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NATIONAL BUREAU OF STANDARDS REPORT

4169

EXAMINATION OF THE GASEOUS COMBUSTION PRODUCTS
OF SEVERAL INTERIOR FINISHES

by

Alan Schriesheim



U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Floor, Roof and Wall Coverings Section
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for

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ABSTRACT

An examination was made of the gaseous combustion products of several interior finishes at three temperatures. The gases included many that were toxic. For each material, the amount of gases varied depending upon the combustion temperature.

1. INTRODUCTION

An investigation was carried out on the gaseous combustion products of several wall covering materials. It was anticipated that some of the gases might be toxic and, in particular, that those materials containing chlorine might give rise to hydrogen chloride and phosgene.

The principal gases arising from the combustion of organic materials in air are carbon monoxide and carbon dioxide. However, when elements other than carbon, hydrogen, and oxygen are present, there is a possibility that the combustion will produce several kinds of toxic gases. Thus, hydrogen chloride, ammonia, cyanogen, and sulfur compounds have been found with materials such as chlorinated hydrocarbons, wool, silk, and rubber, respectively (1-4).^{1/} Generally, the toxic hazard of these gases is small when compared to that of the carbon monoxide produced in the combustion.

In order to study the gases that were produced upon combustion of some interior finishes, an apparatus was designed and built in which the materials could be burned at various temperatures and in fixed amounts of air. Also, a series of chemical

^{1/} The numbers in parentheses indicate references at the end of this paper.

tests was devised whereby the gaseous combustion products could be analyzed and any toxic gases present determined.

2. MATERIALS

The materials used and the methods of preparing the specimens are described on pages 1 to 5 of N.B.S. Report 4120, "Evaluation of Flame Spread and Vapor Permeability Properties of Interior Finishes" (5). These materials were received in sheets approximately 1 ft. by 1 ft. and samples of appropriate area were cut from these sheets with a hacksaw.

This cutting was done by slicing off the outer phenolic bonded layer of the plywood. Then the required area was marked off on this outer layer so as to give several strips 1/4 in. wide that fitted into the combustion boats.

The paint films were made by applying the paint to gummed dextrin paper with a paint brush and the paint allowed to dry. Strips of appropriate area were cut from these sheets and placed in water so that the paint film floated free of the paper. This film was then dried and used.

Table 1 lists the materials along with the specimen numbers, which are identical with those in N.B.S. Report 4120. In addition to the materials listed in Report 4120, an additional surface finish, Saran, was included. This material is listed in Table 1 as Specimen 42.

3. METHODS

3.1 Combustion Method

3.1.1 Apparatus

The experimental method used in this study involved the building of an apparatus in which a given amount of sample could be burned in a known volume of air.

Figure ~~3~~² is a photograph of the entire apparatus which is shown schematically in figures 1 and 2.

2/ All Figures are grouped at the end of this report.

Table 1. Schedule of specimen assemblies for tests

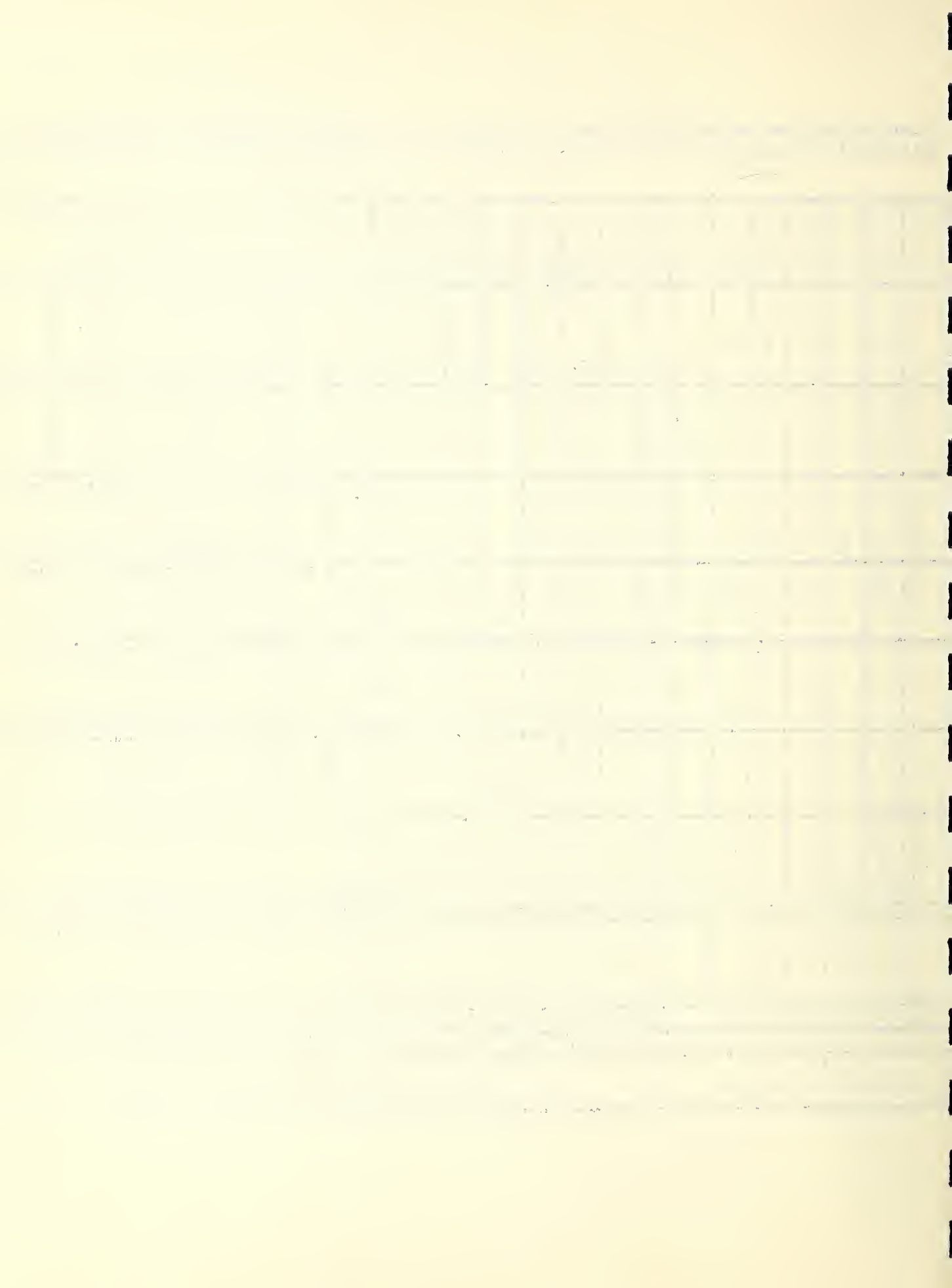
Under the specimen number the letters of the alphabet are placed on fire or high humidity, b the next material, etc. The average coverage of 2.1 through 2.20 for descriptions of materials.

Specimen No. Material	1	2	3	4	5	6	7*	8	9	10	11	12	13
SK (2 cts, 330 ft ² /gal ea) Albi 99 (1 ct 200 ft ² /gal) Dex Dex R			a	a	a	a	a	a	a	a		a	a
Dxpr Al Crlx No. 1 Crlx No. 2						b		b	c	b	a	b	b
Crlx No. 3 PVA Flkt (1 ct, 250 ft ² /gal) Flpr (1 ct, 250 ft ² /gal) Prlu (1 ct, 460 ft ² /gal) Prph (1 ct, 440 ft ² /gal) Al Life-F (1 ct, 650-700 ft ² /gal)													
Al Life-V (1 ct, 440 ft ² /gal) Al Life-P (1 ct, 35 ft ² /gal)													
SK (as SK above)					b		b	c		c		c	c
Kerl 7 (2 cts, 125 ft ² /gal ea) Kerl 8 (2 cts, 125 ft ² /gal ea) BdrF (2 cts, 125 ft ² /gal ea) Fban (1 ct, 32 ft ² /gal)													
Xply Har SK (as SK above)	a	a	b	b	c	c	c	d	d	d	b	d	d e
TESTS													
Flame spread	x	x	x	x	x	x	x	x	x	x	x	x	x
Vapor permeability	x	x	x	x	x	x							
Decomposition products	x	x	x	x	x				x				
Flammability													

*Tested with 24 hours air-dry curing; no accelerated curing.

line with the materials used; the letter a being the material exposed to material is given in parentheses after the name abbreviation. See Sections

14	15	16	17	18	19	20	21	22	24	25	26	31	32	33	34	35	36	37	38	39	40	41
				a	a												a					a
						a																
				b				a												a		
a		a		b																b		
b		b		d																b		
	a		a		b																a	
	b		b		c																b	
														a								
						b	b	b		a				b							a	b
											a											
									a													
c	c		c	e	d	c	c	c	b		b	b	b	b	e	b					b	c
														f	c						c	d
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
x	x	x	x	x	x		x		x					x	x	x					x	x
		x	x	x	x	x	x	x	x							x	x	x	x	x		
																x						



The combustion furnace, figure 2, was constructed of pyrex glass, except for the central combustion chamber extending down its center. This chamber was a short length of silica combustion tubing that had been sliced in half horizontally for half of its length. The chamber was sealed to the walls of the reaction vessel through a graded silica-pyrex seal.

