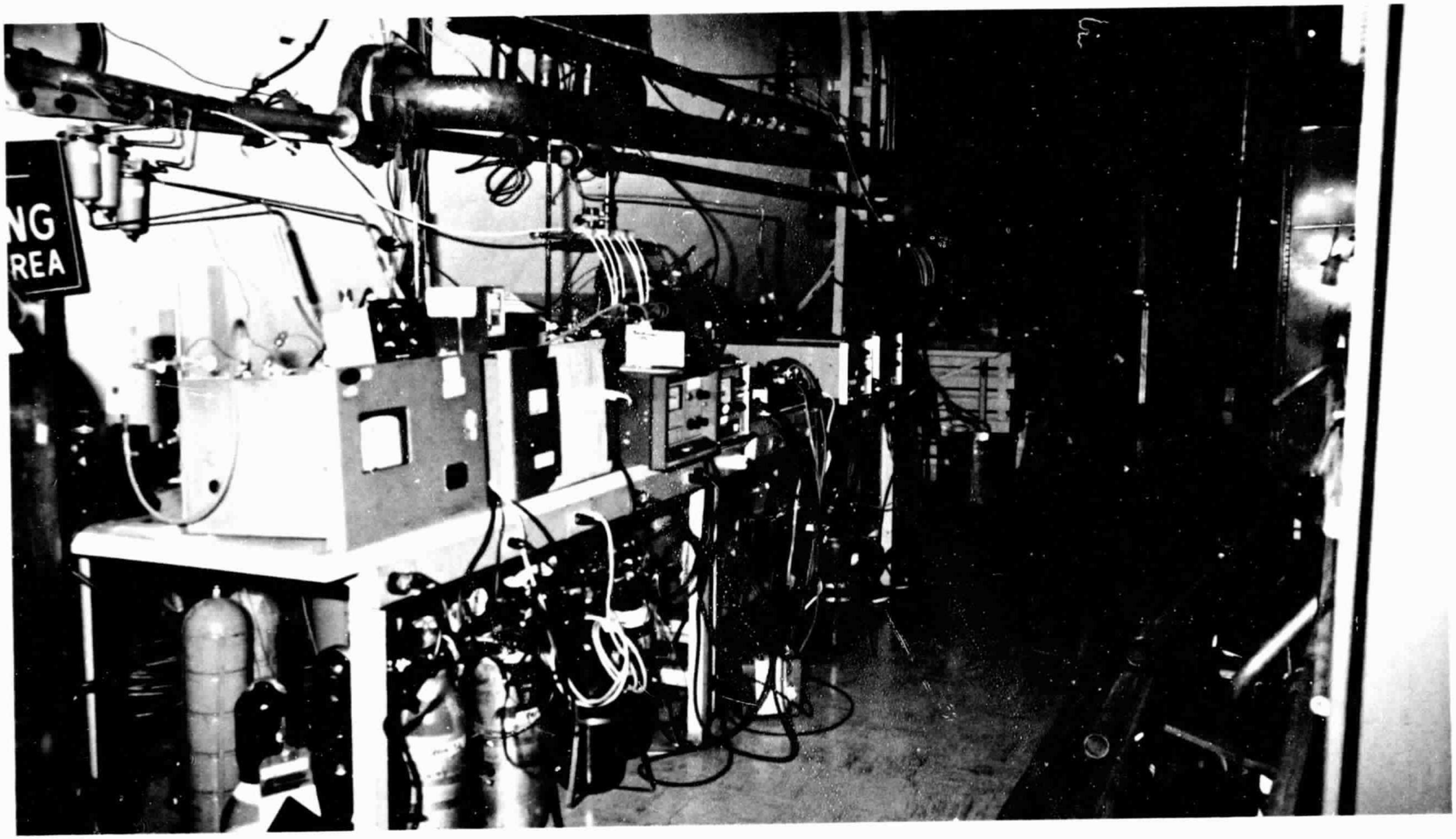

FIGURE 7. GAS ANALYSIS EQUIPMENT

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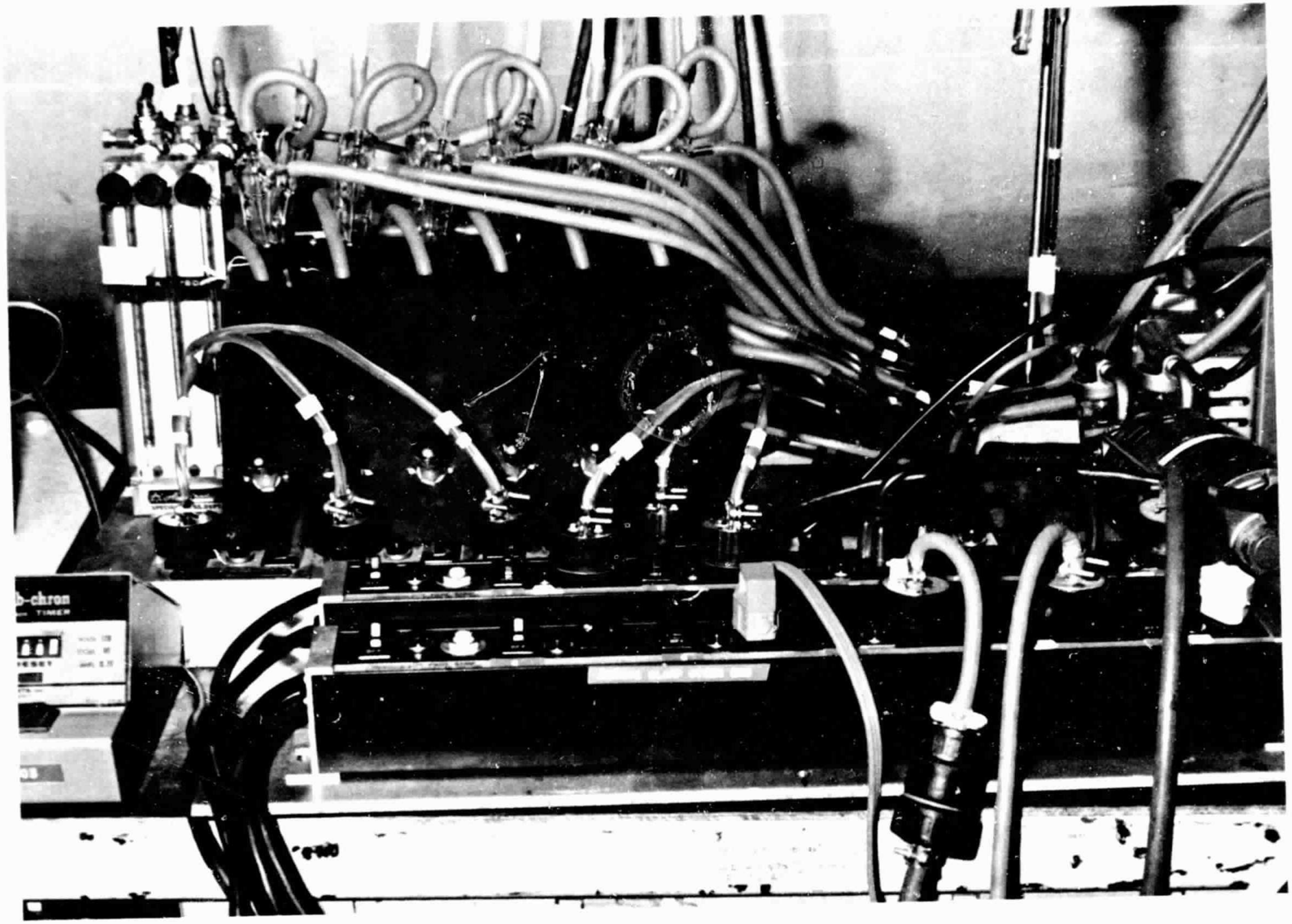


FIGURE 8. NASA-FURNISHED BUBBLER SYSTEM

The NASA bubbler system sampled air from the lavatory exhaust and the cabin adjacent to the rat cage. The sampling lines were 1/4-inch O.D. teflon lines, leading into impingers via a teflon manifold. The impingers contained 0.1-N NaOH. Each bubbler ran for 2 minutes, consecutively from the beginning of the test, for the first 12 minutes. The flow rate was 0.5 lpm. Additionally, at each location, a continuous sample was taken for the duration of the test at 1 liter per minute.

Each bubbler sample was analyzed for HCL, HF, and HCN as follows:

a. Chlorides (as HCL) — Chlorides were measured by potentiometric titration with $AgNO_3$ using a chloride ion selective electrode.

b. Fluorides (as HF) — Fluorides were measured by fluoride specific ion selective electrode.

c. Cyanide (as HCN) — Cyanide was measured using the pyridizine — pyrazolone method.

DISCUSSION OF THE SECONDARY IGNITION SOURCE TESTS

General comments that can be made on the various sources and conditions include:

a. The AL $\bar{x}$ BC source proved to be the most severe threat, probably due to fuel geometry and the higher heat content.

b. All fuel sources in which the airline mix was used produced more smoke, objectionable odors, and irritants than the shredded paper.

c. More uniformity of heat flux for a longer period of time was exhibited by the shredded paper source in the B quantity than the other sources.

d. Upon opening the door additional air was admitted to the fire resulting in a substantial increase in the heat flux at the ceiling of the lavatory. This increase was somewhat proportionate to fuel quantity, i.e., the available heat content. However, it is believed that with the exception of the Arson Attempt this increase was as much a function of geometry (i.e., fuel height) as it was of quantity and available heat content.

e. Upon opening the door the cabin air temperature increased from ambient to approximately $80^{\circ}C$ ($176^{\circ}F$) uniformly throughout the cabin approximately 100 seconds after door opening, with the larger sources. This represented no significant cabin temperature hazard. However, a definite hazard to the ceiling was created by opening the door and it is doubtful if the capacity and potential effectiveness of onboard extinguishers would be capable of combating this threat.

Heat Flux in the Closed Door Tests

Figures 10, 11, 13, 14, and 16 show the average heat flux incident upon the selected calorimeters. The results are the averages of three tests over the time periods of 0 to 100, 100 to 200, and 200 to 300 seconds. This time span included the periods of maximum activity for all cases except for that of SP x̄ BC in which the maximum activity extended for an additional 200 seconds at approximately the same level shown in the 200- to 300-second time period. Figures 9, 12, and 15 show the various types and quantities of fuel installed prior to the test. In tests where trash bags were used, a small quantity of shredded paper was placed over the ignitor wire to ensure a more uniform time of ignition.

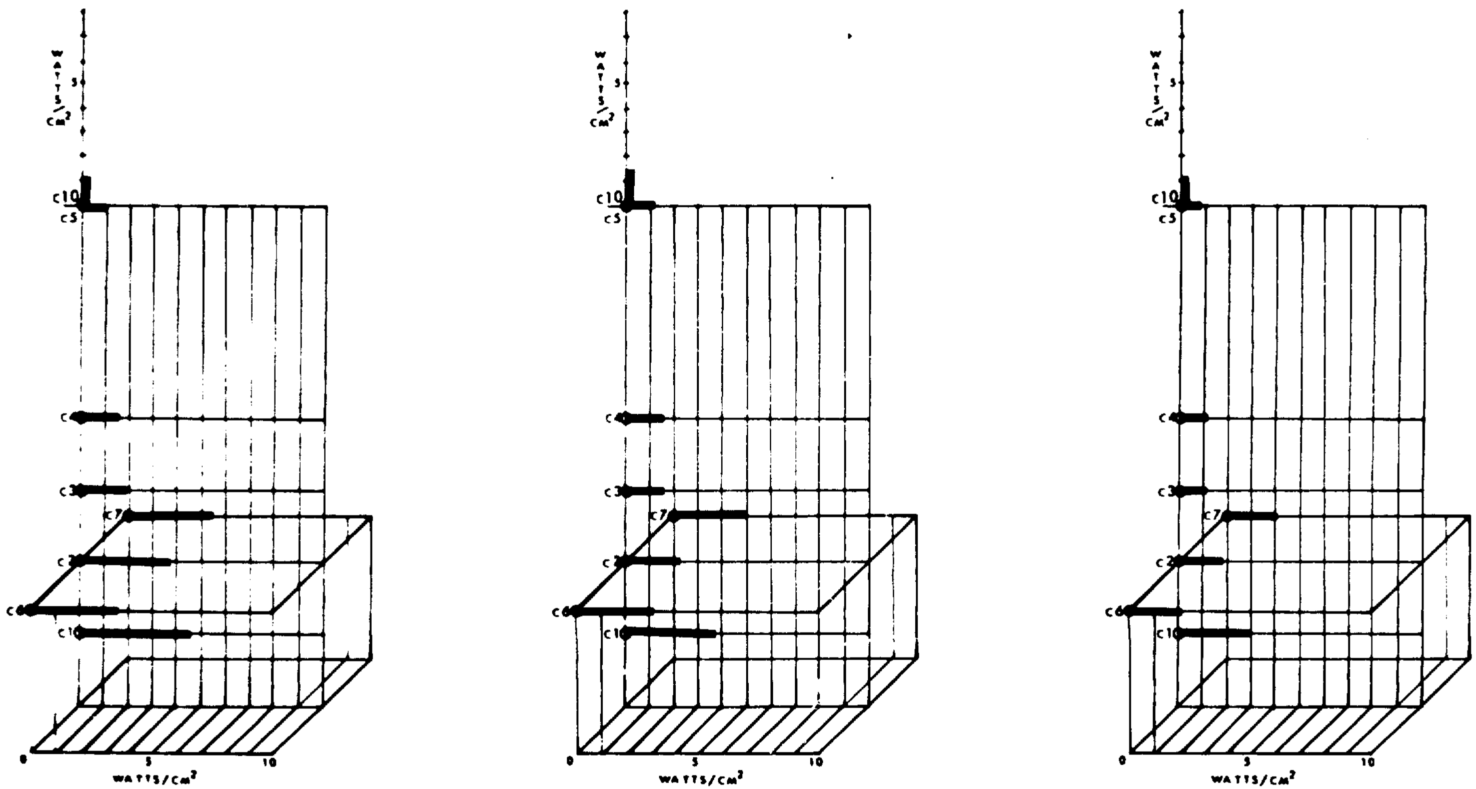
An examination of small and large quantities of airline trash shown in Figures 10 and 11 show that a substantial increase in heat flux occurred with the larger quantities in the 200- and 300-second period. This is in contrast with the performance of two similar quantities of shredded paper in which little difference can be noted except for the heat flux toward the top of the module. This is believed to have been the result of the contents of the upper bags of airline trash falling into the fire while the second basket of shredded paper was held in a position farther away from the air supply.

In the case of the Arson Attempt, there was some initial concern as to the possible hazards of this test. Figure 16 shows that the Arson Attempt presented less of a hazard than AL x̄ BC probably because the severity of the fire was limited by the oxygen availability rather than the fuel quantity.

