CONFERENCE TO REEVALUATE THE TOXICITY OF VINYL CHLORIDE, POLYVINYL CHLORIDE AND STRUCTURAL ANALOGUES

March 20-21, 1980

National Institutes of Health
Masur Auditorium
Building 10
Clinical Center
Bethesda, Maryland

Cosponsors

National Institutes of Environmental Health Sciences
National Institute for Occupastional Safety and Health
Occupational Safety and Health Administration

Thursday, March 20, 1980

8:00 A.M. REGISTRATION

8:30 A.M. INTRODUCTORY REMARKS
Dr. David Rall, NIEHS

SESSION I – CARCINOGENESIS BIOASSAYS OF VINYL CHLORIDE MONOMER

Chairperson: Dr. Umberto Saffiotti, NCI

8:45 A.M. 1. Carcinogenicity Bioassays of Vinyl Chloride Monomer: A Model of Risk Assessment on Experimental Basis
Dr. Cesare Maltoni, Institute of Oncology and Tumor Center, Bologna

9:45 A.M. 2. Experimentally Induced Pulmonary Cancer
Dr. Y. Suzuki, Mt. Sinai Medical School

10:00 A.M. Discussion

10:15 A.M. Break

10:45 A.M. 3. The Role of Aging on Cancer Induced by Vinyl Chloride Monomer
Dr. David Groth, NIOSH

11:00 A.M. 4. Carcinogenic Effects of Exposure to Vinyl Chloride Monomer and Ethyl Alocohol on Rats
Dr. Martha Radike, University of Cincinnati

11:15 A.M. 5. Cancer Induction Following Single and Multiple Exposures to a Constant Amount of Vinyl Choride Monomer
Dr. Robert Hehir, CPSC

SESSION II – TOXICOLOGY STUDIES OF POLYVINYL CHLORIDE

Chairperson: Dr. Peter Infante, OSHA

11:30 A.M. 6. Pneumoconiosis in Animals Exposed to Polyvinyl Chloride Dust
Dr. David Groth, NIOSH

11:45 A.M. 7. Results of Carcinogenesis Bioassay of Polyvinyl Chloride
Dr. Chris Wagner, BMRC, Penarth, Wales
- deposition of PVC in lung, liver, spleen — no fibrosis or cancer just retention

Thursday, March 20, 1980

SESSION III – SPUTUM CYTOLOGY OF VINYL CHLORIDE WORKERS

Chairperson: Dr. Peter Infante, OSHA

12:00 P.M. 8. Results of Sputum Cytology Among Workers Exposed to Vinyl Chloride Monomer and to Polyvinly Chloride
Dr. Cesare Maltoni, Institute of Oncology and Tumor Center, Bologna

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Dr. H. Weber, Der Staatliche Gewerbearzt
, Fed. Republic Germany

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2:45 P.M. 12. Power Considerations in Epidemiologic Studies of Vinyl Chloride Workers
Dr. Jay Beaumont, NIOSH

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9:15 A.M. 22. Pneumoconiosis Induced by Polyvinyl Chloride Dust
Dr. A. Arnaud, Marseille, France

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9:30 A.M.	23. An Epidemiologic Study of Pneumoconiosis in the Italian Polyvinyl Chloride Industry Dr. Guiseppe Mastrangelo, Padova, Italy
9:45 A.M.	24. A Case-Control Study of Lung Cancer Among Vinyl Chloride-Polyvinyl Chloride Workers Dr. Richard Waxweiler, NIOSH
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11:30 A.M.	28. Mutagenic Effects of Vinyl Chloride Dr. Jill Fabricant, University of Texas, Galveston
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SESSION IX – ENVIRONMENTAL EXPOSURE TO VINYL CHLORIDE-POLYVINYL CHLORIDE AND LIVER ANGIOSARCOMA

Chairperson: Dr. Pier Bertazzi, Institute of Occupational Health, Milan

Friday, March 21, 1980 1974 EPA study

2:00 P.M. 30. Fugitive Emissions of Vinyl Chloride-Polyvinyl Chloride
~~Dr. Susan B. Wyatt, EPA~~

2:15 P.M. 31. ~~Case Control Study of~~ Liver Angiosarcoma ~~Among Residents in New York~~ a Signal Lesion of VC Exposure
~~Dr. Nicholas Vianna, N.Y.S. Department of Health~~

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Chairperson: Dr. Kim Hooper, University of California, Berkeley

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Dr. William Busey, Experimental Pathology Laboratories

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Friday, March 21, 1980

5:00 P.M. 39. Dr. Joseph Wagoner, EDF

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Proceedings from the Conference will be published

Program Planning Committee

Dr. Richard B. Everson
NIEHS, Research Triangle Park, North Carolina

Dr. Peter F. Infante
OSHA, Washington, D.C.