A strip of mica, 3.5 in. by 1.2 in., was placed on top of the open part of the silica tube, and twenty feet of 28 gauge, B.S. platinum wire, coiled in 1/4 in. diameter spirals, was wound around the silica tube and over the mica strip. This arrangement allowed the sample to remain in the cool end of the silica tube until the platinum coil reached the desired temperature. Inclining the combustion furnace caused the specimen to slide down the silica tube into the hot platinum coil.

A thermocouple was incorporated into the apparatus in order to record the temperature. Both thermocouple and platinum lead-in wires entered the furnace through openings that were sealed gas tight with woods metal.

The neck of the 2-l. furnace flask was replaced by a 55/50 ground glass female joint, and the open end of the pyrex tube consisted of a 55/50 ground glass male joint. The two halves of the apparatus were held together by the two springs shown in figure 2.

The combustion furnace was attached to the vacuum manifold through the spiral, figure 1, and the ball joint. This spiral was constructed of 7 mm. pyrex tubing that had been coiled into 5 circles each having a diameter of 6 inches. The combination of spiral and ball joint provided enough elasticity so that the combustion furnace could be inclined without snapping a glass part.

3.1.2 Sample-Air Ratio

Burning a specimen in the foregoing apparatus corresponded to the burning of a surface finish in a closed room. In order to duplicate service conditions, the volume of an unventilated unit which was in use in the field was calculated. From a knowledge of this volume and the volume of the reaction vessel, a sample size was determined that yielded the same area-volume ratio as in field use.

The ratio of sample to air used in this study was $21.6 \text{ cm.}^2/2,230 \text{ cm.}^3$, and was obtained by assuming that the walls and ceiling were covered by the surface finish.

3.1.3 Combustion Procedure

The specimen, of appropriate area, was weighed into a porcelain combustion boat and the boat placed in the silica tube as far from the platinum coil as possible. Then the 2-l. glass bulb was placed in position, the two springs attached, and the current turned on.

The vessel was evacuated by opening the stopcock to the vacuum manifold. This evacuation was necessary to remove any organic vapors that might be present which would lead to spurious readings on the mass spectrometer. After evacuation, the vacuum stopcock was closed and the draw-off valve opened to the atmosphere. The latter valve was left open until the combustion temperature was attained, as indicated by the thermocouple, and then closed.

After reaching the desired temperature, the combustion chamber was inclined, as indicated in figure 4, causing the combustion boat containing the specimen to slide down the silica tube into the platinum coil. Therefore, the specimen was kept at, or near, room temperatures until the moment of combustion, and the entire sample burned at a constant temperature. The pyrex flask was cooled by air jets shown in figure 1.

Combustion was maintained for 12 min., the current turned off, and the apparatus allowed to cool to room temperature. The gases were then collected as described in section 3.1.5, and the boat taken out and weighed.

3.1.4 Sample Size Variation with Temperature

Under actual service conditions, a fire is initiated at atmospheric pressure. This condition was duplicated in the reaction vessel by allowing the draw-off tube to remain open until combustion temperature was reached, and then closed.

The actual combustion, however, was carried out under slightly increased pressure because of the formation of gaseous products in a closed system. This pressure increase was recorded on the manometer.

A method that has been used to allow the combustion gases to expand utilizes a balloon into which the volatile materials escape (1). However, a balloon introduces errors arising from (a) the difficulty of washing absorbed gases, as hydrogen chloride, from the fabric; (b) the possible introduction of organic vapors into the mass spectrometer; and (c) the diffusion of gases through the fabric.

Because combustion was carried out at three temperatures, 250°, 400° and 550°C, different amounts of air were left in the apparatus at the start of each combustion. Therefore, in order to have a constant area-air ratio, i.e., 21.6 cm.²/2,230 cm.³, the volume of air at 25°C was used as a reference standard and the area of each specimen adjusted accordingly. This adjustment was made using the following formula:

$$A_1/A_2 = \frac{P_1}{P_2}$$

where

- A₁ = Area of the sample at 25°C.
- A₂ = Area of the sample at combustion temperature.
- P₁ = Pressure in the combustion furnace at 25°C.
- P₂ = Pressure in the combustion furnace at the combustion temperature.

Since A₁ is known and P₁ and P₂ can be measured, A₂ is readily calculated.

In practice, values of P₂ were obtained before any combustions were made. This was done by allowing the combustion temperature to be reached in the reaction vessel while it was completely closed. The pressure at this temperature was recorded, and a graph made of pressure versus temperature. Values of P₂ to be put into equation 1 were read directly from this graph which was linear over the range of temperatures, 250°C, 400°C, and 550°C, used in this study. Thus, it was not

necessary to measure P_2 at the beginning of each run and the draw-off tube was left open, as indicated previously, so as to avoid any pressure buildup before a combustion.

3.1.5 Collection of Combustion Products

Several sample bulbs having volumes of 50 ml. and 2,000 ml. were made. The 50 ml. bulb was used for the mass spectrometer, figure 5, and the 2,000 ml. bulb was used for the carbon monoxide analyses, figure 7. Before a run, each sample bulb was evacuated by attaching it to the vacuum manifold.

After cooling the apparatus to room temperature, the sample bulb was placed on the draw-off arm and the stopcock from the furnace opened. In this manner, air that was in the draw-off arm was mixed with combustion gases. The error introduced by this air is negligible due to the small volume of the draw-off tube compared to the volume of the furnace. After the air and gases had mixed, the sample bulb stopcock was opened and a sample of the gases sucked into the sampler. The sampler was allowed to remain in this position for five minutes to insure proper mixing. Then both stopcocks were closed and the sample bulb attached either to the mass spectrometer or to the carbon monoxide apparatus.

After cooling the reaction vessel, a vacuum was invariably present within the apparatus. In those cases where hydrogen chloride was suspected, the draw-off tube was attached to a beaker containing dilute (pH = 10) sodium hydroxide. This solution was sucked into the reaction vessel and allowed to stand for 15 minutes. Due to the high affinity of hydrogen chloride gas for water, any of this gas not absorbed upon the vessel walls was expected to dissolve in the base. After 15 minutes, the springs were removed and the solution poured into a beaker. The reaction vessel was then washed several times with distilled water and these water washings combined and analyzed by the method described in section 3.2.3.

3.2 Analytical Methods

3.2.1 Mass Spectrometer Determinations

The mass spectrometer sample bulb containing combustion gases was placed on the inlet system of the mass spectrometer (figure 6). An analysis was carried out for gases having a mass number of 1 to 100. The analytical results are recorded in Table 6.

The mass spectrometer was a Consolidated Engineering type 21-103.

3.2.2 Carbon Monoxide

Carbon monoxide was determined by two methods. When present in concentrations of 1,000 parts per million or less, the mass spectrometer was not sensitive enough to give an accurate analysis. It was, therefore, necessary to use the indicator technique (6). The 2,000 ml. sample bulb (figure 7) was filled with combustion gases and the pressure reading on the manometer recorded. The bulb was attached to a source of carbon monoxide free air under pressure, and air allowed to enter the flask until the pressure was slightly above one atmosphere. Then the flask was arranged as in figure 8. The stopcock was opened and the gases passed through the indicator at a constant rate as determined by the flowmeter. At the end of a given time period, the color of the indicator was compared with a color chart and the amount of carbon monoxide in the sample flask determined.

The amount of carbon monoxide present before air was admitted was calculated from a knowledge of the initial and final pressures. Carbon monoxide present in the furnace was calculated from a knowledge of the initial and final volumes.