AL( ) AC & AO

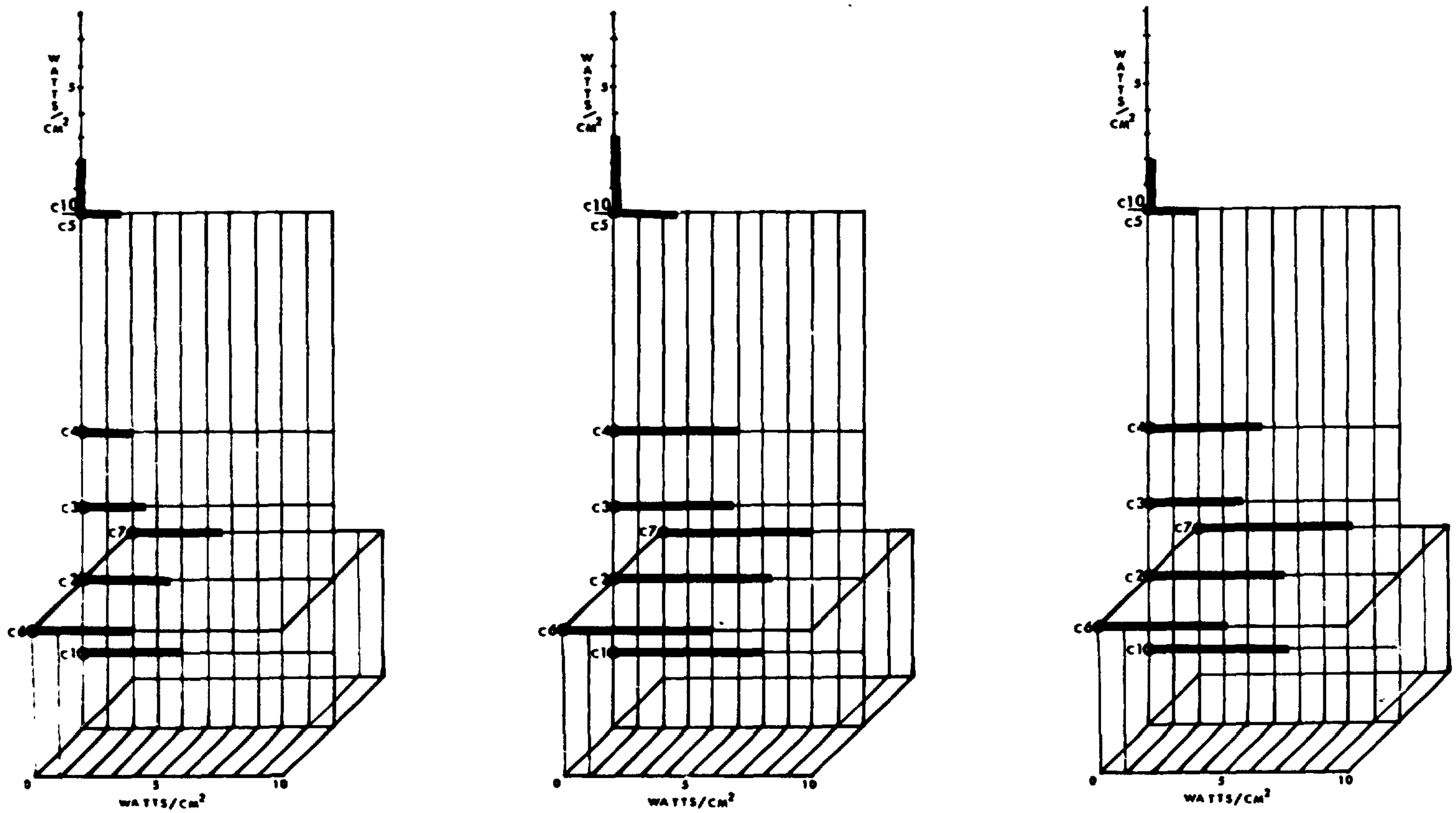
AL( ) BC & BO

FIGURE 9. AIRLINE TRASH FUEL



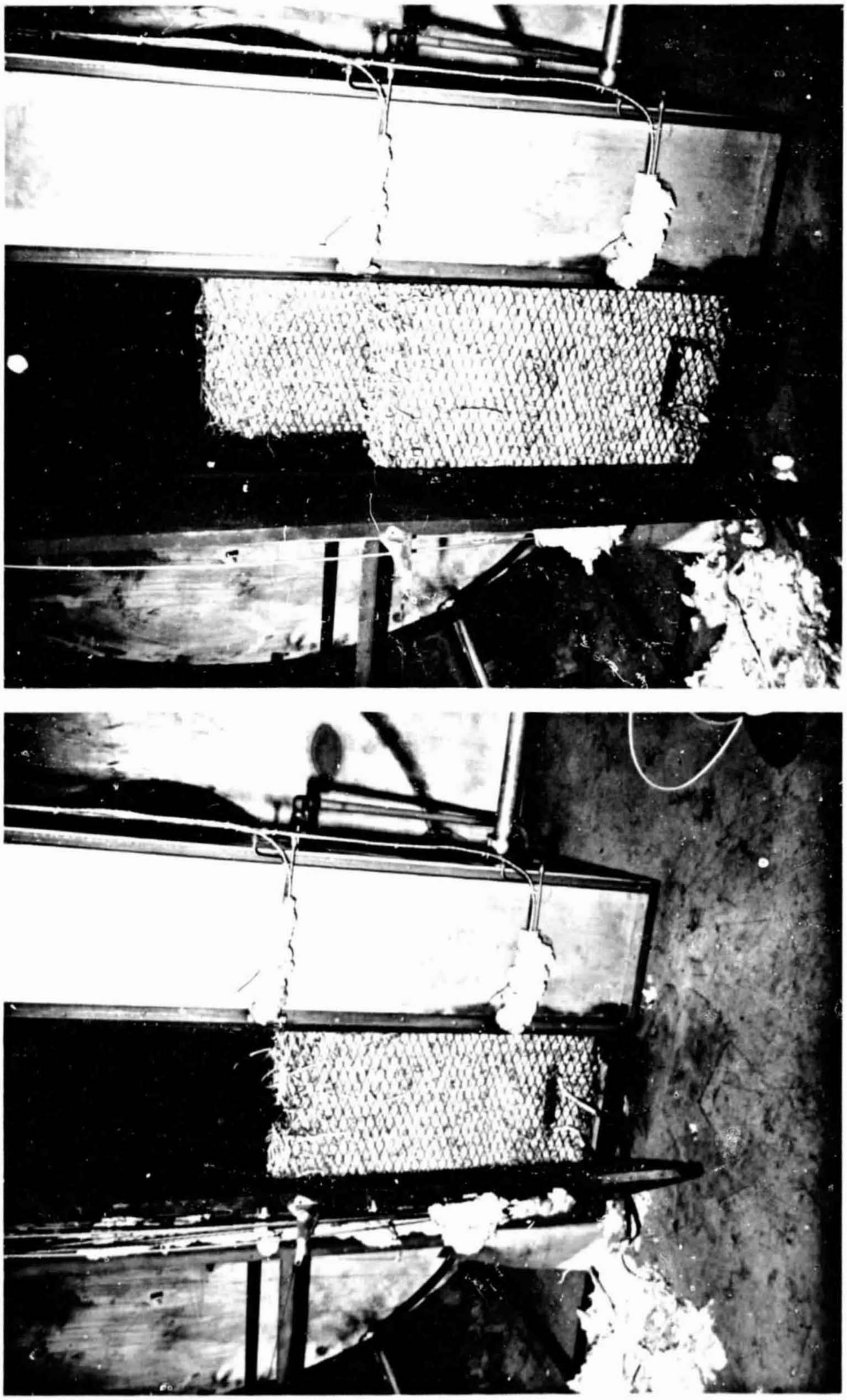
100 SECONDS 200 SECONDS 300 SECONDS

FIGURE 10. AL $\bar{x}$ AC AVERAGED HEAT FLUX



100 SECONDS **200 SECONDS** **300 SECONDS**

FIGURE 11. AL $\bar{x}$ BC AVERAGED HEAT FLUX



SP( )AC&O

SP( )BC&O

FIGURE 12. SHREDDED PAPER FUEL

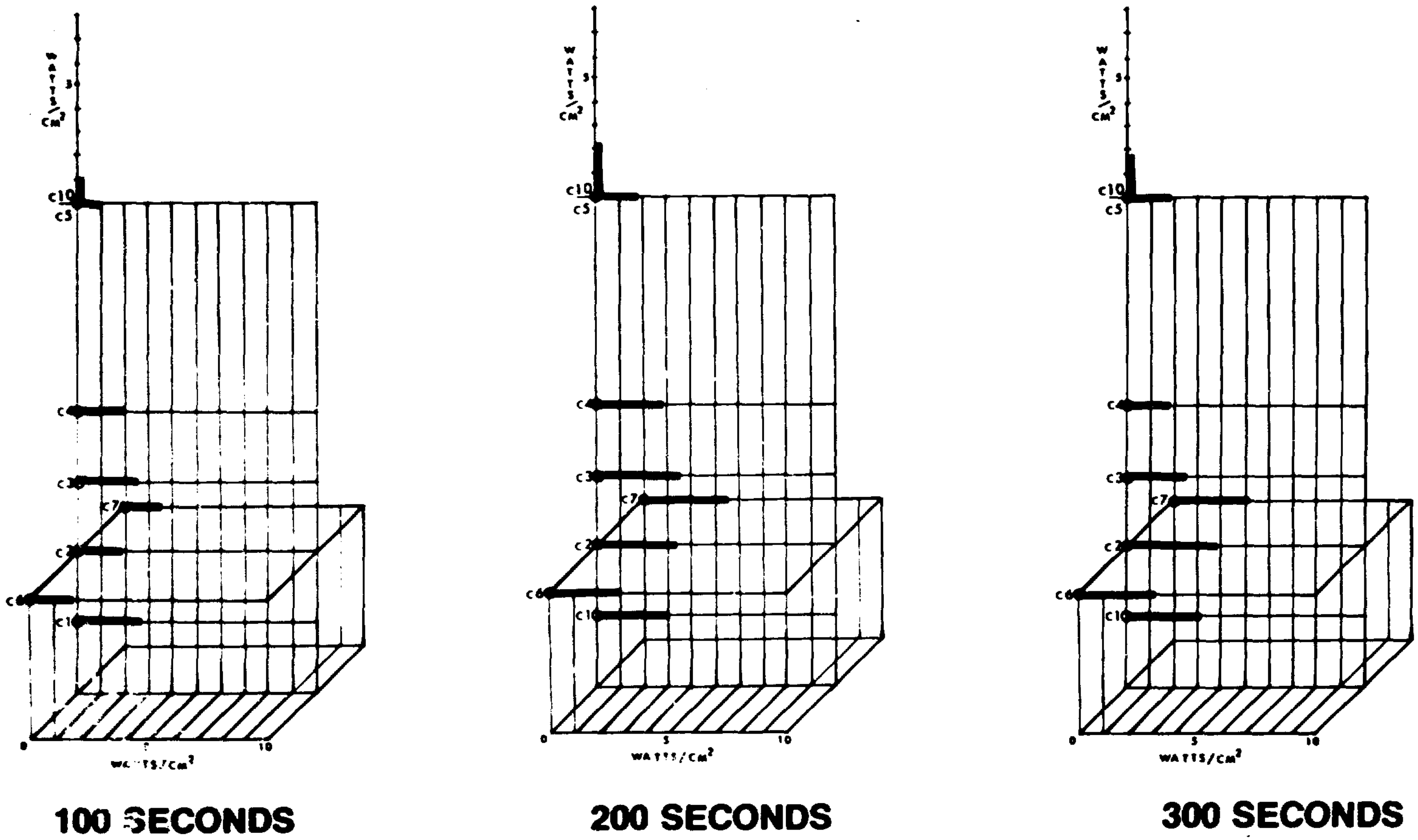
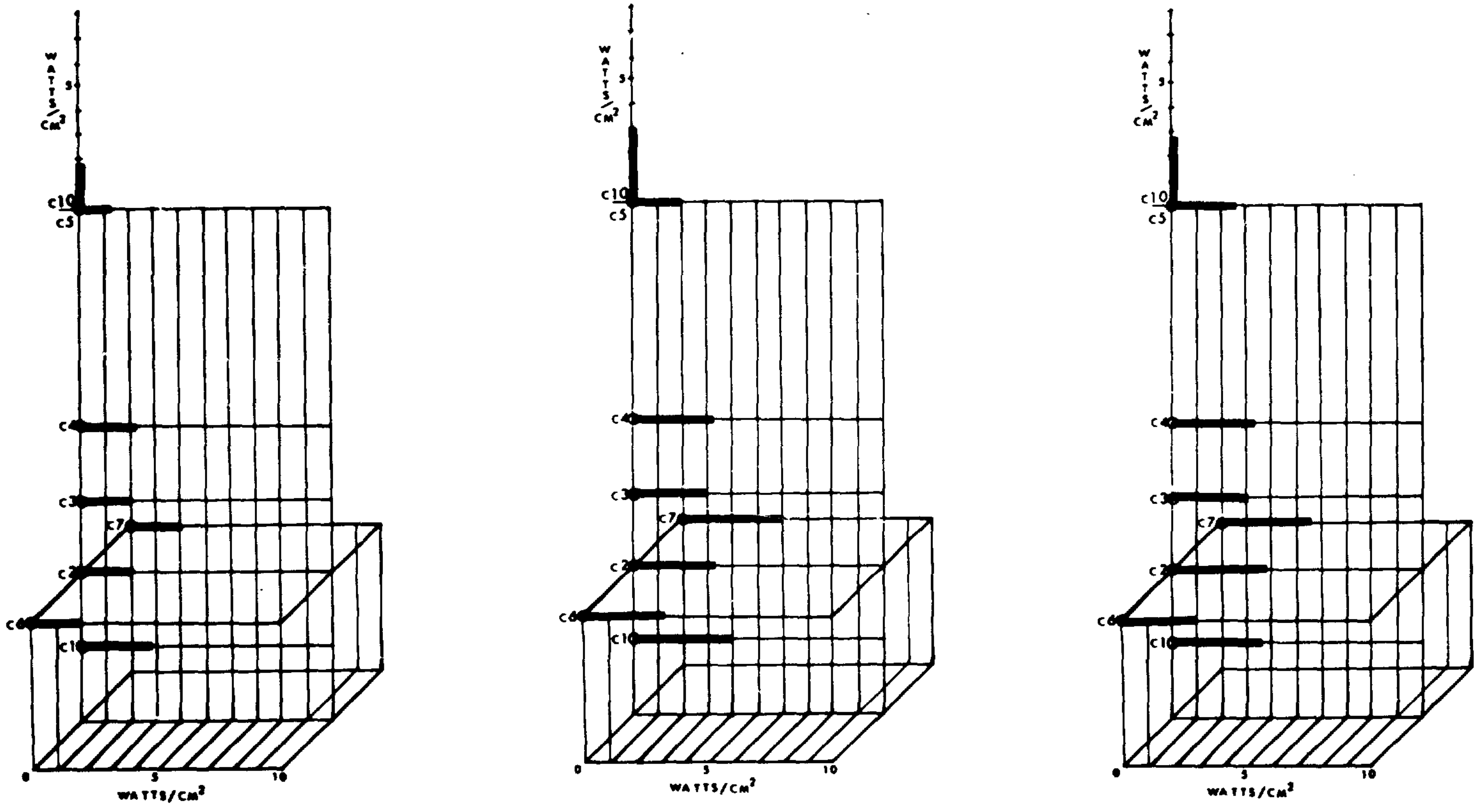


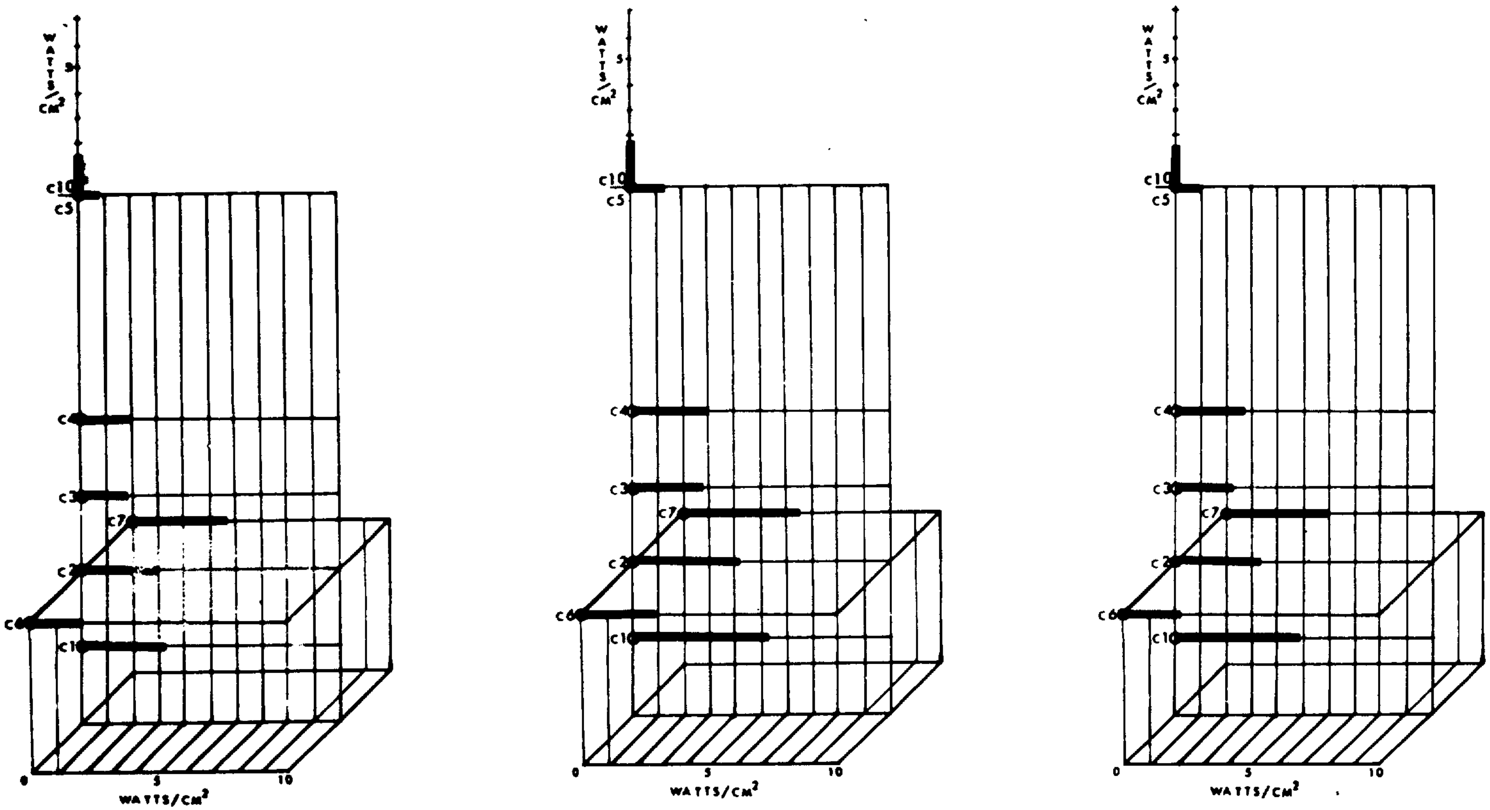
FIGURE 13. SP $\bar{x}$ AC AVERAGED HEAT FLUX