3.2.3 Hydrogen Chloride Determinations

Hydrogen chloride was absorbed upon the walls of the reaction vessel along with any water produced during the course of combustion. Because of this absorption, it was not possible to determine hydrogen chloride by means of the mass spectrometer, and the following analytical method was used.

The water washings that were received from the procedure outlined in section 3.1.5 were adjusted to a pH of 6.0-7.0 and titrated with standard .1N silver nitrate using fluorescein as an indicator (7). The weight of hydrogen chloride was converted into moles of gas and the gas percentage calculated from a knowledge of the volume of the flask and the volume occupied by that number of moles of gas at room temperature.

4. TOXIC HAZARDS

4.1 Carbon Dioxide

Combustion always produced carbon dioxide. This gas, in itself, is not toxic, but production of large amounts was usually associated with a decrease in the oxygen content. Since the burning operation corresponded to a combustion in a completely closed room, a decrease in oxygen might have a deleterious effect upon the occupants.

The lack of oxygen causes asphyxiation in human beings. There are four stages (8) of asphyxiation and each stage corresponds to a definite oxygen percentage.

First Stage:

When the oxygen content of the air is decreased from the normal 21% to between 12 and 16%, the ability to think is diminished and muscular coordination is disturbed. This percentage is somewhat less than the amount of oxygen present at which a candle is extinguished (17%).

Second Stage:

When the oxygen diminishes to values between 10 and 14%, the higher centers of the brain are affected. Consciousness remains, but judgment becomes faulty and muscular efforts lead to rapid fatigue.

Third Stage:

When the oxygen diminishes to between 6 and 10%, movement ceases and loss of consciousness results.

Fourth Stage:

When the oxygen is diminished below 6%, respiration soon ceases and life is maintained for but a few minutes.

4.2 Carbon Monoxide

Carbon monoxide is not a physiologically inert gas like carbon dioxide. Its action depends upon a chemical reaction in which the carbon monoxide combines with the blood hemoglobin (9). Therefore, the hemoglobin is not available for combination with oxygen and asphyxia results. The following table indicates the maximum dosages and the resultant physiological effects:

Table 2. Physiological Effects of Carbon Monoxide (9)

Parts of Carbon Monoxide Per Million Parts of Air	Physiological Effects
100	Shortness of breath on vigorous muscular exertion.
400 - 500	Shortness of breath on slight exertion; occasionally slight headache.
600-700	Decided headache; easily fatigued.
1,000 - 2,000	Headache; collapse and fainting on exertion.
1,500 - 2,000	Unconsciousness; respiratory failure and death if exposure is continued.
4,000 and over	Immediately fatal.

4.3 Hydrogen Chloride

On exposure to air, this gas forms dense white fumes from the condensation of atmospheric moisture and the formation of hydrochloric acid in minute droplets. Both the acid droplets and the gas are highly irritating and make their presence known in this manner (10).

The following table gives the physiological response of the human body to various concentrations of the acid gas.

Table 3. Physiological Response to Various Concentrations of Hydrochloric Acid Gas (10)

Parts of Hydrochloric Acid Per Million Parts of Air	Physiological Action
10	Maximum concentration allowable for prolonged exposure.
10 - 50	Maximum concentration tolerable for a few hours.
50 - 100	Maximum concentration tolerable for 1 hour.
1,000 - 2,000	Dangerous for even short exposures.

4.4 Benzene

Acute poisoning from benzene is generally due to its anesthetic action (11). Inhalation of high concentrations of benzene vapors may result in the rapid loss of consciousness, followed in a short time by death from respiratory failure. The following table lists the physiological responses of the human body to various concentrations of benzene vapor.

Table 4. Acute Physiological Response to Various Concentrations of Benzene (11)

Parts of Benzene Vapor Per Million Parts of Air	Physiological Response
1,500 - 3,000	Slight symptoms after several hrs.
3,000 - 4,700	Maximum concentration that can be inhaled for 1 hr.
7,500	Dangerous to life in 1/2 to 1 hr.
19,000 and above	Rapidly fatal.

4.5 Toluene

Toluene is generally similar in its physiological action to benzene, and its toxic properties may be estimated from table 4.

4.6 Sulfur Dioxide

Sulfur dioxide is a colorless gas with an irritating odor. In the presence of moisture, the dioxide is oxidized and forms sulfuric acid. The following table lists its physiological action.

Table 5. Physiological Response to Various Concentrations of Sulfur Dioxide (12)

Parts of Sulfur Dioxide Per Million Parts of Air	Physiological Response
8 - 12	Causes throat irritation.
10	Maximum concentration for prolonged exposure.
20	Immediate eye irritation and coughing.
50 - 100	Maximum concentration for short exposure.
400 - 500	Dangerous for short exposures.

4.7 Other Gases

The gases found in this study other than the ones previously mentioned were not present in amounts sufficient to cause concern. Gases such as methane, ethane, and ethylene act as anaesthetics and have to be present in amounts ranging from 30,000 to 50,000 p.p.m. to be harmful over long exposure periods. For short exposures, much larger concentrations would have to be present to be toxic. There is no information available on the toxic limit for short exposures.

Phosgene is decomposed by moisture into hydrochloric acid and carbon dioxide. The reaction vessel was usually coated by a thin moisture film after combustion, and no phosgene was detected. Other investigators (1) have found just detectable traces of phosgene upon burning chlorinated plastics, but concluded that the toxic hazard represented by this gas is negligible compared to that represented by the hydrogen chloride and carbon monoxide.

The safe limit for methyl chloride and 1,2-dichloroethane is about 200,000 p.p.m. for short exposures (14). This concentration was never found for any of the materials examined.

5. RESULTS OF THE COMBUSTION GAS ANALYSES

The materials used in this study, the temperatures at which these materials were burned, and the analyses of the gaseous combustion products are listed in tables 6. and 7.

5.1 Chlorine-Containing Vs. Chlorine-Free Interior Finishes

Chlorinated (Specimens 5, 9, 17, 20, 21, 22, 35, 39 and 42) and chlorine-free interior finishes were studied. The principal gases produced from both types of finishes were carbon dioxide and carbon monoxide. At the higher temperatures, many different hydrocarbons were formed, usually including methane, toluene, and benzene.



Table 6

Concentration of Gases Evolved From Plywood Backed Interior Finishes

Materials	Specimen No.	Temp °C	Concentration					
			Carbon Dioxide	Carbon Monoxide	Oxygen	Nitrogen	Methane	Methyl Chloride
Har	1	250	8,500	600	199,400	783,000		
		400	194,000	14,000	27,000	742,000	14,000	
		550	171,000	36,000	28,000	719,000	9,800	
Xply	2	250	53,000	4,000	162,000	771,000		
		400	174,000	1,500	46,000	757,000		
		550	166,000	65,000	19,700	719,000	14,100	
Xply;SK	3	250	12,000	6,000	196,000	781,000		
		400	110,000	3,600	112,000	754,000	2,800	
		550	168,000	47,000	26,700	735,000	8,500	
Xply; Albi 99	4	250	12,500	5,000	200,000	771,000		
		400	12,900	10,000	168,000	799,000		
		550	180,000	32,000	23,300	746,000	6,100	
Xply;SK; Dex	5	250	18,900	3,000	187,000	782,000		
		400	163,000	44,000	29,000	740,000	15,500	
		550	171,000	51,000	20,500	722,000	14,000	1,700
Xply;Dexpr; Dex R; Albi 99	9	250	20,000	600	198,000	769,000		1,500
		400	62,000	12,000	152,000	750,000		3,400
		550	151,000	86,000	23,500	697,000	16,000	3,900
Har;Flpr; Flkt	16	250	13,000	3,000	218,000	744,000		
		400	161,000	14,000	71,000	740,000		
		550	174,000	60,200	2,700	704,000	1,300	
Har;Prph; Prlu	17	250	28,000	1,200	184,500	772,200		
		400	150,000	3,400	70,000	768,000		
		550	172,500	84,300	24,700	687,300	13,600	400
Xply;Flpr; Flkt;Pva; Albi 99	18	250	12,300	1,200	200,000	772,000		
		400	150,000	12,000	50,000	777,000		
		550	177,000	13,000	28,000	756,000	9,800	200
Xply;Prph; Prlu; Albi 99	19	250	10,500	600	203,000	774,000		
		400	100,000	10,000	103,000	777,000		
		550	185,000	43,000	16,100	737,000	5,300	400
Xply;SK; Crlx No. 1	20	250	8,300	1,200	200,800	772,000		
		400	176,200	600	27,000	773,100	7,300	4,300
		550	147,000	132,000	26,000	641,000	19,000	4,300
Xply;SK; Crlx No. 2	21	250	2,800	2,400	184,500	777,200		
		400	150,000	6,500	46,000	742,000		
		550	144,100	110,000	25,100	674,000	14,700	30
Xply;SK; Crlx No. 3	22	250	7,500	1,200	202,000	780,000		
		400	127,200	500	23,000	369,000	5,300	2,400
		550	142,000	104,000	26,900	682,000	1,650	2,400
Xply; Fban	24	250	3,000	900	167,000	793,000		
		400	109,000	3,500	9,500	776,000	2,400	
		550	199,000	24,000	22,700	740,000	2,500	

Maximum Permissible Concentrations

Safe for Long Periods	a	100	a	30,000-50,000	b
Safe for $\frac{1}{2}$ -1 hr	a	400-500	a	b	b
Dangerous for Short Period ($\frac{1}{2}$ -1 hr)	a	1,500-2,000	a	b	b

a See Section 4.1; b see Section 4.7; where no results are reported, no

Decomposed in Air by Heat

of Gases, P.P.M.									%Loss
1,2-Dichloroethane	Ethane	Ethylene	Propylene	1,3-Butadiene	Benzene	Toluene	Hydrogen Chloride	Hydrogen	on combustion
		24,000	400	70	100	Trace			10 48 63
									9 49 74
	1,700	1,800	400		100	Trace		2,900	9 50 79
		1,800			100	Trace			8 48 71
		1,500	300					1,400	4 51 56
	5,000	1,300	600	500	Trace 600 200	Trace 100 100	16,000 27,500 30,000	3,200	16 75 66
	5,100	1,600	2,100	500	200	80	19,700 30,000 39,500	4,200	6 59 71
	1,200	300	600					4,000	2 54 70
	900	2,300	30		200	70	1,000 1,400 3,500		5 43 73
	900	2,000	400		Trace 100 Trace	Trace 100 Trace			1 45 63
	2,300				100		1,000 1,450 3,600		19 35 55
2,300 7,100			300	300	189 200 1,000	189 200 400	7,260 17,300 38,200	6,900	2 41 50
	1,800	11,000	1,300	430	700	200	1,780 2,270 5,590	3,900	6 62 59
1,500 5,400		4,900			100 700	200 200	5,300 20,500 32,300	6,200	14 41 57
	400		100					500	

of Toxic Gases; P.P.M.

b	---30,000-50,000----	b	1,500-3,000	10
b	b	b	3,000-4,700	50-100
b	b	b	7,500	1,000-2,000

gas was detected.

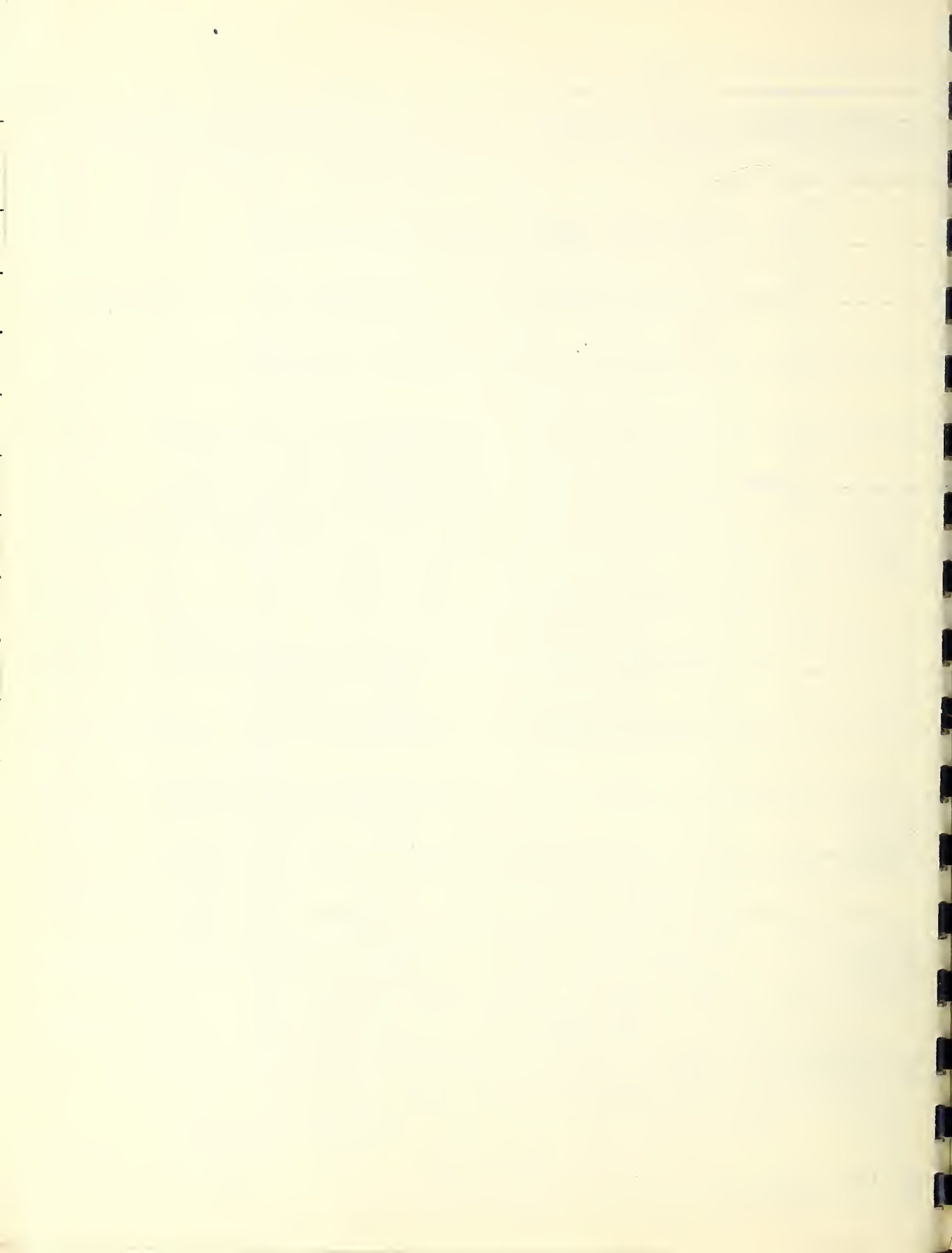




Table 7

Concentration of Gases Evolved From Unsupported Interior Finishes

Materials	Specimen No.	Temp °C	Concentration					
			Carbon Dioxide	Carbon Monoxide	Oxygen	Nitrogen	Methane	Methyl Chlorid
Dex	35	250	6,800	1,000	177,000	790,000		
		400	111,000	6,000	64,000	812,000		
		550	101,000	58,000	3,200	777,000	10,000	800
SK	36	250	9,400	600	200,300	773,000		
		400	18,800		193,000	774,000		
		550	36,000	30	182,000	772,000		
Albi 99	37	250	8,000		192,000	779,000		
		400	16,000		201,000	767,000		
		550	33,000		188,000	770,000		
Flkt;Flpr	38	250	9,200		209,000	772,000		
		400	13,500	60	198,000	778,000		
		550	27,000		198,000	767,000		
Prph;Prlu	39	250	32,900	100	176,000	780,000		
		400	27,200	100	189,000	779,000		
		550	41,000	60	170,000	778,000		
Saran	42	250	23,000		187,000	782,000		
		400	8,200		219,000	762,000		
		550	4,400		170,070	814,450		