100 SECONDS **200 SECONDS** **300 SECONDS**

FIGURE 14. SP $\bar{x}$ AC AVERAGED HEAT FLUX

FIGURE 15. ARSON ATTEMPT FUEL



100 SECONDS

200 SECONDS

300 SECONDS

FIGURE 16. AA $\bar{x}$ AC AVERAGED HEAT FLUX

Heat Flux in the Opened Door Tests

In these tests the lavatory door was opened by the computer energizing a solenoid which allowed a weight to fall a predetermined distance opening the door of the lavatory approximately 60 degrees. The time selected for opening the door was 150 seconds for the Airline Trash and Shredded Paper tests and 100 seconds for the Arson Attempt. The results of these tests are shown in Figures 17 through 21. These results have been shown in a similar fashion to those of the closed door series. In these tests, the average heat flux is shown for the same calorimeters in the periods of 50 seconds before and after the time that the door was opened. The calorimeters mounted on the door which include C1, 2, 3, 4, 6, and 7 move away from the door opening and the fire. Therefore, they indicate a lower heat flux than if they had been in their original position. Major items of significance on these tests include:

a. An increase, at the ceiling of the lavatory, of up to four times the heat flux with the larger quantities of fuel.

b. The Arson Attempt produced twice the heat flux of that produced by AL $\bar{x}$ AO.

c. With the exception of AA $\bar{x}$ AO, the increased heat flux at the ceiling for the larger quantities of fuel was probably the result of fuel height as much as increased quantity or available heat content.

d. The lack of severity of the AA $\bar{x}$ AO, in comparison with those tests conducted by NASA JSC in an open cabin, is probably due to the method of containing the lighter fluid before the test rather than saturating the trash prior to ignition and the fact that a portion of this material escaped via the exhaust duct prior to door opening.

Products of Combustion

The measured real-time gaseous products of combustion resulting from each fuel source and door condition are shown in the following series of selected computer printed plots, Figures 22 through 26. Two cases for each source are shown: one with the door closed, shown on the left, and the other with the door open, shown on the right. For each case, the upper plot