Maximum Permissible Concentrations

Safe for Long Periods	a	100	a		30,000- 50,000	b
Safe for $\frac{1}{2}$ -1 hr	a	400-500	a		b	b
Dangerous for Short Period ($\frac{1}{2}$ -1 hr)	a	1,500- 2,000	a		b	b

aSee Section 4.1; b see Section 4.7; where no results are reported, no

Decomposed in Air by Heat

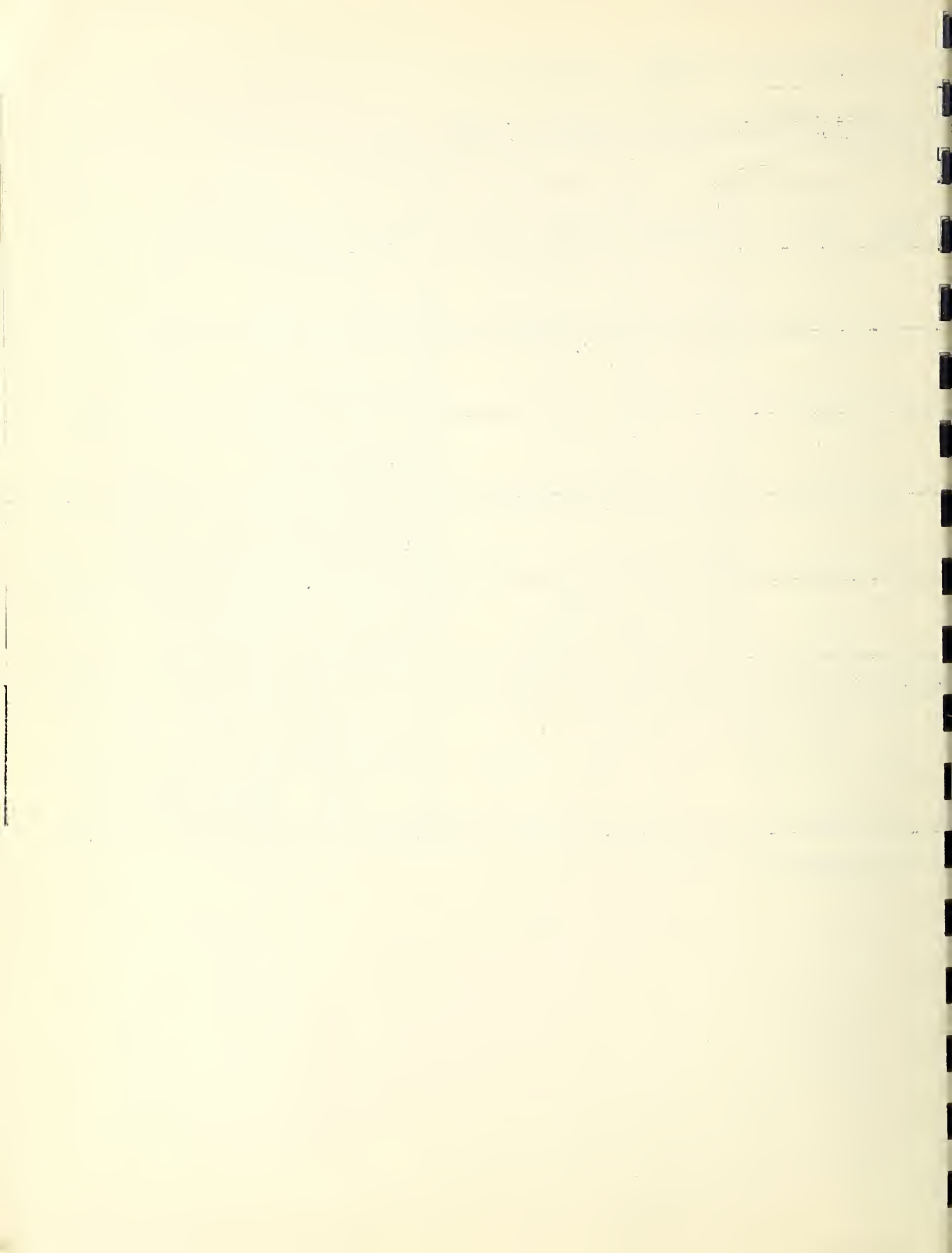
of Gases, P.P.M.

1,2-Dichloroethane	Ethane	Ethylene	Propylene	1,3-Butadiene	Benzene	Toluene	Hydrogen Chloride	Sulfur Dioxide	% Loss on Combustion
		4,800	1,200	500	300	70	23,700 33,200 47,300		16 40 53
									16 24 44
					90	100			12 67 66
					Trace	Trace		400 800	2 11 40
					Trace Trace 100	Trace Trace 100	1,080 1,510 3,950	700 500 100	9 60 70
					40	40	5,750 8,300 11,000		19 55 79

of Toxic Gases; P.P.M.

b	--30,000-50,000----			b	1,500-3,000	10	10	
b	b	b	b	b	3,000-4,700	50-100	50-100	
b	b	b	b	b	7,500	1,000-2,000	100-500	

Gas was detected.



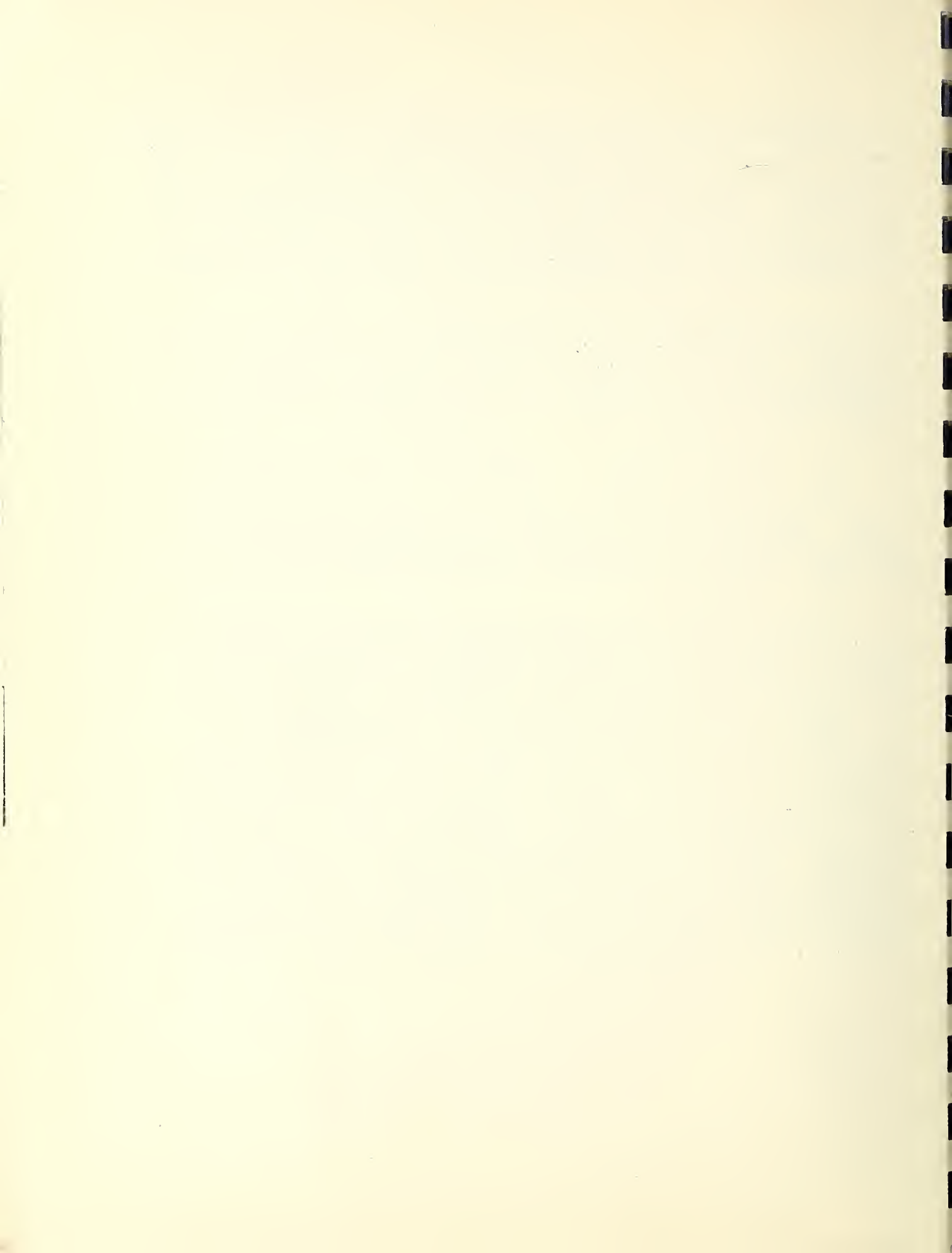
From the chlorinated interior finishes, considerable amounts of hydrogen chloride were evolved, even at the lowest temperature used (250°C). At higher temperatures, these chlorinated materials gave rise to a host of chlorine-containing hydrocarbons. In general, the chlorinated interior finishes produced amounts of carbon monoxide and hydrogen chloride which were above the safe limits for short exposures. In a similar study, other investigators (1) found that chlorinated plastics, upon combustion in air, produced toxic amounts of the above gases.

In the combustion of chlorine-free materials, carbon monoxide represented the greatest toxic hazard. Specimen 38 also produced hazardous amounts of sulfur dioxide. With few exceptions, the concentration of carbon monoxide increased with temperature until, at 550°C, observed values were 10 to 50 times the safe amount for short exposures.

5.2 Plywood Backed Vs. Unsupported Interior Finishes

The smallest volume of gases was evolved from the paint films (Specimens 36, 37, 38, 39 and 42); this was due to their low weight per unit area. A plywood specimen having the same area as an unsupported specimen weighed approximately 50 times as much.

Table 7. lists the combustion gases produced when the materials were burned without a plywood backing. Specimens 36 and 37 produced the smallest amounts of hazardous gases. Specimens 36, 37, 38 and Fireban showed the least tendency to increase the hazardous gases produced by specimens 1 and 2. Specimen numbers of the respective built-up interior finishes are 3, 4, 16 and 31. However, specimens 16 and 18 were built up of materials that gave rise to sulfur dioxide (specimens 38 and 39). Sulfur dioxide was not detected in the built-up specimens and it is believed that this was due to the oxidation of the sulfur dioxide to sulfuric acid by the water formed when the plywood was burned. Sulfuric acid in water solution would be absorbed upon the walls of the reaction chamber and might not be detected by the mass spectrometer. Specimens 16 and 18 therefore might represent a toxic hazard due to the sulfur dioxide which, although not detected, was probably present as sulfuric acid.

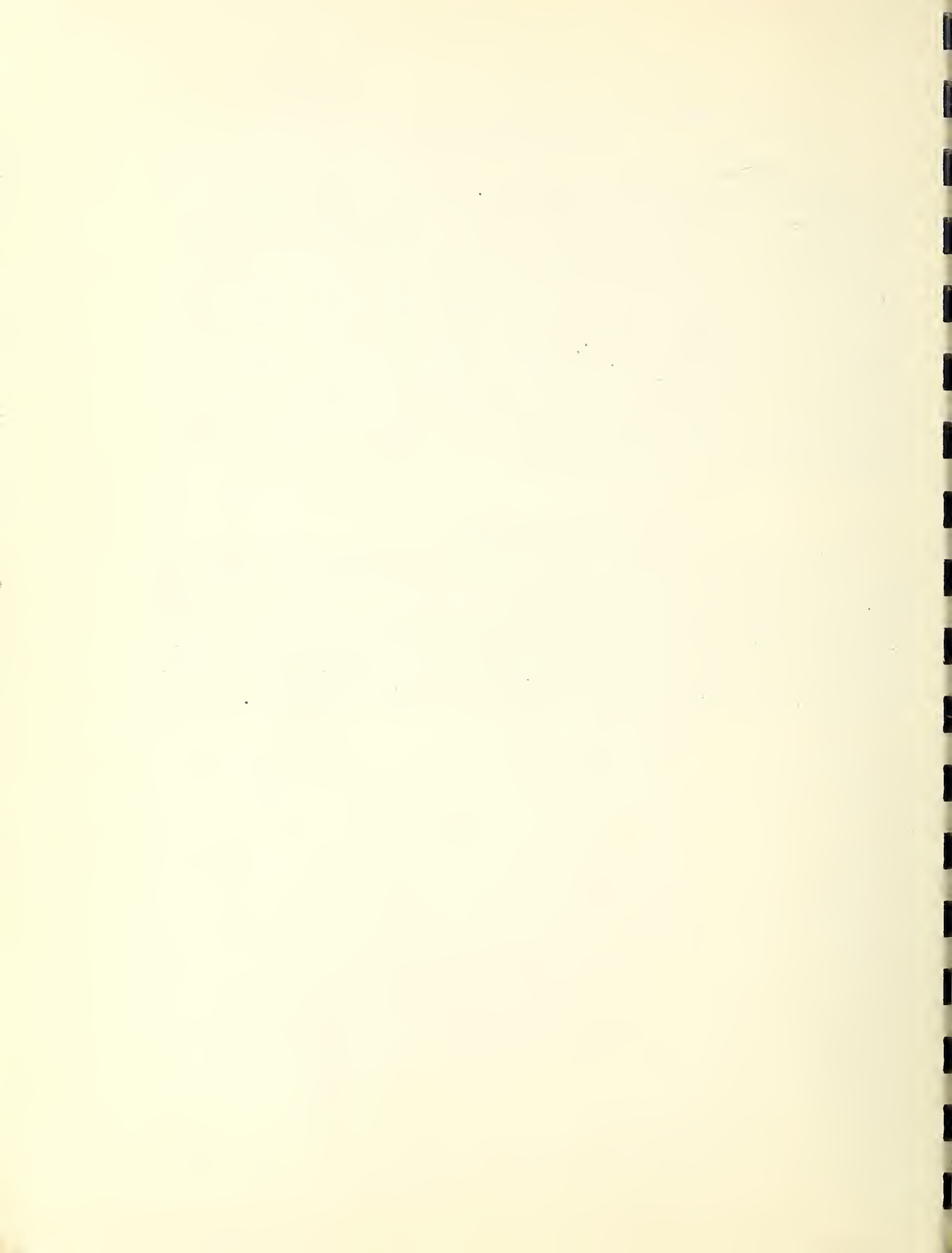


5.3 Application of Experimental Results to Field Conditions

In interpreting the results, caution should be exercised in extrapolating them to those that would be obtained in practice. As indicated in section 3.1.2, in this investigation samples were burned in a completely closed chamber; in a ventilated room, decomposition products might not accumulate to such a hazardous extent. Criticism might also be leveled at the fact that forced heating sometimes took place under conditions of insufficient oxygen to cause combustion, and the combustion products might not represent those produced in actual service. However, Kingman et. al. (15), have found that the oxygen content of ventilated rooms drops to as low as 3,000 p.p.m. after 15 minutes of burning. Thus, as pertains to the oxygen content, the results appear to be in accord with experiments carried out under conditions in which the rooms were ventilated.