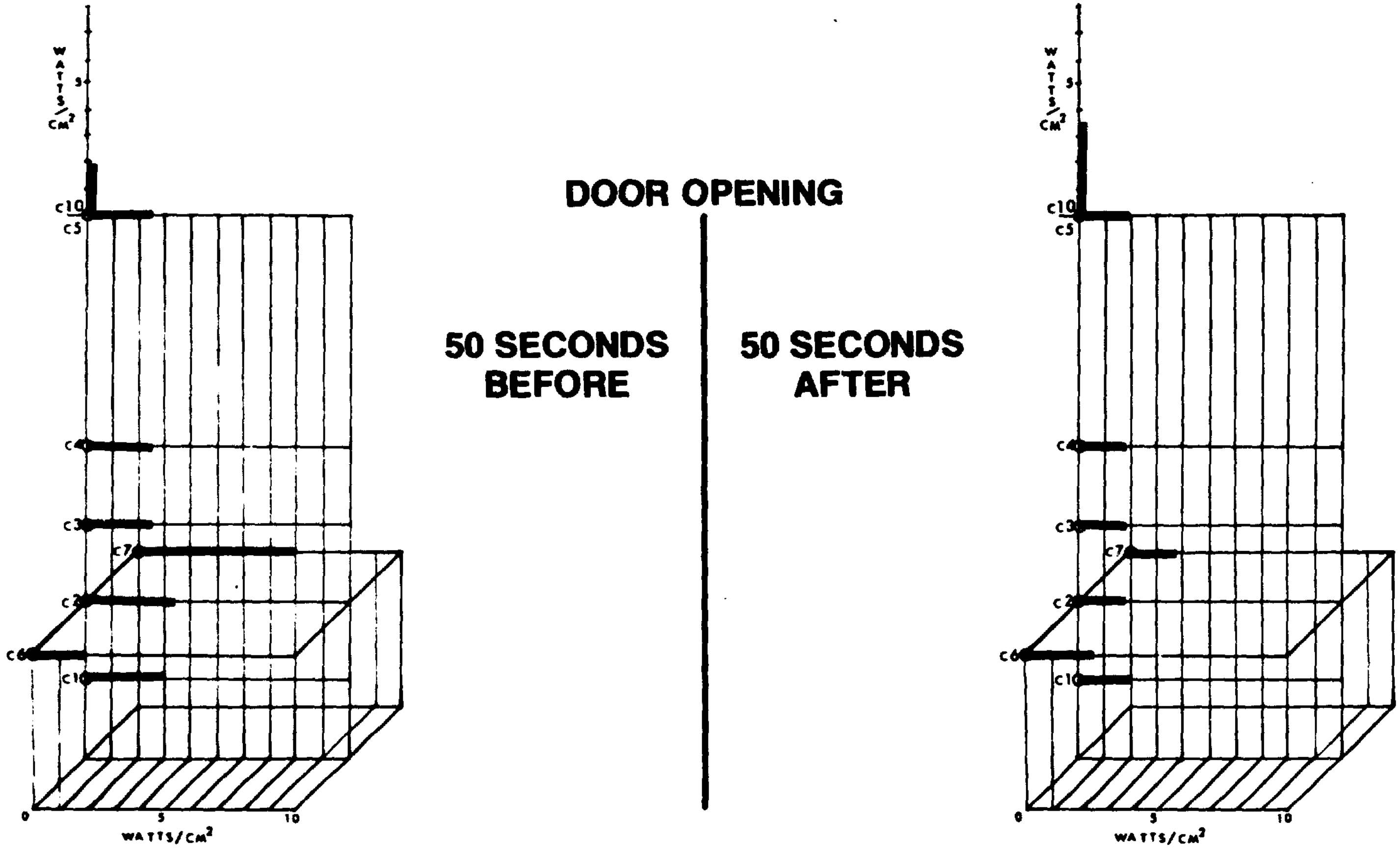


FIGURE 17. AL $\bar{x}$ AO AVERAGED HEAT FLUX

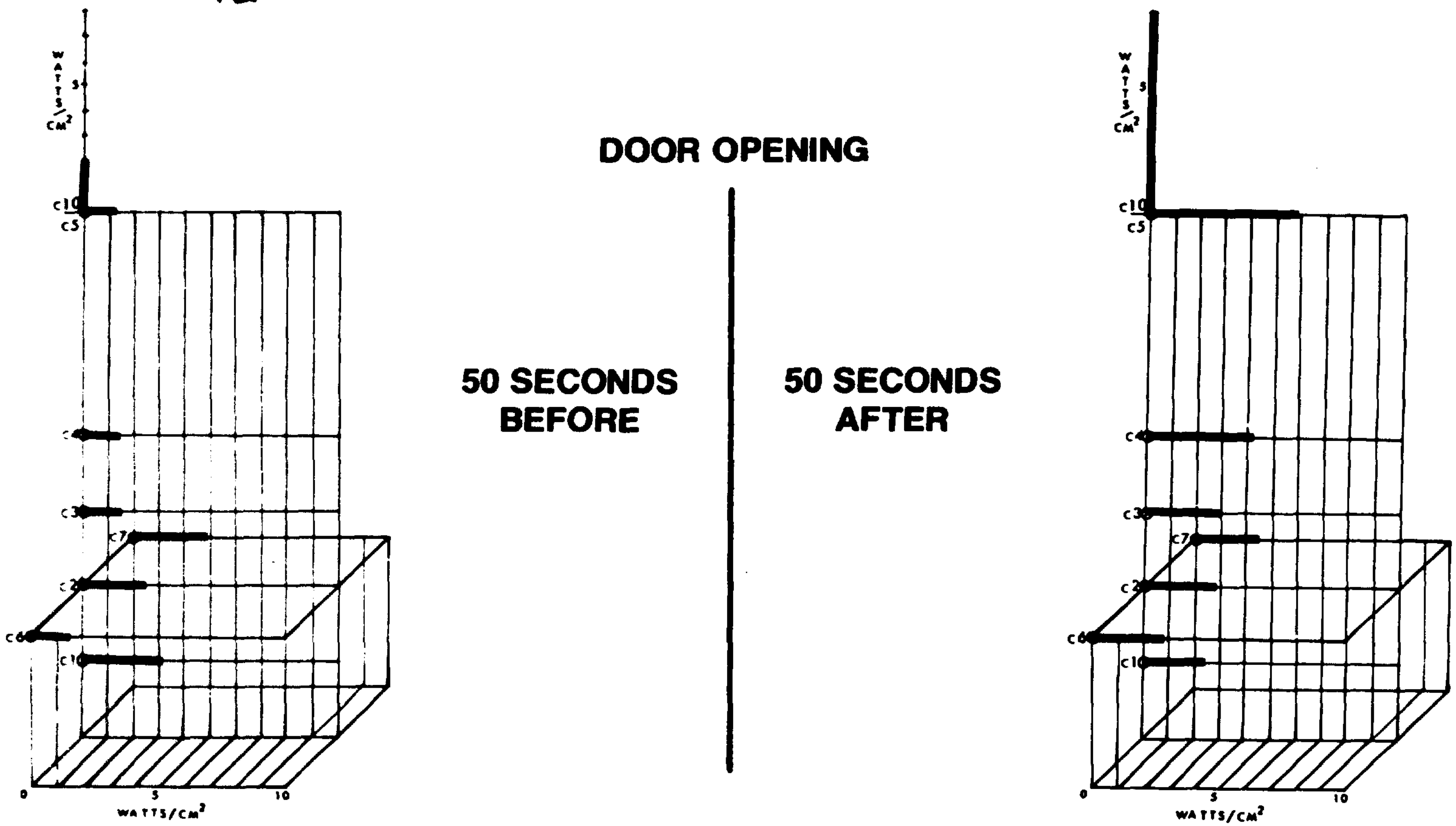


FIGURE 18. AL $\bar{x}$ BO AVERAGED HEAT FLUX

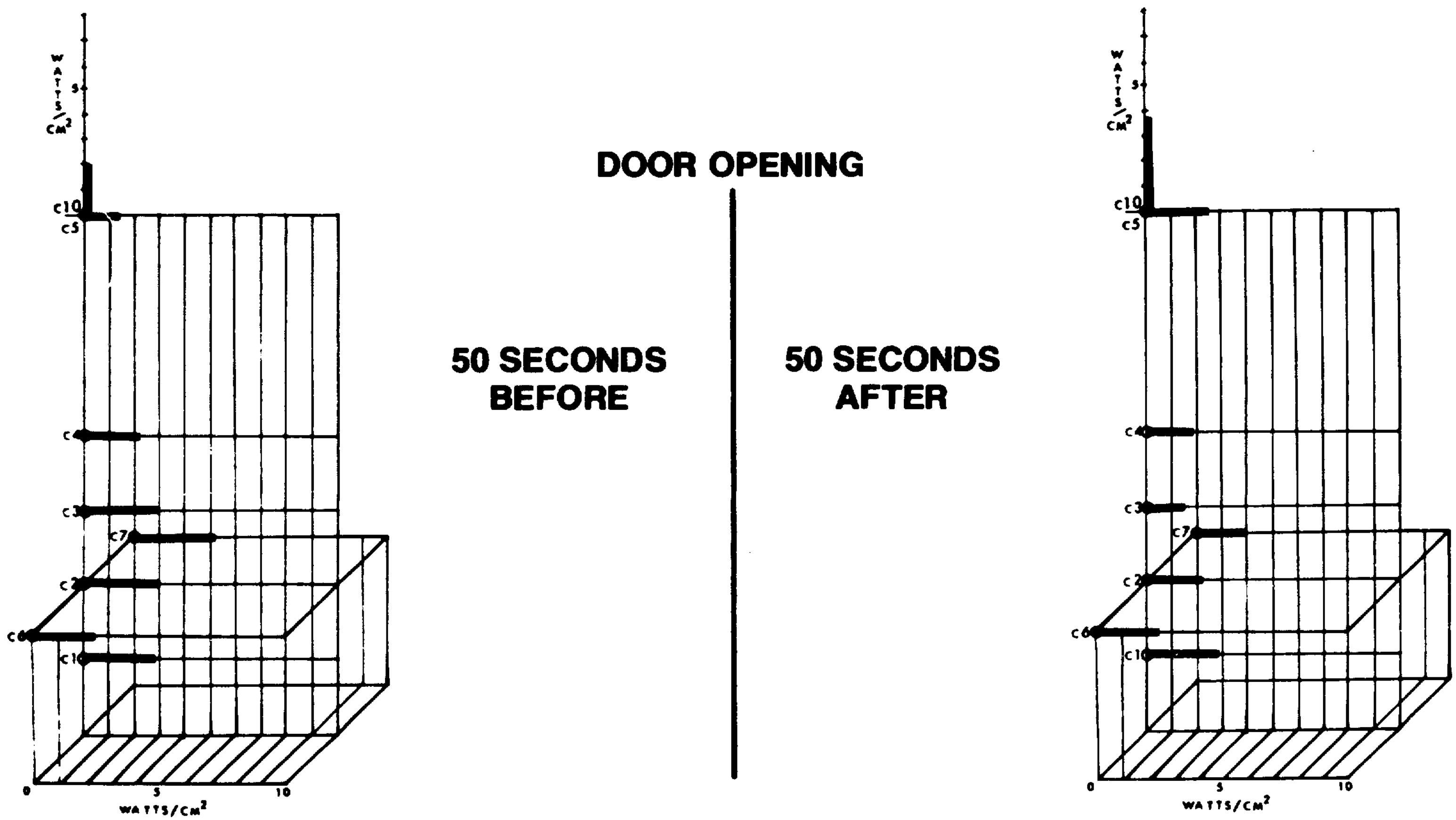


FIGURE 19. SP $\bar{x}$ AO AVERAGED HEAT FLUX

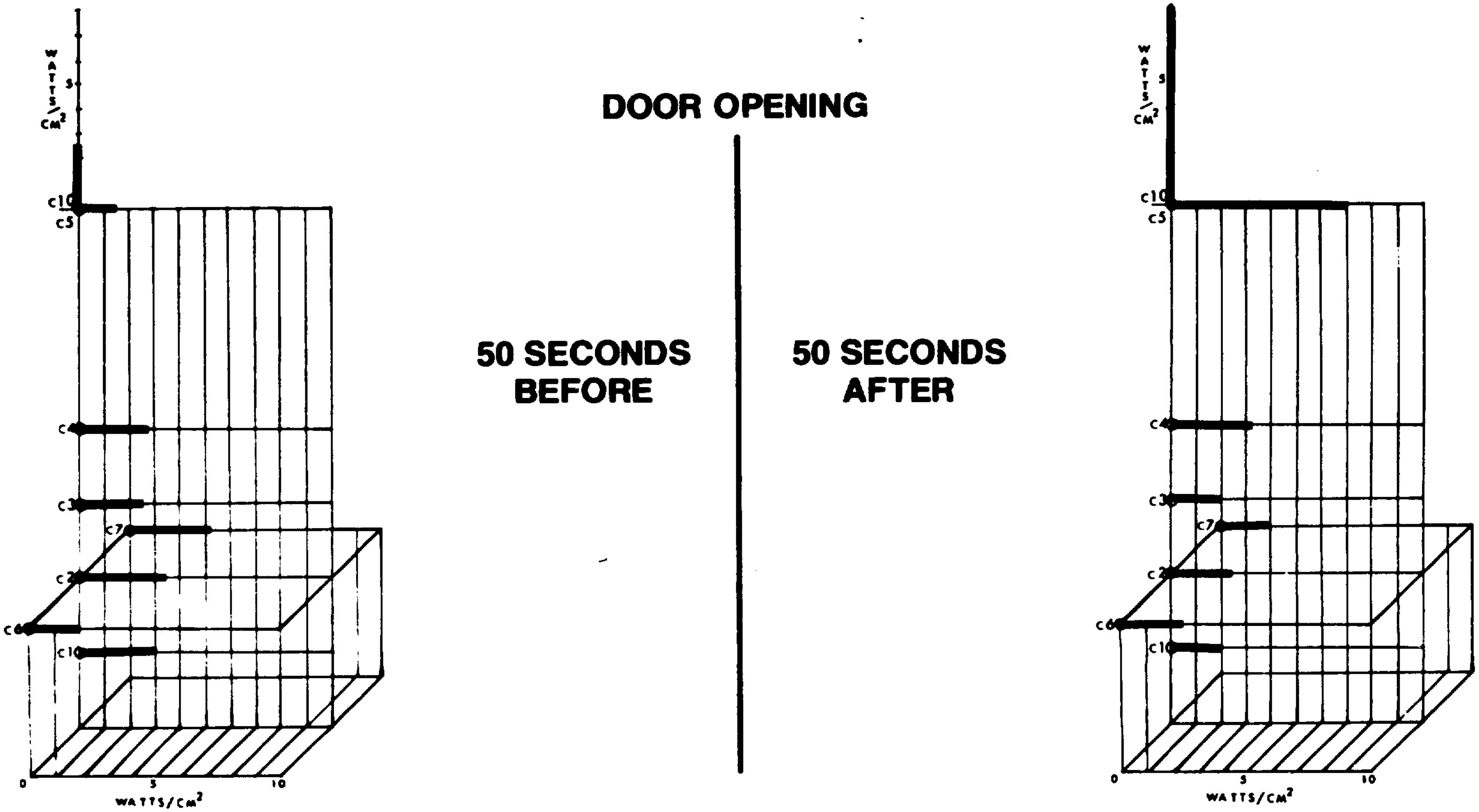


FIGURE 20. SP $\bar{x}$ BO AVERAGED HEAT FLUX

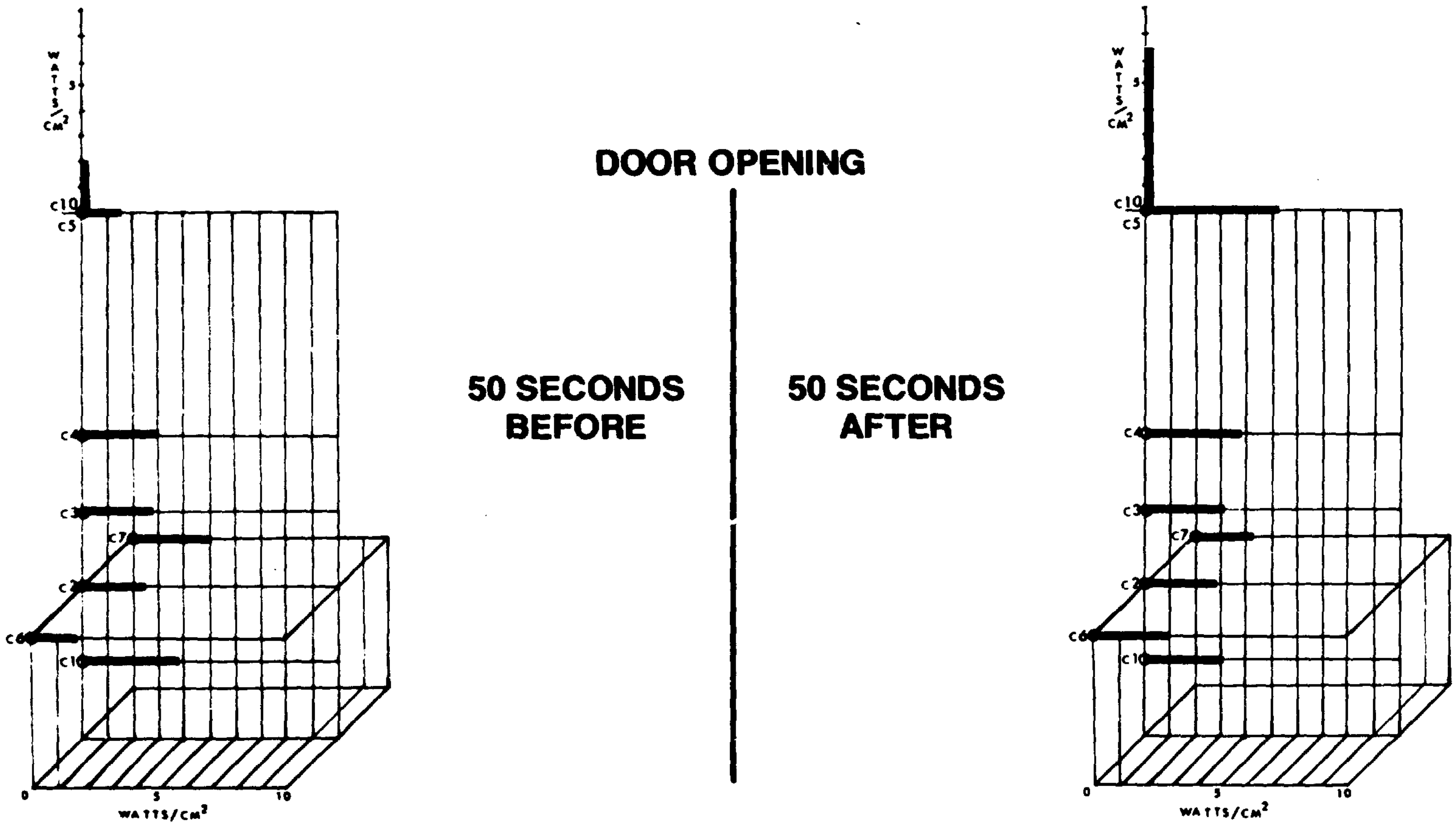
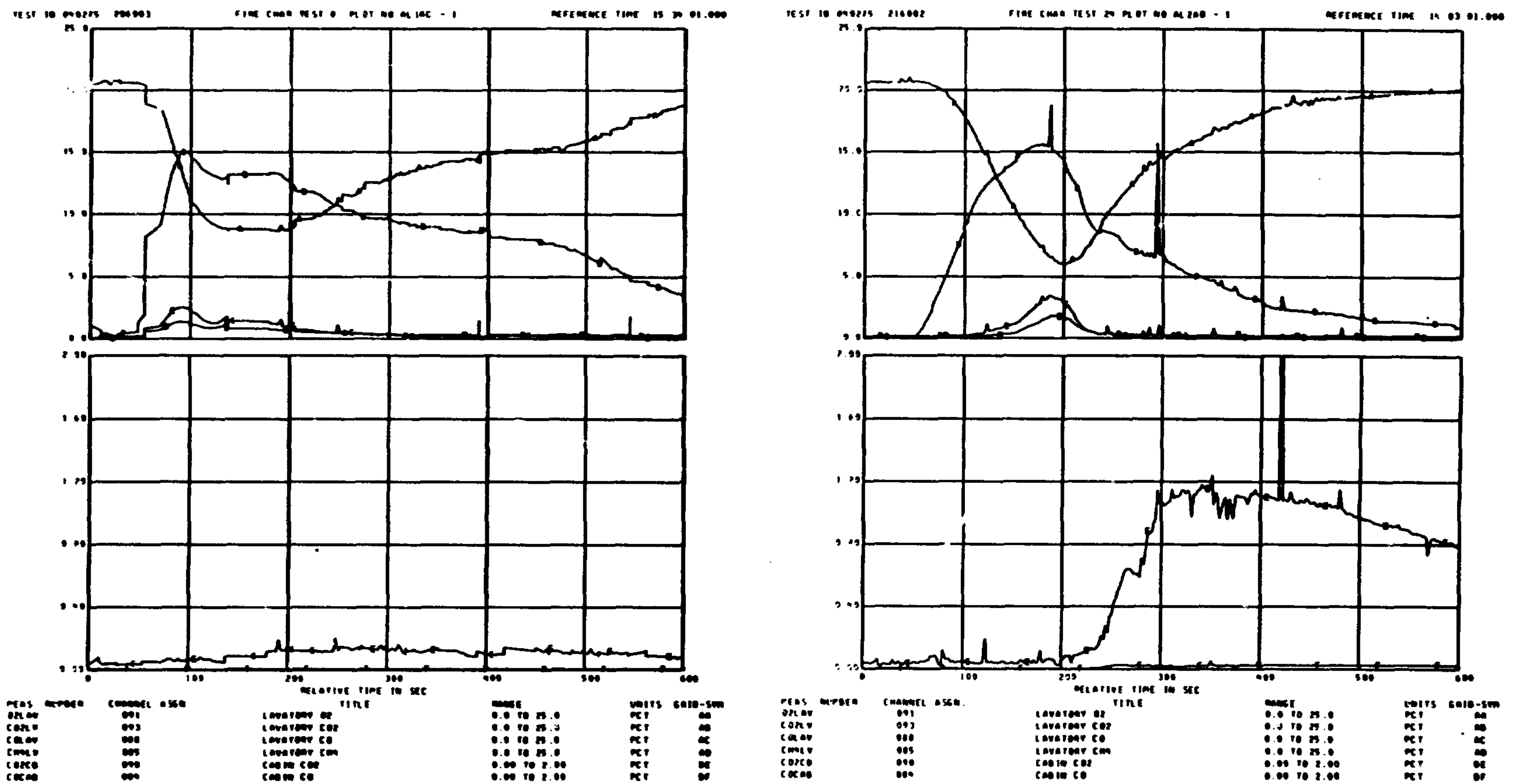


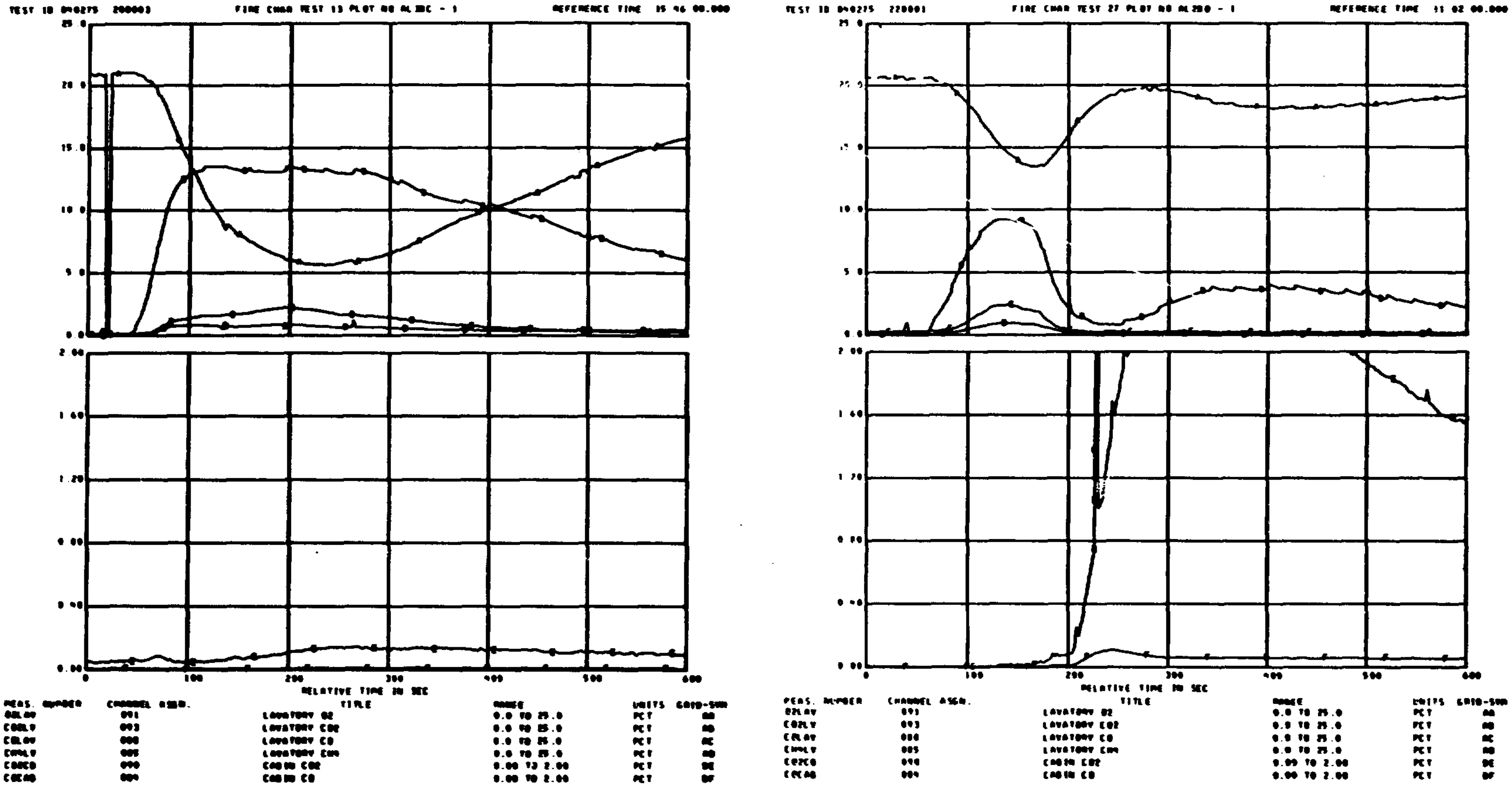
FIGURE 21. AA $\vec{x}$ AO AVERAGED HEAT FLUX