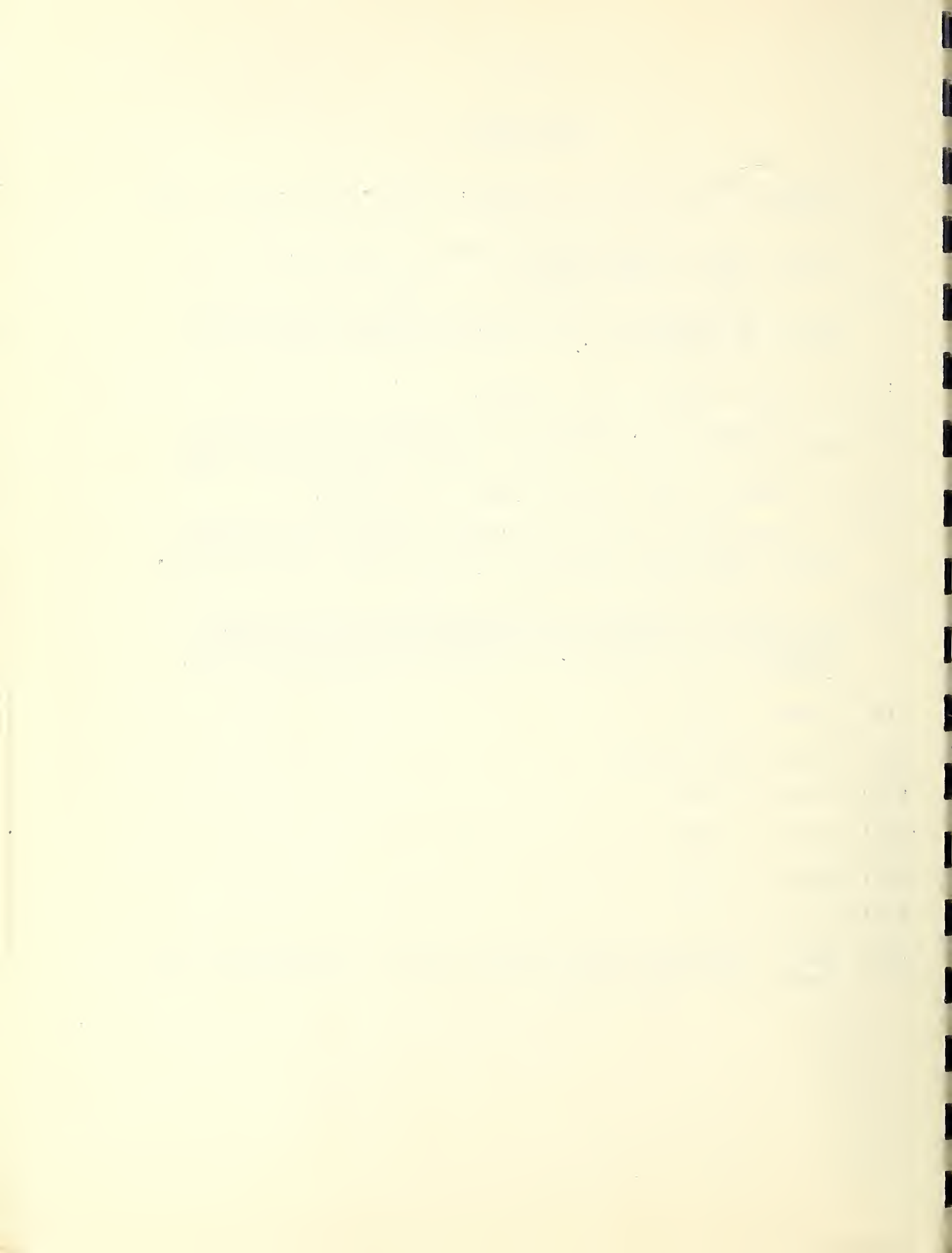
Acknowledgment

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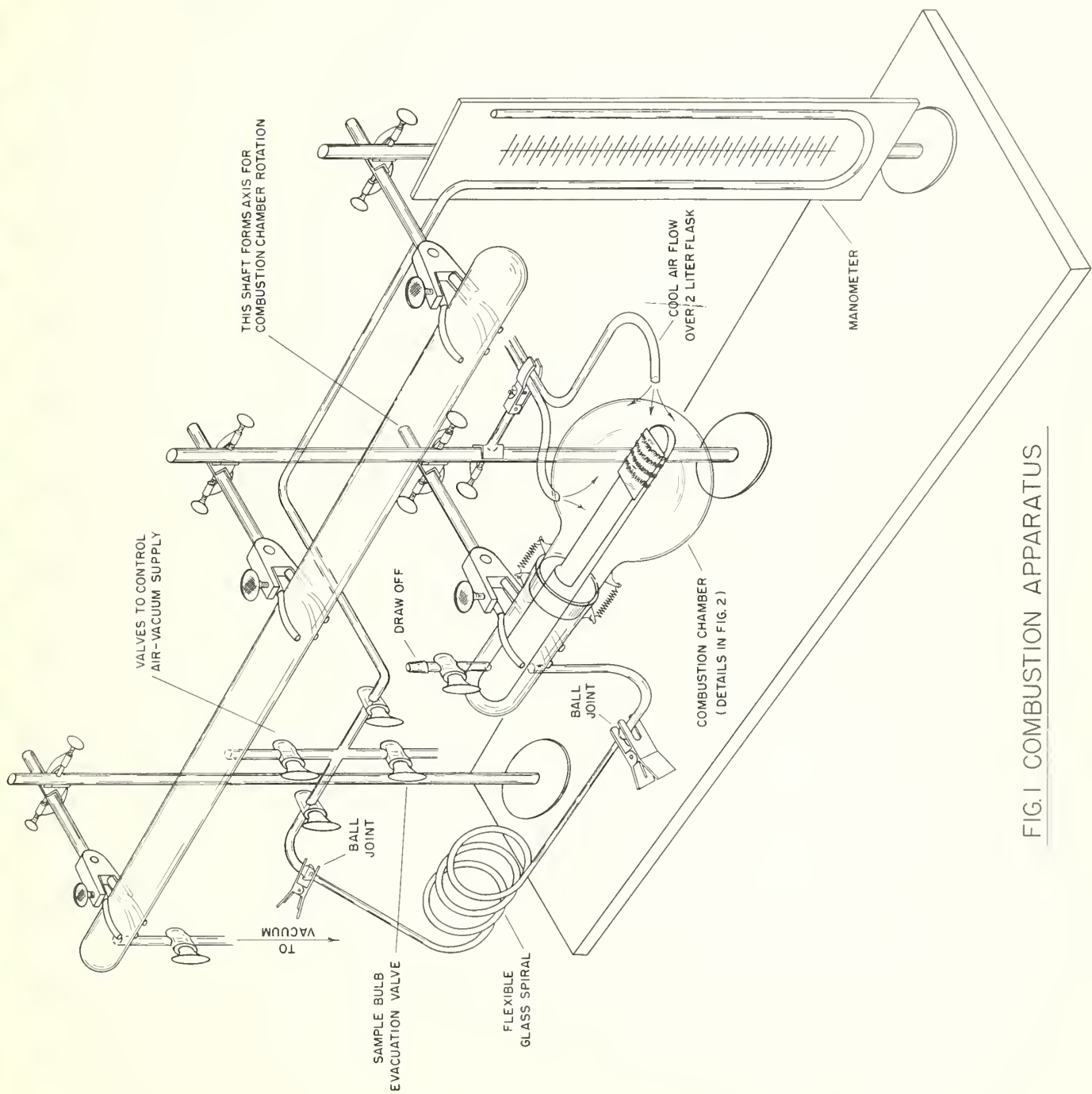