CLOSED DOOR

DOOR OPENED AT 150 SECONDS

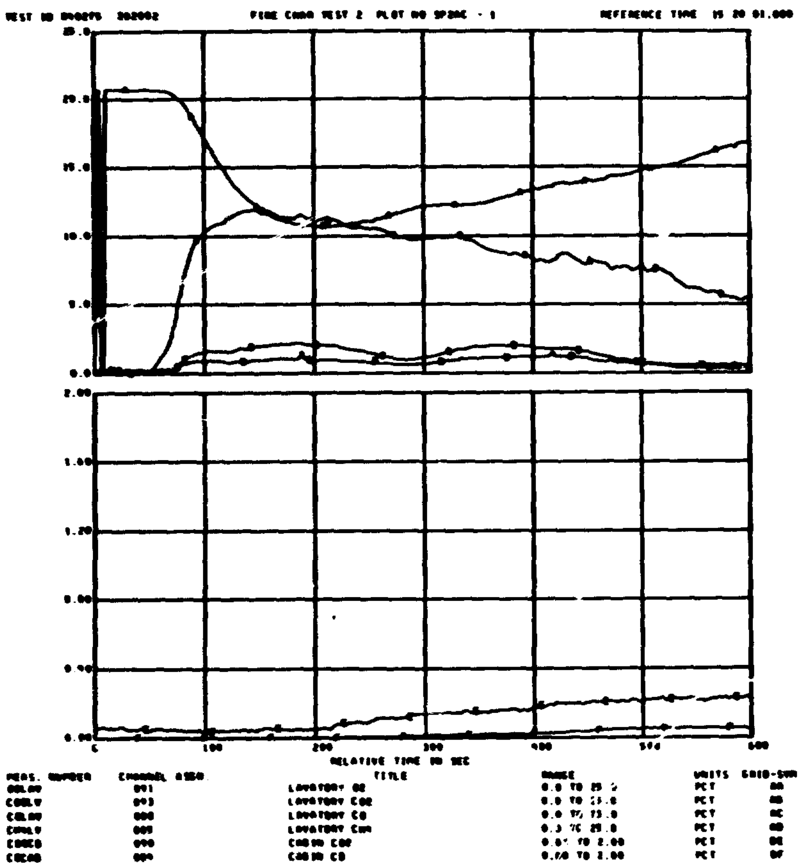
FIGURE 22. LAVATORY EXHAUST AND CABIN AIR GAS ANALYSIS AL ( ) AC AND AO



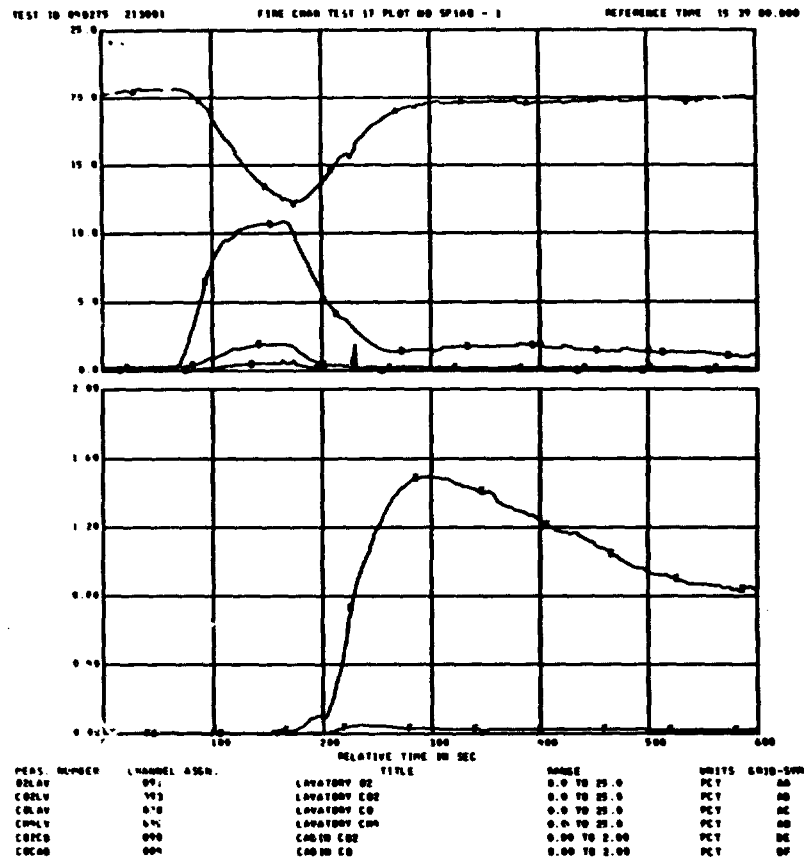
CLOSED DOOR

DOOR OPENED AT 150 SECONDS

FIGURE 23. LAVATORY EXHAUST AND CABIN AIR GAS ANALYSIS AL ( ) BC AND BO

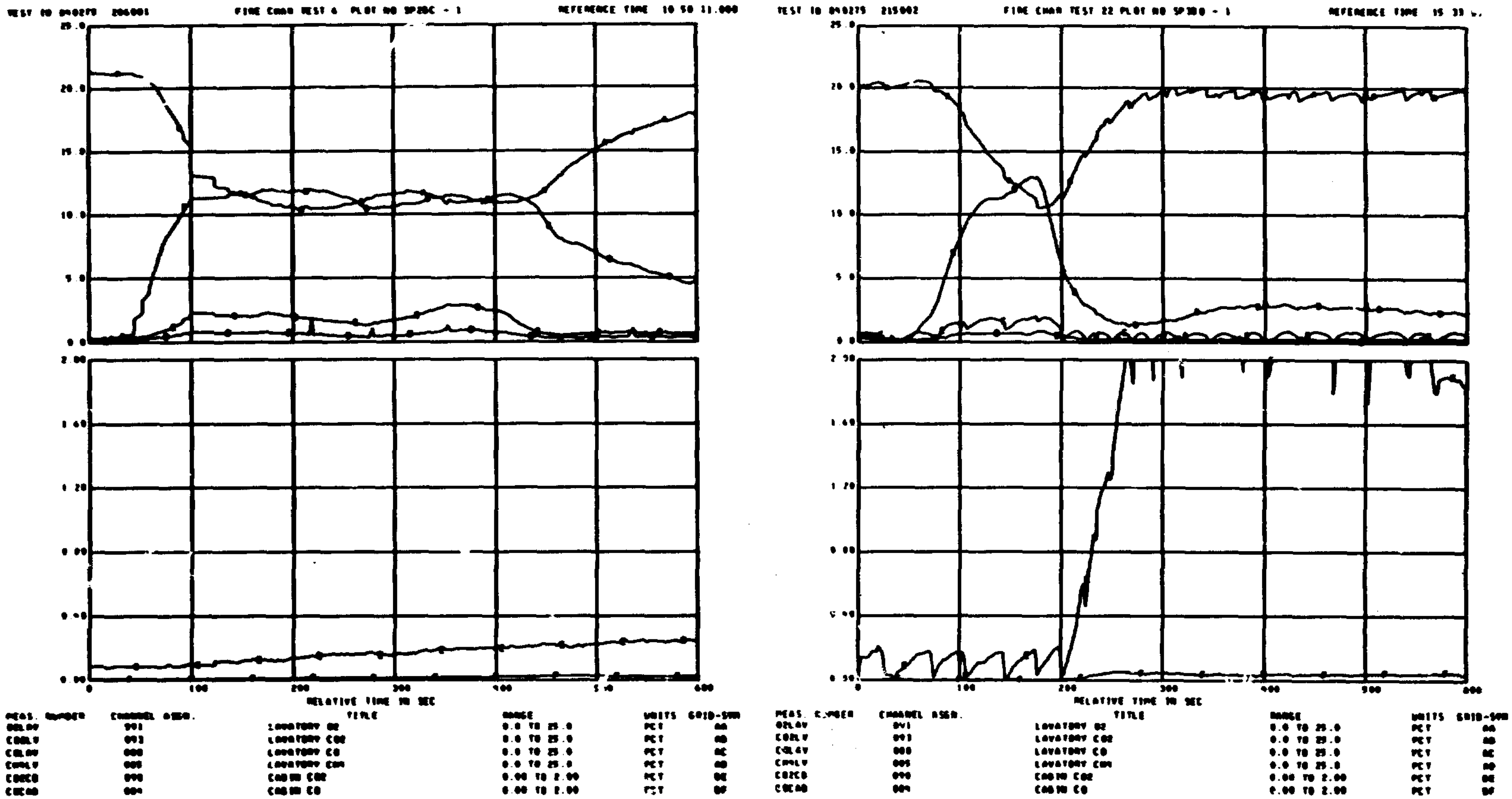


CLOSED DOOR



DOOR OPENED AT 150 SECONDS

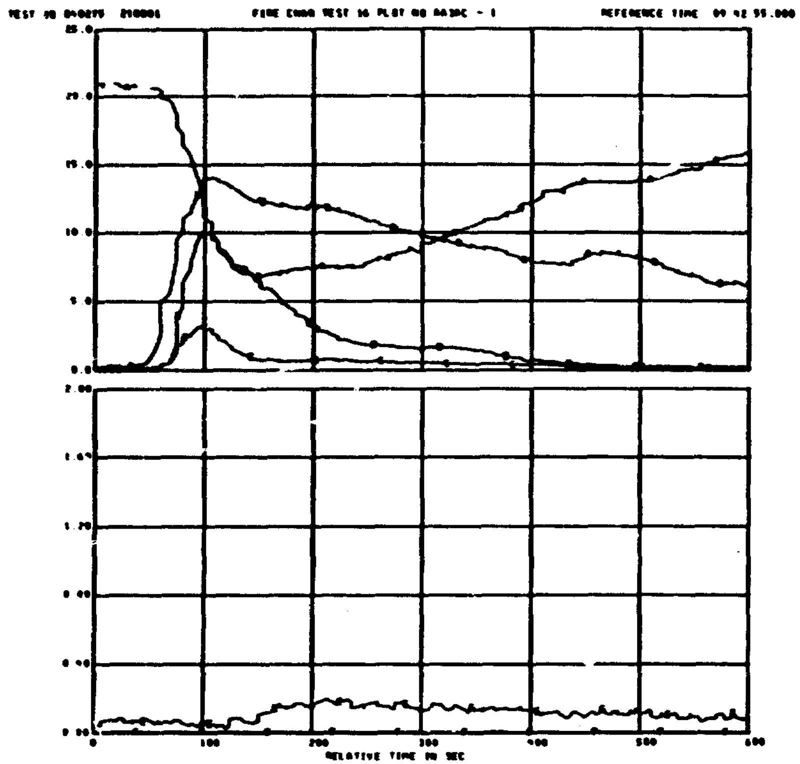
FIGURE 24. LAVATORY EXHAUST AND CABIN AIR GAS ANALYSIS SP ( ) AC AND AO



CLOSED DOOR

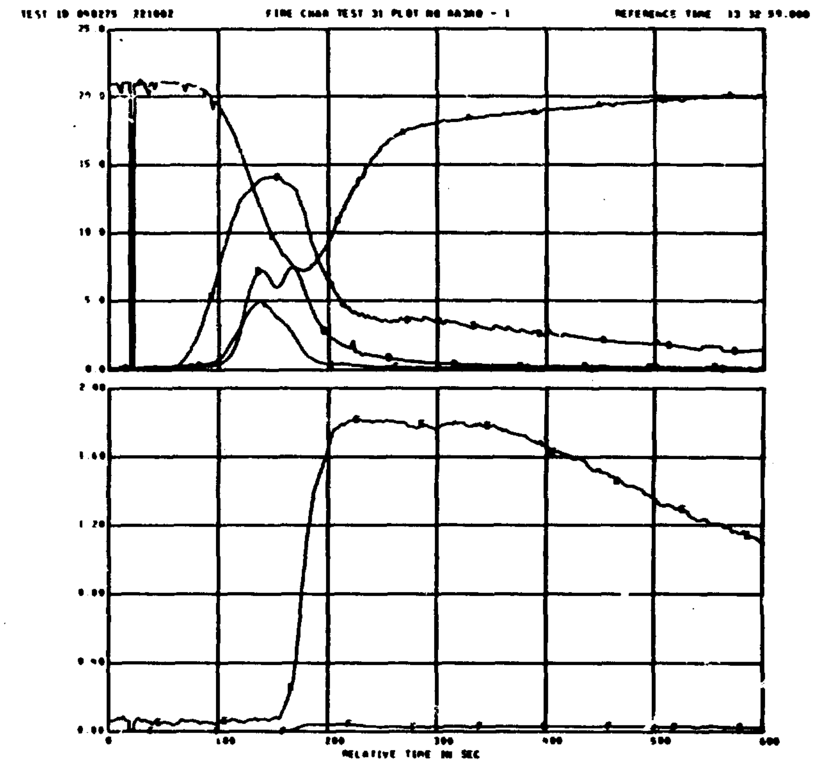
DOOR OPENED AT 150 SECONDS

FIGURE 25. LAVATORY EXHAUST AND CABIN AIR GAS ANALYSIS SP ( ) BC AND BO



MEAS. NUMBER	CHANNEL ASGN.	TITLE	RANGE	UNITS	GRID-SYM
O2LAV	091	LAVATORY O2	0.0 TO 25.0	PCT	AA
CO2LV	093	LAVATORY CO2	0.0 TO 25.0	PCT	AB
COLAV	088	LAVATORY CO	0.0 TO 25.0	PCT	AC
CH4LV	085	LAVATORY CH4	0.0 TO 25.0	PCT	AD
CO2CB	090	CABIN CO2	0.00 TO 2.00	PCT	AE
COCAB	084	CABIN CO	0.00 TO 2.00	PCT	AF

CLOSED DOOR



MEAS. NUMBER	CHANNEL ASGN.	TITLE	RANGE	UNITS	GRID-SYM
O2LAV	091	LAVATORY O2	0.0 TO 25.0	PCT	AA
CO2LV	093	LAVATORY CO2	0.0 TO 25.0	PCT	AB
COLAV	088	LAVATORY CO	0.0 TO 25.0	PCT	AC
CH4LV	085	LAVATORY CH4	0.0 TO 25.0	PCT	AD
CO2CB	090	CABIN CO2	0.00 TO 2.00	PCT	AE
COCAB	084	CABIN CO	0.00 TO 2.00	PCT	AF

DOOR OPENED AT 100 SECONDS

FIGURE 26. LAVATORY EXHAUST AND CABIN AIR GAS ANALYSIS AA ( ) AC AND AO

shows the percent content of the lavatory exhaust for O_2, CO_2, CO, and equivalent CH_4. The lower plot represents the percent content of CO_2 and CO in the cabin air at the location of the animal subject's cage. The results of the analysis of the bubbler samples are shown in Tables I through IV.

In the closed door tests the O_2 and CO_2 content of the lavatory exhaust reflects the degree and duration of combustion activity. With the exception of the Arson Attempt, they show a low content of CO and equivalent CH_4 which would indicate that a very efficient combustion process existed. In the Arson Attempt, the noticeable increase in CO content reaches its peak concentration at the same time as the hydrocarbons reflecting the fuel-rich combustion condition of this fire. The effect upon the cabin in the closed door series of tests was near zero for CO and only a minimal change can be noted in the amount of CO_2 present.

In the open door tests the effect upon the lavatory exhaust, when the door was opened, was a reversal of the indicated combustion products and the oxygen toward their ambient condition. This reversal was not always immediate. The time lag noted was representative of the time required for establishing new convective exhaust flow patterns into the cabin as evidenced by the rapid increase in cabin CO_2 and the very small response in CO content.

The results of analysis of the bubbler samples of the closed door series are shown in Tables I and II with those of the open door series in Tables III and IV.

These tables summarize the values found for HCL, HF, and HCN in air during the test. The continuous bubbler sampled 30 liters of air, while each separate bubbler sampled approximately 1 liter. Bubbler 1 sampled from 0 to 120 seconds, bubbler 2 from 120 to 240 seconds, and so on, up to bubbler 6, from 600 to 620 seconds. The bubbler results within the lavatory showed HF and HCN concentrations of less than or about 1 ppm, and HCL concentrations in the ppm range. In the cabin, no measurable amounts of HF, HCL, or HCN were reliably found. Infrequently, an anomolously high value of HF, HCL, or HCN would be found, but these values could be ignored, since they exhibited a larger amount of gas than the continuous bubbler, although the continuous bubbler must have sampled the air at the same time as the bubbler in question. The bubbler data were open to question in the calibration tests since the concentrations of the gases were so small.

TABLE I
CLOSED DOOR
LAVATORY CONTENT OF HF, HCL, AND HCN
(PARTS PER MILLION)

GAS	SAMPLE	TESTS				
		AL2AC	AL2BC	SP2AC	SP2BC	AA2AC
HF	CONT	4.08	<0.04	<0.02	<0.03	0.02
1	1	<0.73	<0.55	<0.25	<0.60	1.22
2	2	1.28	<0.68	<0.63	<0.69	3.74
3	3	1.25	<0.19	<0.37	<0.59	0.18
4	4	<0.69	<0.10	<0.30	<0.56	0.13
5	5	<0.69	<0.10	<0.64	<0.35	0.13
6	6	<0.38	<0.10	<0.35	<0.35	0.13
HCL	CONT	4.90	5.70	0	0	164
	1	90	49.0	0	0	201
	2	77	163.0	0	0	229
	3	76	150	0	0	93
	4	26	0	0	1.3	12
	5	327	0	390	0	458
	6	405	413	0	25	47
HCN	CONT	0.2	0.11	0.003	0	0.22
	1	1.0	0.6	0.60	0	
	2	1.0	0	1.80	0	
	3	0.8	0	0.90	0	Not Analyzed
	4	0.8	0	1.00	0	
	5	0.8	0	0.80	0	
	6	0.8	0	0.70	0.20	

TABLE II
CLOSED DOOR
CABIN AIR CONTENT OF HF, HCL, AND HF
(PARTS PER MILLION)

GAS	SAMPLE	TEST				
		AL2AC	AL2BC	SP2AC	SP2BC	AA2AC
HF	CONT	0.05	0.006	0.28	0.02	0.004
	1	0.40	0.16	0.42	0.65	0.21
	2	0.12	0.16	1.29	0.21	0.37
	3	0.63	0.16	0.67	0.20	0.13
	4	0.21	0.19	12.70	0.10	0.13
	5	0.12	0.1	1.80	0.10	0.13
	6	0.69	0.1	0.94	0.10	0.13
HCL	CONT	0	0	0	0	2.3
	1	0	0	0.95	0	0
	2	91	12	0	1.4	0
	3	125	0	60	141	0
	4	0	0	0	0	0
	5	0	113	0	0	0
	6	0	0	25	1.3	6.4
HCN	CONT	0.09	0.11	0	0.01	0.05
	1	0	0.60	0	0	
	2	0.8	0	0	0	
	3	0	0	0.4	0	Not Analyzed
	4	0.4	0	0.8	0	
	5	0	0	0	0	
	6	0	0	0	0	

TABLE III
OPENED DOOR
LAVATORY CONTENT OF HF, HCL, AND HCN
(PARTS PER MILLION)

GAS	SAMPLE	TEST									
		AL ( ) AO		AL ( ) BO		SP ( ) AO		SP ( ) BO		AA ( ) AO	
		(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
HF	CONT	0.004	0.004	0.004	0.004	0.18	0.004	0.007	0.004	0.004	0.004
	1	0.12	0.12	0.13	0.12	0.37	0.37	0.13	0.12	0.13	0.12
	2	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.12	0.12	0.12
	3	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.12	0.12	0.12
	4	0.12	0.12	0.11	0.13	0.12	0.13	0.12	0.12	0.12	0.12
	5	6.69	0.12	0.13	0.12	0.12	0.13	12.4	0.12	0.12	0.12
	6	0.12	0.12	0.12	0.12	0.12	0.13	0.23	0.13	0.12	0.13
HCL	CONT	0	0	0	0	12.0	0	0	0	0	1.08
	1	0	0	0	0	80.0	0	0	0	346	98
	2	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	57	0	0	0	0	403
	4	0	0	0	0	106	0	0	0	0	0
	5	12.0	0	0	0	339	0	0	0	0	37
	6	0	0	0	0	0	0	0	0	122	74
HCN	CONT	0.28	0.38	0.24	0.22	0	0	0	0	0.21	0.23
	1										
	2										
	3	Not Analyzed		Not Analyzed		Not Analyzed		Not Analyzed		Not Analyzed	
	4										
	5										
	6										

TABLE IV
OPENED DOOR
CABIN AIR CONTENT OF HF, HCL, AND HF
(PARTS PER MILLION)

GAS	SAMPLE	TEST									
		AL ( ) AO		AL ( ) BO		SP ( ) AO		SP ( ) BO		AA ( ) AO	
		(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
HF	CONT	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	1	0.12	0.12	0.13	0.12	0.12	0.12	0.13	0.12	0.13	0.12
	2	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.12	0.13	0.12
	3	0.12	0.12	0.12	0.12	0.12	3.74	0.13	0.12	0.12	0.12
	4	0.12	0.12	0.11	0.13	0.12	0.13	0.12	0.12	0.12	0.12
	5	0.12	0.12	0.13	0.12	0.12	0.13	0.12	0.12	0.12	0.12
	6	0.12	0.12	0.12	0.12	0.12	5.56	0.12	0.13	0.12	0.13
HCL	CONT	0	0	0	0	6.4	0	0	0	0	0
	1	0	0	0	0	24	0	0	0	370	0
	2	12.0	0	0	0	0	0	0	0	0	0
	3	12.0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	78
	5	0	0	0	0	0	0	0	0	0	0
	6	61	0	0	0	250	0	0	0	0	99
HCN	CONT	0.12	0.10	0.33	0.35	0.12	0	0	0.18	0.10	0.14
	1										
	2										
	3	Not Analyzed		Not Analyzed		Not Analyzed		Not Analyzed		Not Analyzed	
	4										
	5										
	6										

Smoke Density and Cabin Pressure

Recorded smoke density in the closed door tests were minimal. Visual observations made from the CFS air lock noted some increased obscuration with the airline trash as well as a more objectionable residual odor. In the open door series the following differences were noted and are illustrated in Figures 27 and 28.

Shredded paper produced only minimal obscuration with regard to the quantities produced by the other sources.

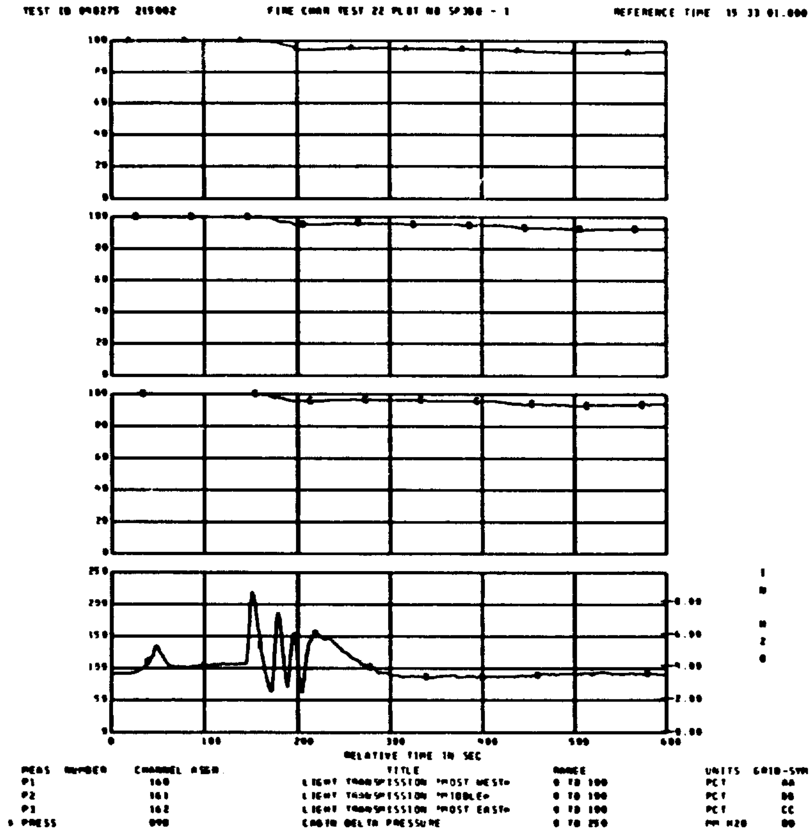
In the tests of the large quantities of airline trash, a uniform layer of smoke approximately 46 cm (18 inches) thick rapidly progressed toward the air lock at the ceiling level. Upon reaching the air lock it cascaded down over the viewing port obscuring all visibility. In a short time of 20 to 40 seconds, this layer was displaced approximately the same distance uniformly down with clear visibility above this layer. The smoke was then mixed by the ventilation system and visibility again obscured.

In all tests the photometers indicated the first increase in smoke density at the instrument farthest from the lavatory confirming the visual observations and the substantial convective effect of the hot air from the fire within the cabin.

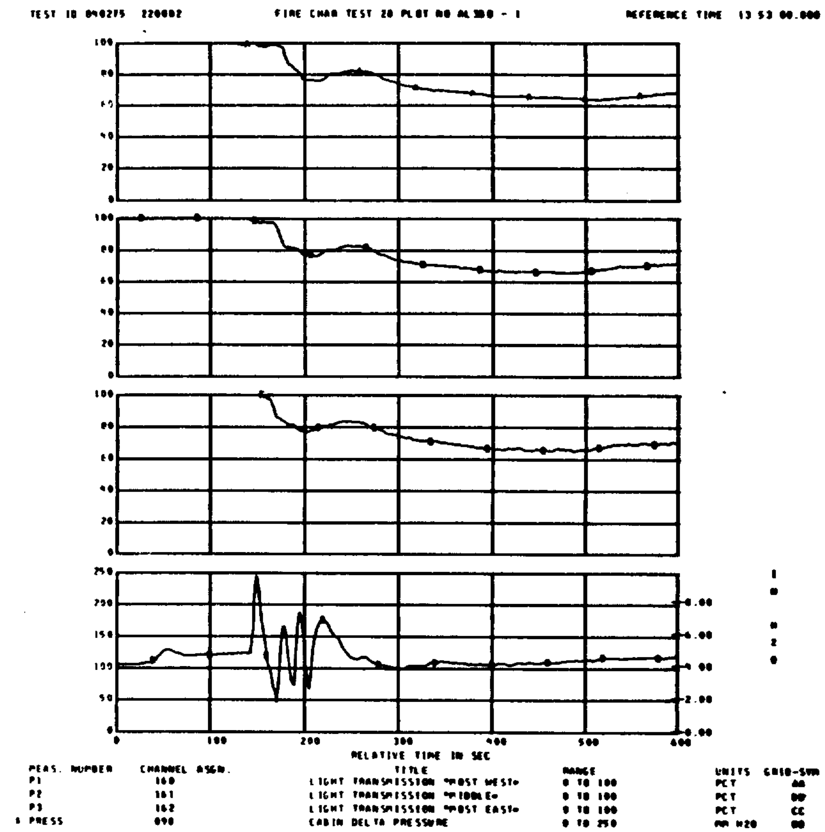
The effect of the exposure of the cabin to this relatively small volume of heated air is shown by the increase in cabin pressure with an almost immediate rise to over double the initial condition. The oscillations following this rise are the result of manual control of the ventilation system and not the result of a thermal effect.

Biological Effects

All subjects survived all the tests. There was evidence in nearly all test recordings of reduced amplitude in respiration, particularly when irritant gas species were present. Where there were only minimal irritants and more asphyxiants present, respiration was increased in amplitude. Irritants were present in greater quantities when the ignition source was composed of airlines trash, than when shredded paper was used. Generally, less effects were noted on the subjects in the Arson Attempt when lighter fluid was used than in the case of airline trash.



SHREDDED PAPER
MAXIMUM QUANTITY



AIRLINE TRASH
MAXIMUM QUANTITY

FIGURE 27. AIRLINE TRASH AND SHREDDED PAPER SMOKE DENSITY

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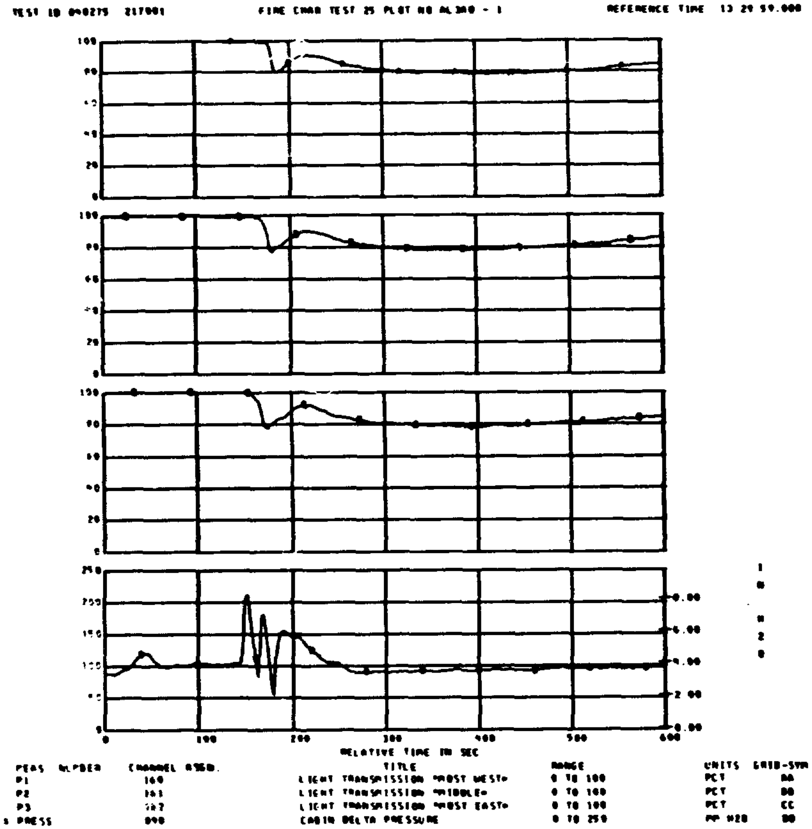
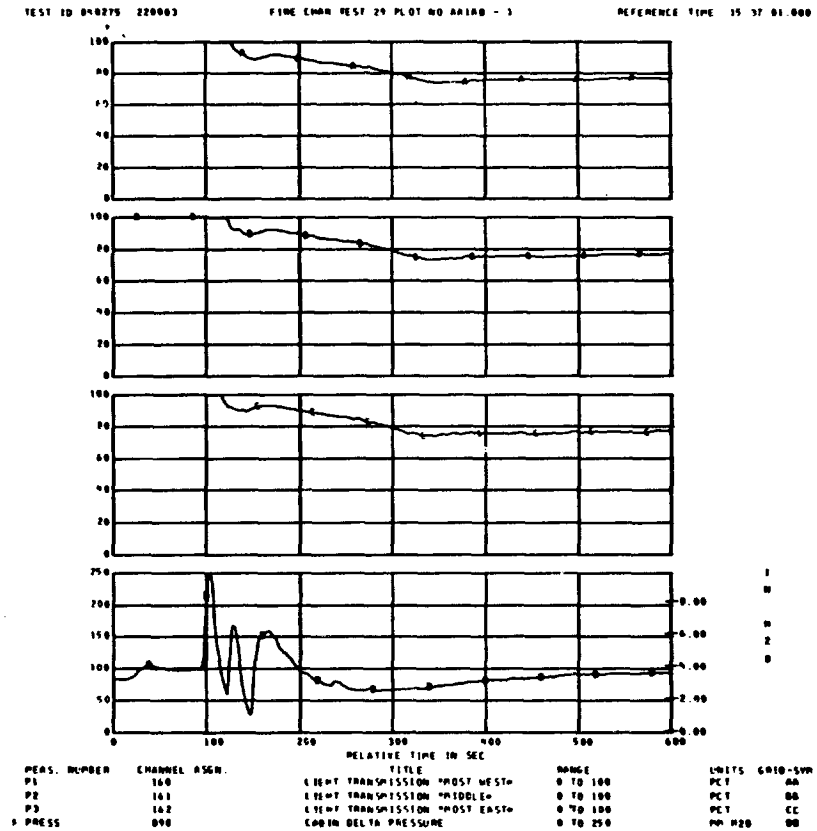


AIRLINE TRASH
MINIMUM QUANTITY



ARSON ATTEMPT
MINIMUM QUANTITY

FIGURE 28. AIRLINE TRASH AND ARSON ATTEMPT SMOKE DENSITY

Cardiac arrhythmias were noted in only three tests – AL2BC, SP2BO, and AA1AO. All the ignition source tests were 30 minutes in duration, and the subject was in the CFS for 10 to 20 minutes after the end of each test before retrieval. In all cases of arrhythmia, the normal cardiac rhythm returned within a few minutes after the subject was exposed to normal air outside the cabin, and two of the three returned to normal while still inside the CFS.

Correlation With Gas Analysis Data

There appeared to be little or no definite correlation between the development of cardiac arrhythmia and the type of fire source used, since only one arrhythmia was seen to be associated with each of the fire source materials. Carbon dioxide and HCl were the only two gases which appeared to reach any levels of significance, but these were of such short duration as to produce no lasting cardiac arrhythmia. This accounts for the disappearance of the arrhythmia before the termination of the tests in which they did appear.