FIG. 1 COMBUSTION APPARATUS



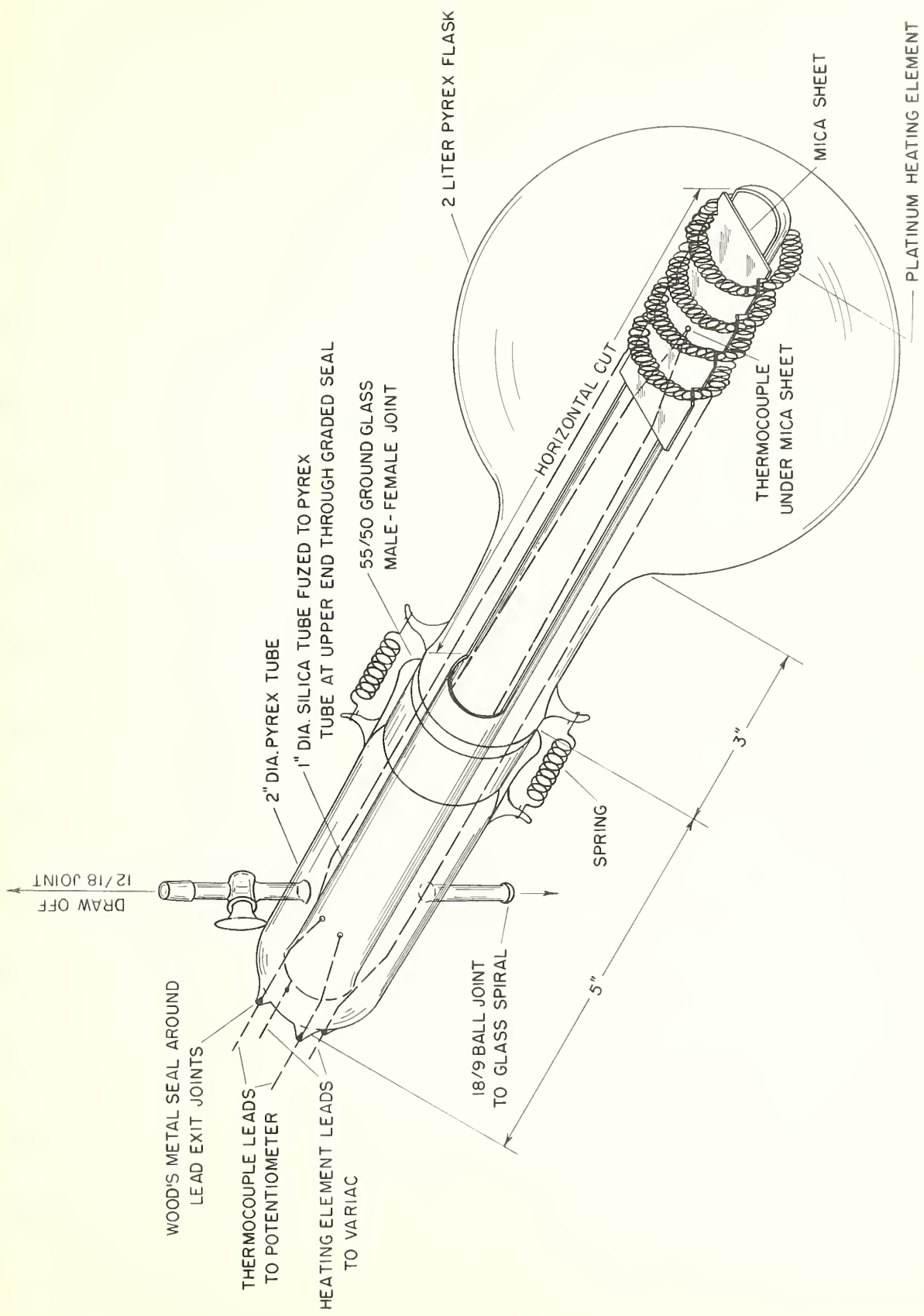


FIG. 2 DETAILS OF COMBUSTION CHAMBER



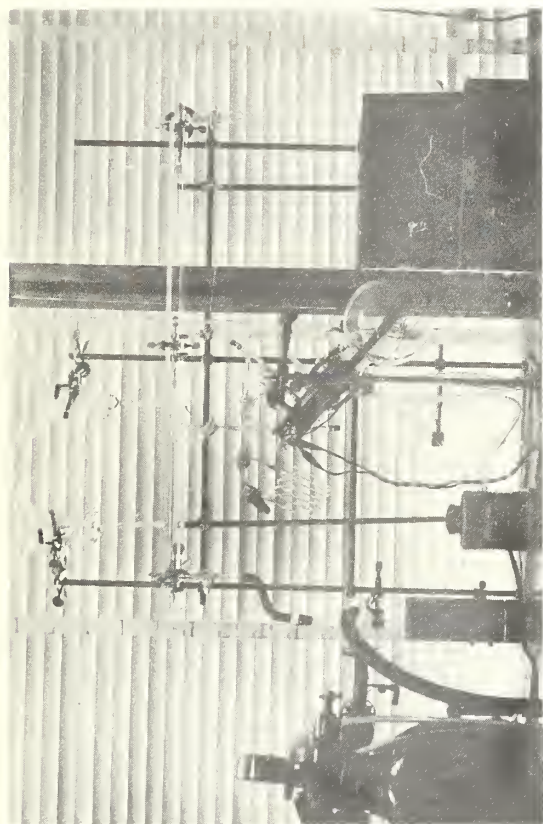


FIGURE 3.
COMBUSTION APPARATUS

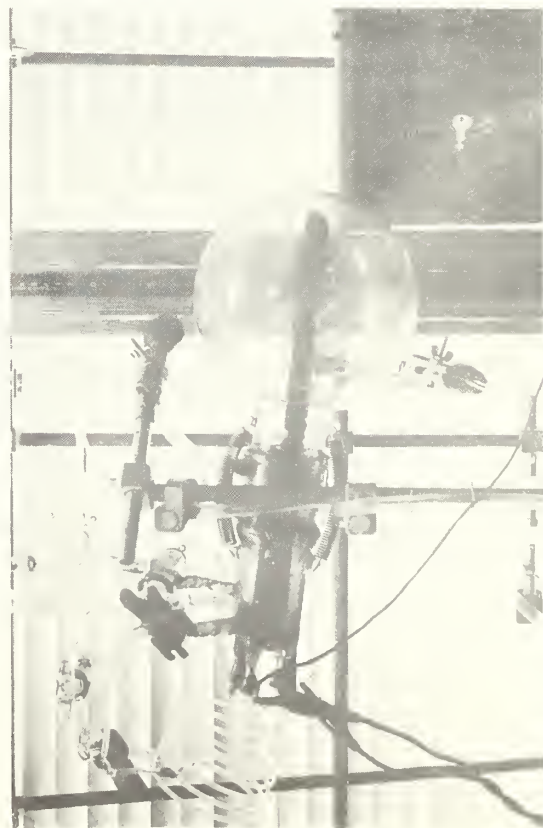


FIGURE 4.
COMBUSTION FURNACE IN HORIZONTAL POSITION

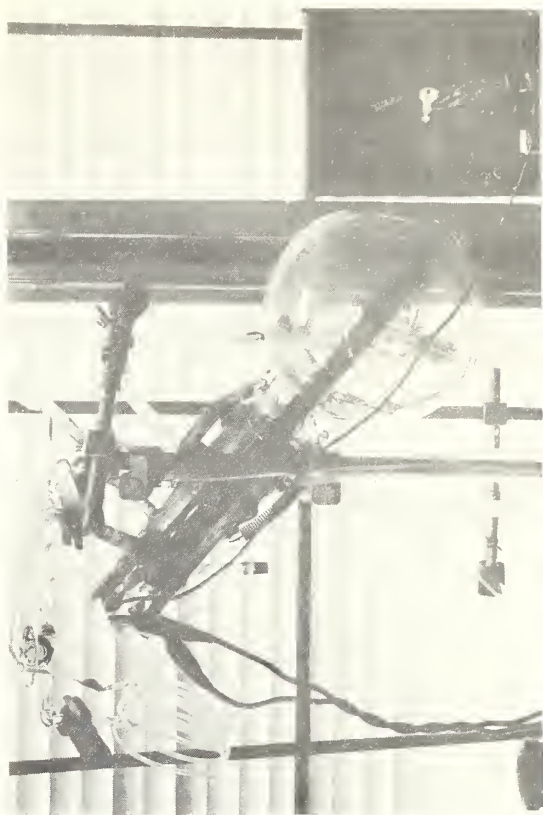


FIGURE 5.
COMBUSTION FURNACE IN INCLINED POSITION

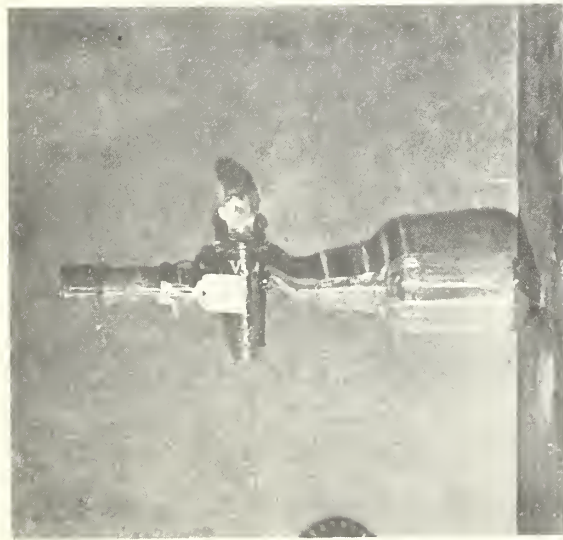


FIGURE 6.
MASS SPECTROMETER
SAMPLE BULB



FIGURE 7.
CARBON MONOXIDE
SAMPLE BULB



FIGURE 8.
MASS SPECTROMETER INLET WITH SAMPLER

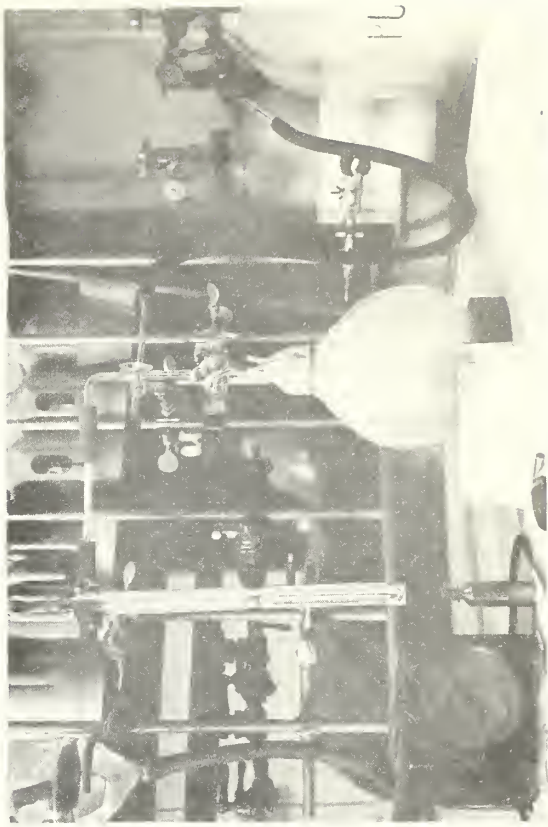


FIGURE 9.
CARBON MONOXIDE APPARATUS

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