BASELINE TEST

Upon completion of the source fire series the largest airline trash fuel load was selected for use at a meeting attended by representatives of industry, NASA JSC, AMES AND JPL. The selection of this source was based upon its maximum fire threat and composition of combustible materials that might be found in common usage. The test lavatory and all panels directly adjacent were fabricated from contemporary materials used in current aircraft and conformed to the latest requirements of FAR 25. All of the panels used in this test were of typical honeycomb construction. The specific materials used in the lavatory were:

a. A decorative laminate was applied on both panel structural surfaces with a thermal plastic adhesive. The laminate is approximately 0.15 mm (0.006 inch) thick with outer layers of clear polyvinyl fluoride over a rigid vinyl core.

b. The structural faces of the panel consist of a two-ply laminate on each face. Each ply is a "C" stage phenolic impregnated glass cloth (181) with a "B" stage epoxy adhesive.

c. The honeycomb core 6.35-mm (0.25-inch) cell, 32.04 kg/cu m (2.0 lb/cu ft) density was of aromatic polyamide paper impregnated with phenolic-resin type.

d. Edge closeout was accomplished using a rigid polyurethane foam with a density of 400.46 kg/cu m (25.0 lb/cu ft).

Cabin environment, instrumentation, and data recording were identical with the closed-door tests, in which an animal subject was exposed and bubbler samples of the cabin and lavatory exhaust were taken. The interior of the CFS prior to the test is shown in Figure 29. The only difference in test procedure was that the test data were recorded for a period of 1 hour at which time gaseous nitrogen was introduced into the lavatory to preserve any residual fuel from further smoldering decomposition and ventilation was terminated.

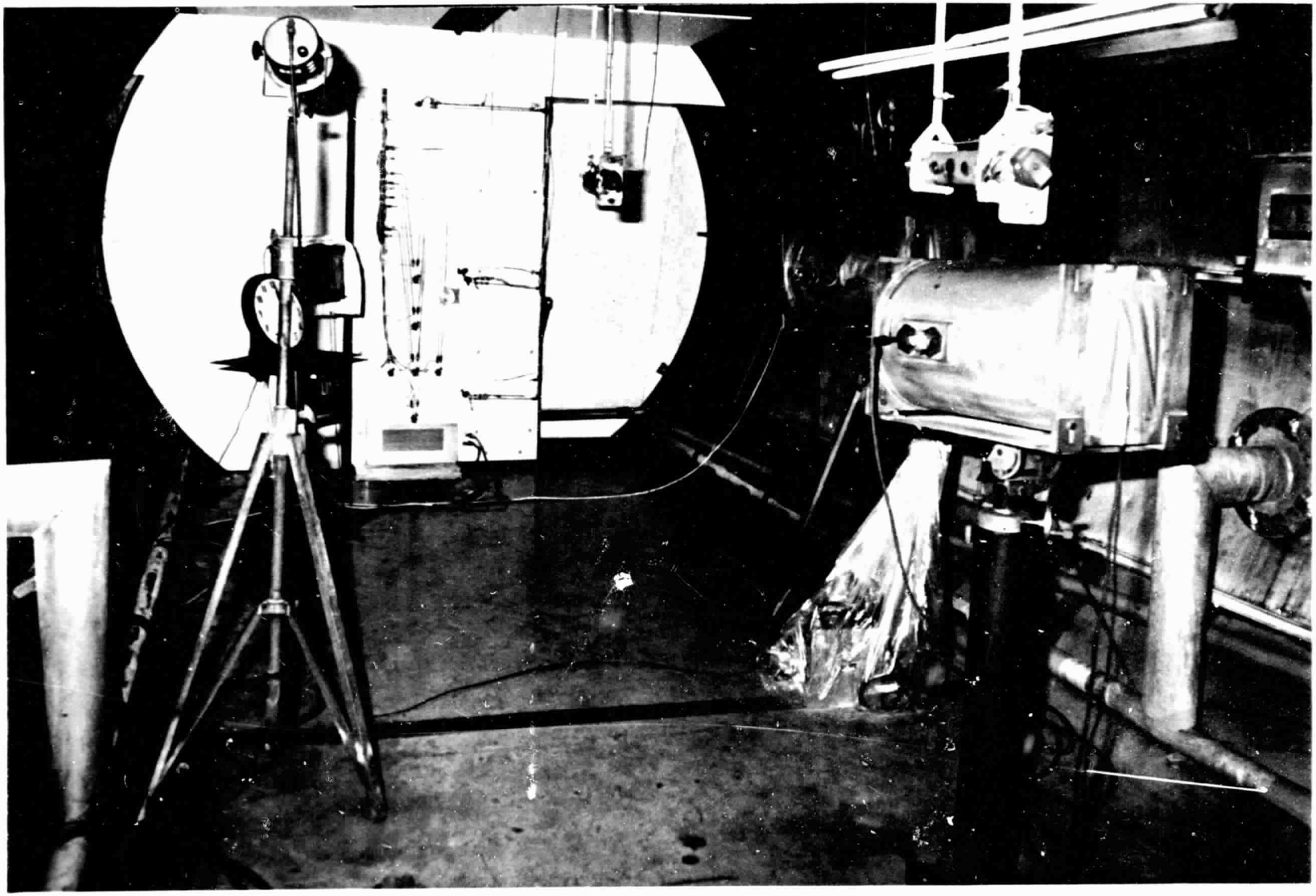


FIGURE 29. BASELINE BEFORE TEST

BASELINE AND SOURCE FUEL HEAT FLUX COMPARISON

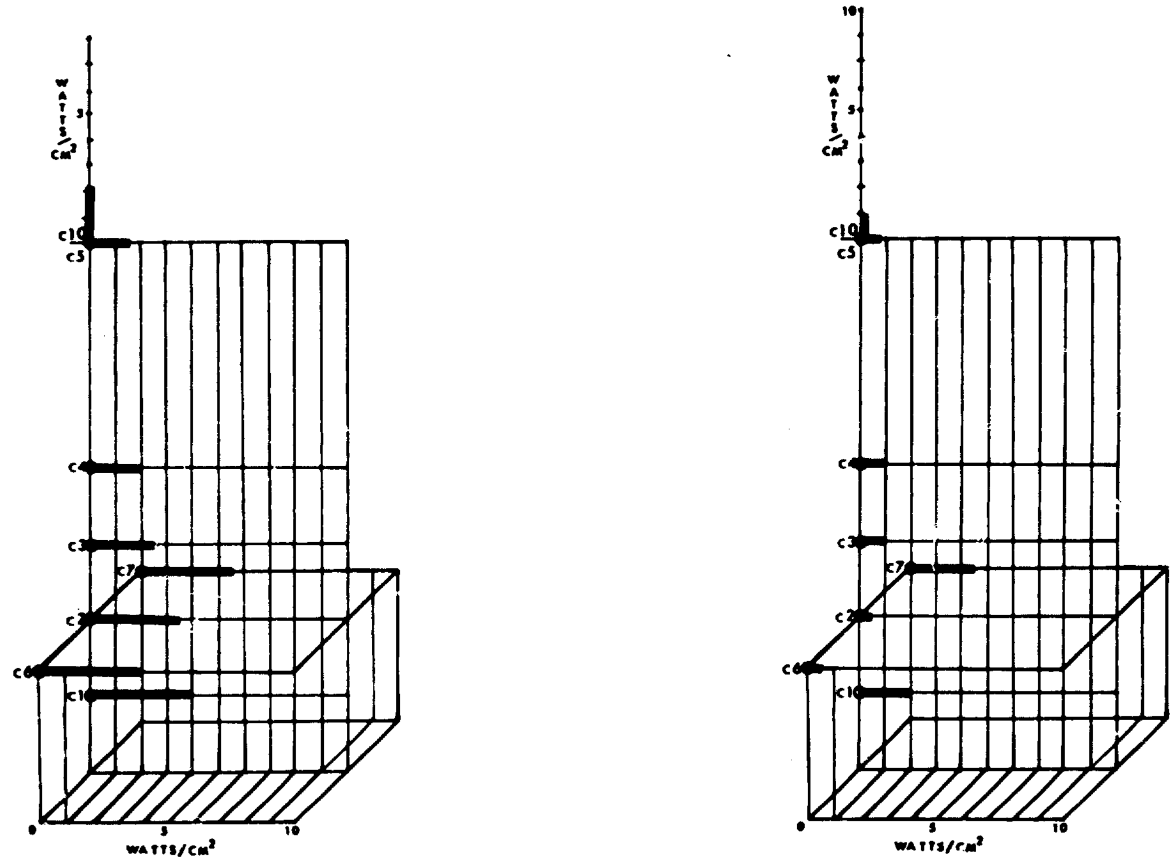
Figures 30, 31, and 32 show the average heat flux time history of the fire in comparison with that of the source fuel only. While ignition occurred normally, the fire developed at a slower rate than the source fuel in the first 100 seconds. This may have been the result of an inhibiting action of the halogens produced by the decompoisition of the interior decorative laminate. This was also the case in the period from 100 to 200 seconds except for C1 and C7. It is interesting to note that these are the periods when the maximum halogens were detected in the lavatory exhaust. On the exterior of the module the first decomposition of the decorative laminate occurred at 190 seconds on the lower right-hand portion of the door. The period between 200 and 300 seconds proved to be the most active in the test. This maximum activity relative to the source test was concentrated at C7 and C8. The peak reading of C7 reached 31.92 w/sq cm (28.11 Btu/sq ft/sec) at 254 seconds. The first exterior flame occurred at C8 and the lower door jamb. Activity in this area increased until 300 seconds when the period of maximum visible external involvement was reached. At this time the door jamb was involved with flickering gaseous flames over the lower half of the door. The post-test damage noted on the door was clearly produced during this period.

A second period of activity occurred between 1400 and 1900 seconds which was concentrated in the same general area and with intensities of roughly one-fourth to one-half of those experienced in the initial period. The decomposition in the area of the wash stand which formed a plenum chamber for the exhaust probably occurred during this period.

BASELINE PRODUCTS OF COMBUSTION

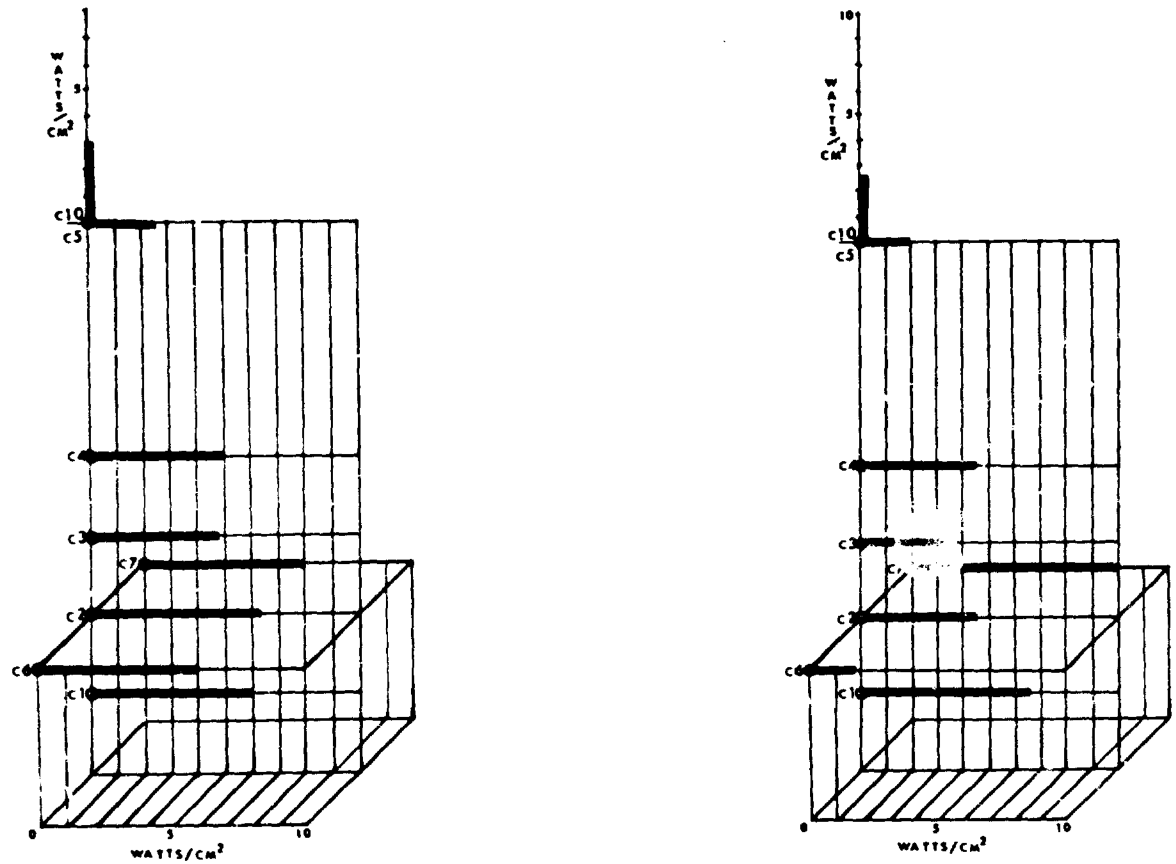
The real-time products of combustion of both the baseline and its source fuel are shown in Figure 33.

In comparison with the source fire series, the baseline products of combustion show an inhibited burning in the initial 100 seconds of the fire and are consistent with the thermal results. The consumption of oxygen and the production of carbon dioxide reached approximately the same levels as the source fire tests. In the baseline test these levels were continued, however, for a longer period of time. The major difference is in the amounts of CO and CH_4 produced



ALBC **BASELINE**

FIGURE 30. 0-100 SECONDS AVERAGED HEAT FLUX



ALBC

BASELINE

FIGURE 31. 100-200 SECONDS AVERAGED HEAT FLUX

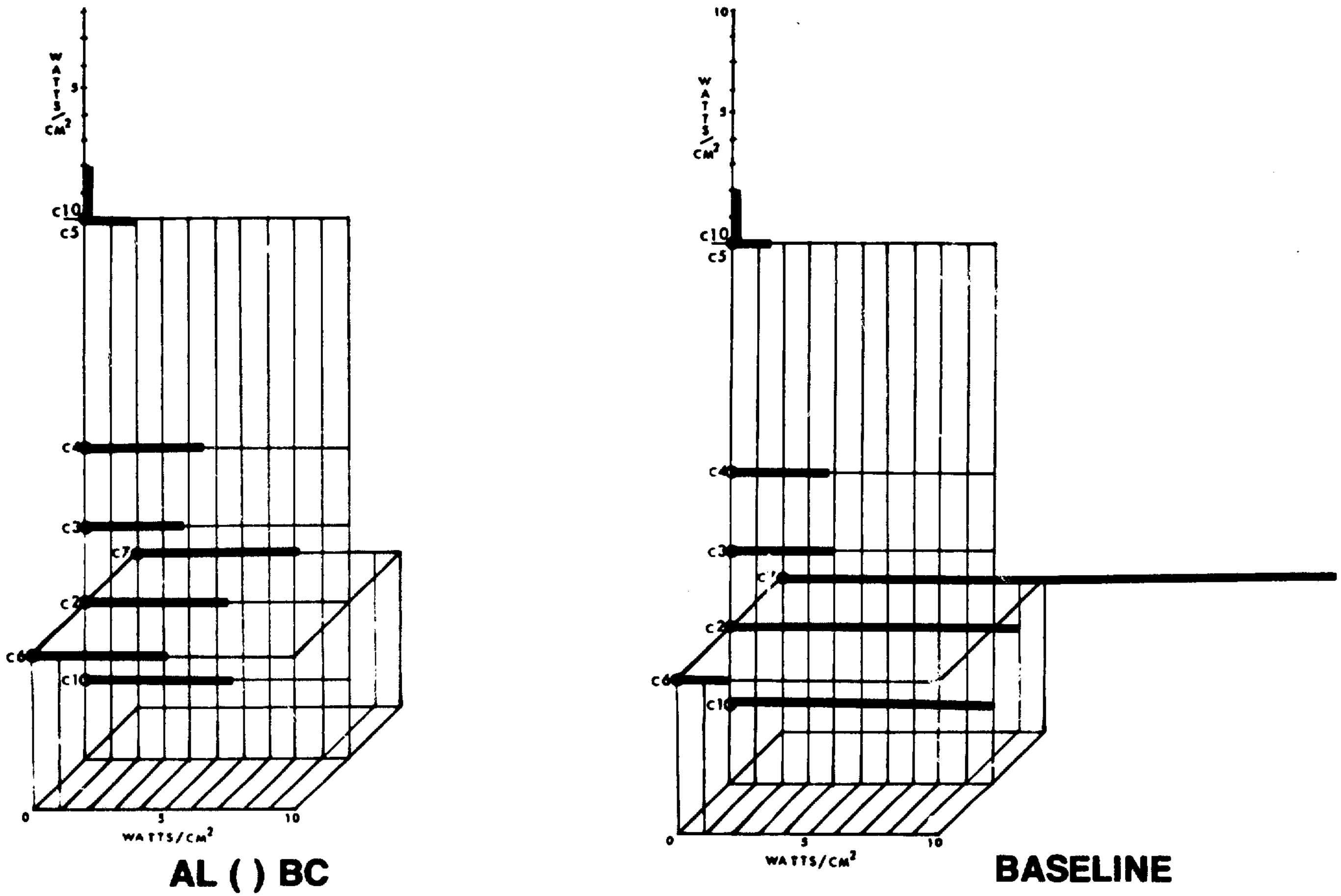
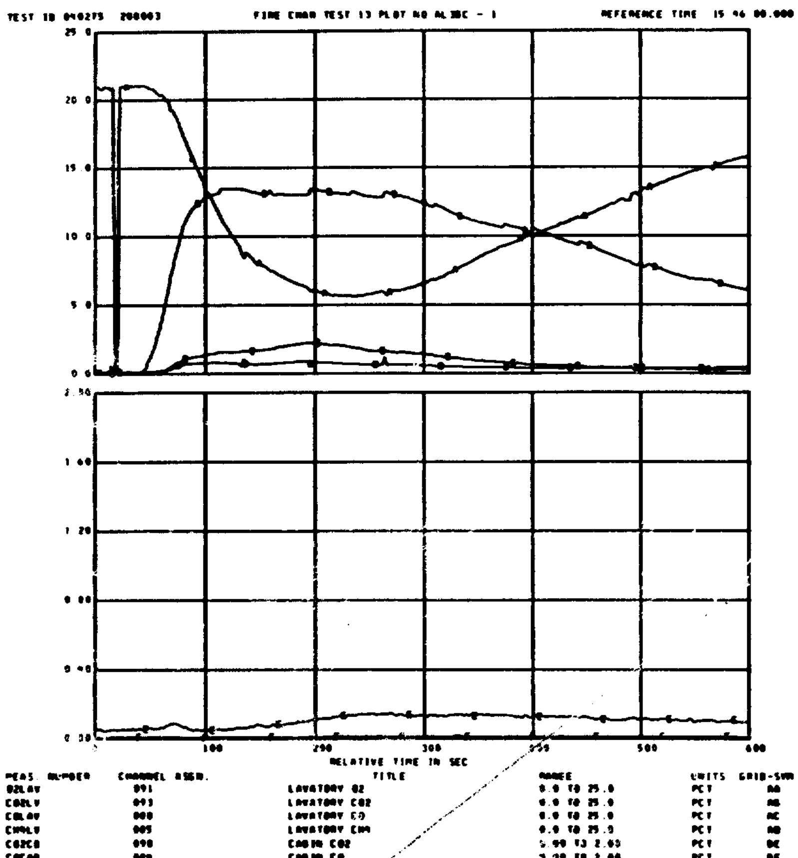
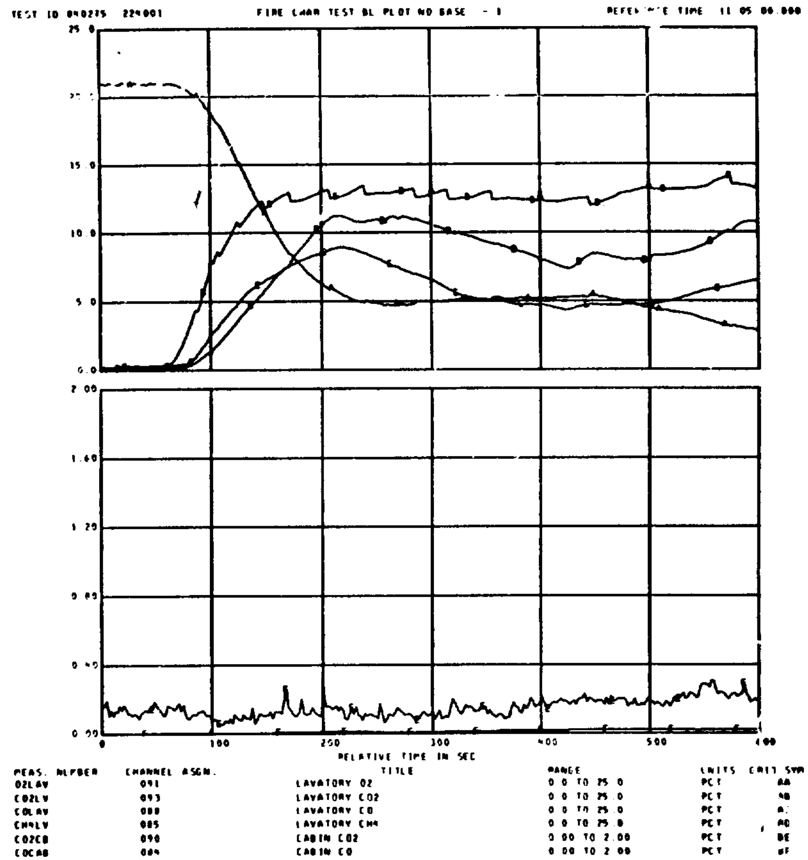


FIGURE 32. 200-300 SECONDS AVERAGED HEAT FLUX



AL ( ) BC



BASELINE

FIGURE 33. COMPARISON OF SOURCE FUEL AND BASELINE PRODUCT OF COMBUSTION

which are believed indicative of module involvement and the increase of available fuel. Separation of the lavatory exhaust at its attachment to the lavatory by panel decomposition occurred at some period during the test. We believe that this occurred between 2100 and 2500 seconds at which time all of the thermal indications were decaying at a constant rate.

The results of analysis of the bubbler system are shown in Table V.

TABLE V

BUBBLER ANALYSIS OF BASELINE TEST
(PARTS PER MILLION)

	HF		HCL		HCN	
PERIOD CONTINUOUS	LAVATORY 4890	CABIN 5.0	LAVATORY 7757	CABIN 27	LAVATORY 112	CABIN 1.9
0-120	803	8.0	121	121	11	0
120-240	22	5.0	577	118	106	0
240-360	17	4.0	0	245	154	0
360-480	8	1.0	198	186	76	0
480-600	22	3.0	380	159	87	0
600-720	11	2.0	501	56	105	0

The results indicate the effect of the contribution of lavatory materials in the lavatory exhaust data. The module, however, effectively contained these gases as evidenced by the minimal results upon the cabin environment. The data indicate that while HCL was present in irritant quantities, the content of HF reached only a maximum of 8 ppm and HCN was only present, if in all, in quantities too small to measure.

BASELINE SMOKE DENSITY

The smoke density and cabin pressure for the first 1200 seconds of this test are shown in Figure 34.

The reduction in light intensity followed the time and intensity of the fire both in and on the module. As in the source fire series the intensity was reduced first at the photometer farthest from the source. Minimum transmission reached 45 percent at 400 seconds at photometer No. 3. At this time both of the other photometers were reading approximately 85 percent. These equalized at 600 seconds at approximately 80 percent. In the later stages of the

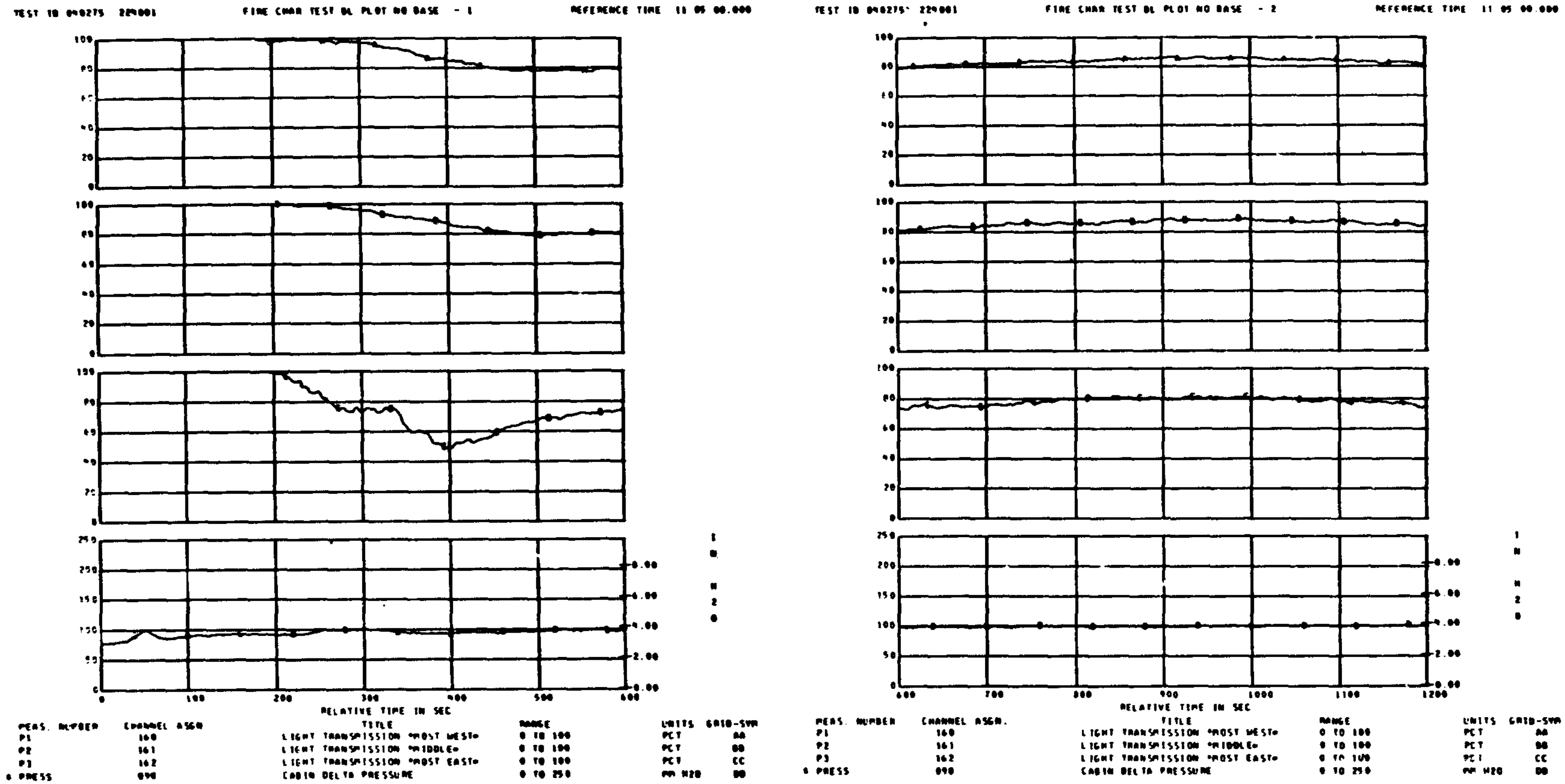


FIGURE 34. BASELINE SMOKE DENSITY

the fire beginning at 1100 seconds, these readings decreased to a low of 40 percent between 2100 and 2200 seconds and are believed representative of the second stage of the fire in the wash stand area.

SUMMARY OF BASELINE TEST RESULTS

The appearance of the lavatory after the fire and the remaining residual fuel are shown in Figure 35 and illustrate the resistance afforded by contemporary constructions to this severe threat.

The animal subject was retrieved 8 minutes after test termination and the chamber again closed for a period of approximately 90 minutes. The only adverse effect noted on the subject was the deposit of soot on his fur. The chamber was then ventilated for a period of 30 minutes to ensure the removal of the nitrogen. The chamber was then entered and the following observations on the conditions found are:

a. A strong odor of phenolic resin was evident.

b. The module was intact with the decorative laminate in the area of the door and that covering the area of the wash stand thermally shrunken but not decomposed.

c. The only evidence of adjacent damage was locally confined to the lower area of the aft bulkhead where splitting and shrinking of the decorative laminate was noted with some decomposition of the polyurethane edge blocking at this point.

d. In gaining entry into the module it was necessary to use a pen knife to sever the fused polyurethane edge blocking at the door jamb.

e. Residual source fuel weighing 0.52 kg (1.14 pounds) was found inside.

f. Upon disassembly discoloration of the adjacent module panel was found without significant effect on its inner surface. The weight loss on the lavatory module was found to be 11.22 kg (24.73 pounds) representing an average weight loss of 23.58 percent.

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RESIDUAL FUEL REMAINING

EXTERIOR OF LAVATARY

FIGURE 35. BASELINE FIRE EFFECTS

Post-test analysis of the animal data indicates the subject had not experienced any cardiac arrhythmias and that suppression of respiration detected was consistent with the quantities of irritant gases present.

NEW TECHNOLOGY

No inventions or new technologies were developed during this program.

CONCLUSIONS

In regard to the hazard of a fire contained within a noncombustible module with a limited air supply, the following conclusions are:

a. The existing thermal hazard is proportionate to the fuel quantity up to a point where the air fuel mixture becomes fuel-rich. After this point is reached, additional quantities of fuel will simply prolong the fire at some maximum level. This level is determined by the fuel composition and distribution with regard to the available air.

b. The distribution of the fuel within the compartment relative to the airflow is of major importance (i.e., if the fuel configuration, as with the bags of airline trash, channels the airflow). This will result in a more intense fire at local points. This is in contrast to the case of the shredded paper source where a more uniform airflow through the fuel mass is provided, resulting in a uniform heat release of the available fuel.

With regard to the hazard resulting from opening the door of a module containing a developed fire:

a. The fires studied in the open door series produced no unsurvivable conditions within the cabin; it is doubtful if a cabin attendant without thermal protection could have approached close enough to have been effective in any fire fighting activity.

b. With the larger quantities of fuel contained in the module, the opening of the door also presents a serious threat to the overhead ceiling panels.

c. Upon opening the door with the airline trash fuel source, the cabin would be subjected to more smoke at a much earlier time than if the door had remained closed.

Results of the baseline test indicate that:

a. A survivable environment for the rat subject existed within the cabin for the full time of the test.

b. While survivable, the cabin would have been very unpleasant to occupy due to smoke density and irritant gases.

c. Combustion products in toxic quantities were confined to the lavatory module. The low levels of toxic combustion products present in the cabin were to some degree the result of dilution and removal by the cabin ventilation system. Had the test simulated an unventilated post-crash fire any gases generated within the cabin would continue to increase in concentration. However the amount generated would be reduced by the lower intensity of the unventilated module fire.

d. The fire did not propagate in adjacent structures.

e. With the exception of the polyurethane rigid foam, which is used uniformly throughout the industry for edge closeouts in panel construction, the contemporary materials resisted combustion remarkably well.

f. The polyurethane blocking is believed to have been the material that provided the additional fuel resulting in the substantial increase of thermal activity of the baseline fire. This material decomposes at a relatively low temperature and its concentration, at the edges of the door and door jamb where the fuel released by this material was in a position to utilize the air being drawn through the cracks at the door edge, resulted in a severe localized fire.

g. The decorative laminate, composed of vinyl and tedlar covering the module, presents little exterior hazard as this material splits and shrinks when exposed to heat rather than burning. This is also evidenced by the low quantities of HF existing within the cabin during the test.

RECOMMENDATIONS

The hazard of opening the module door of a fully developed fire has been established. Therefore, a method of combating a module fire should be developed which might include either a fixed installation within the module or a bayonet device that could be inserted into the module without the necessity of opening the door.

A material of superior fire resistance to the currently used polyurethane rigid foam edge closeout material is required. Replacement of this product by one of improved fire resistance would substantially improve the fire resistance of contemporary composite panels.

Comparative tests should be conducted of improved materials under the same conditions as in the baseline test exposure, to evaluate the degree of improvement afforded by the new concepts.

REFERENCES

1. Gaume J. G., Animal Exposure During Burn Tests, Final Contract Report, NASA CR 137802, January 1976.

2. Gaume J. G. Bioassay Technologies, Douglas Report MDC J7453, January 1977.