Dr. Philip J. Landrigan
NIOSH, Cincinnati, Ohio

Dr. Raymond E. Shapiro
NIEHS, Research Triangle Park, North Carolina

Dr. Richard J. Waxweiler
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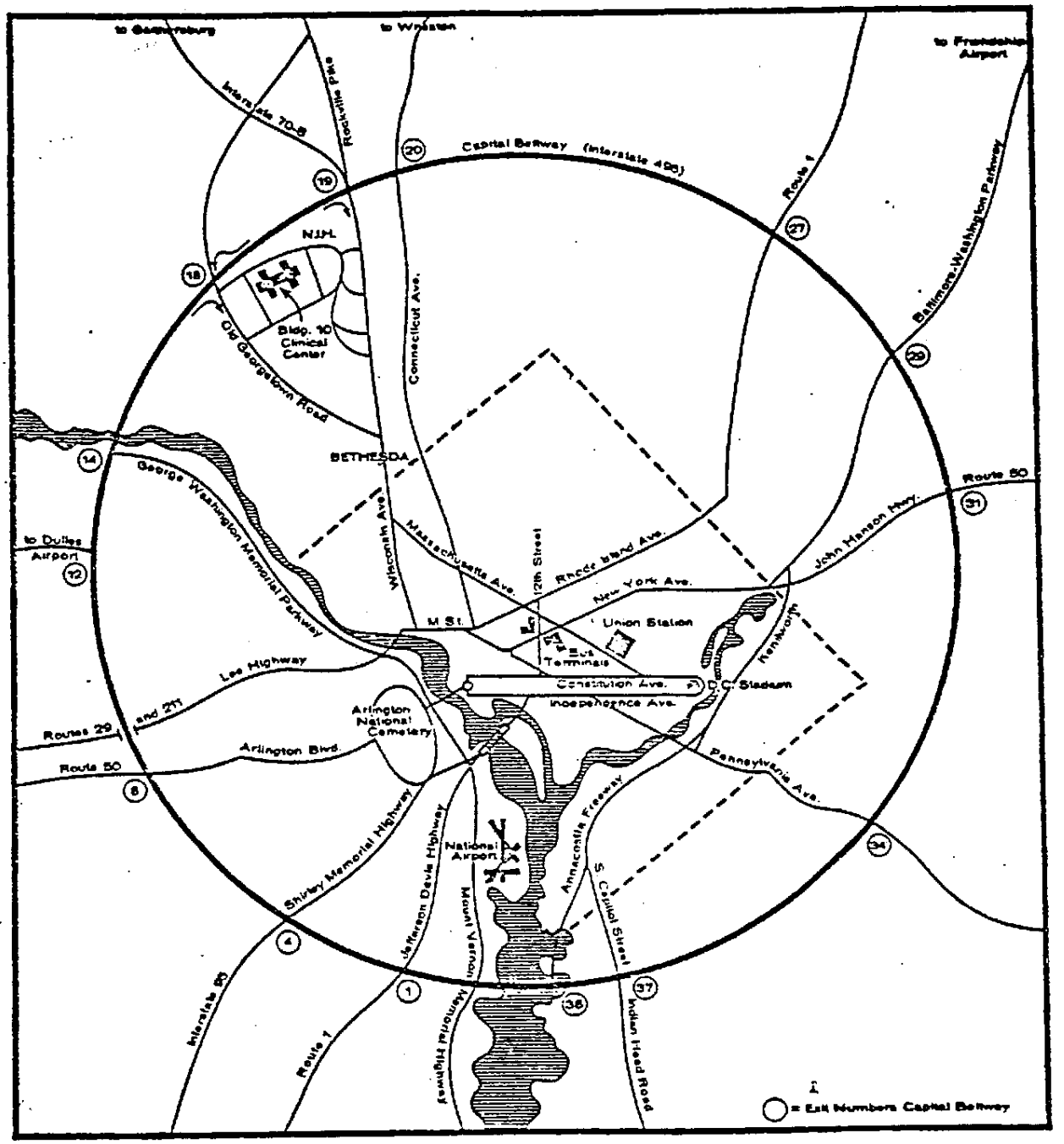

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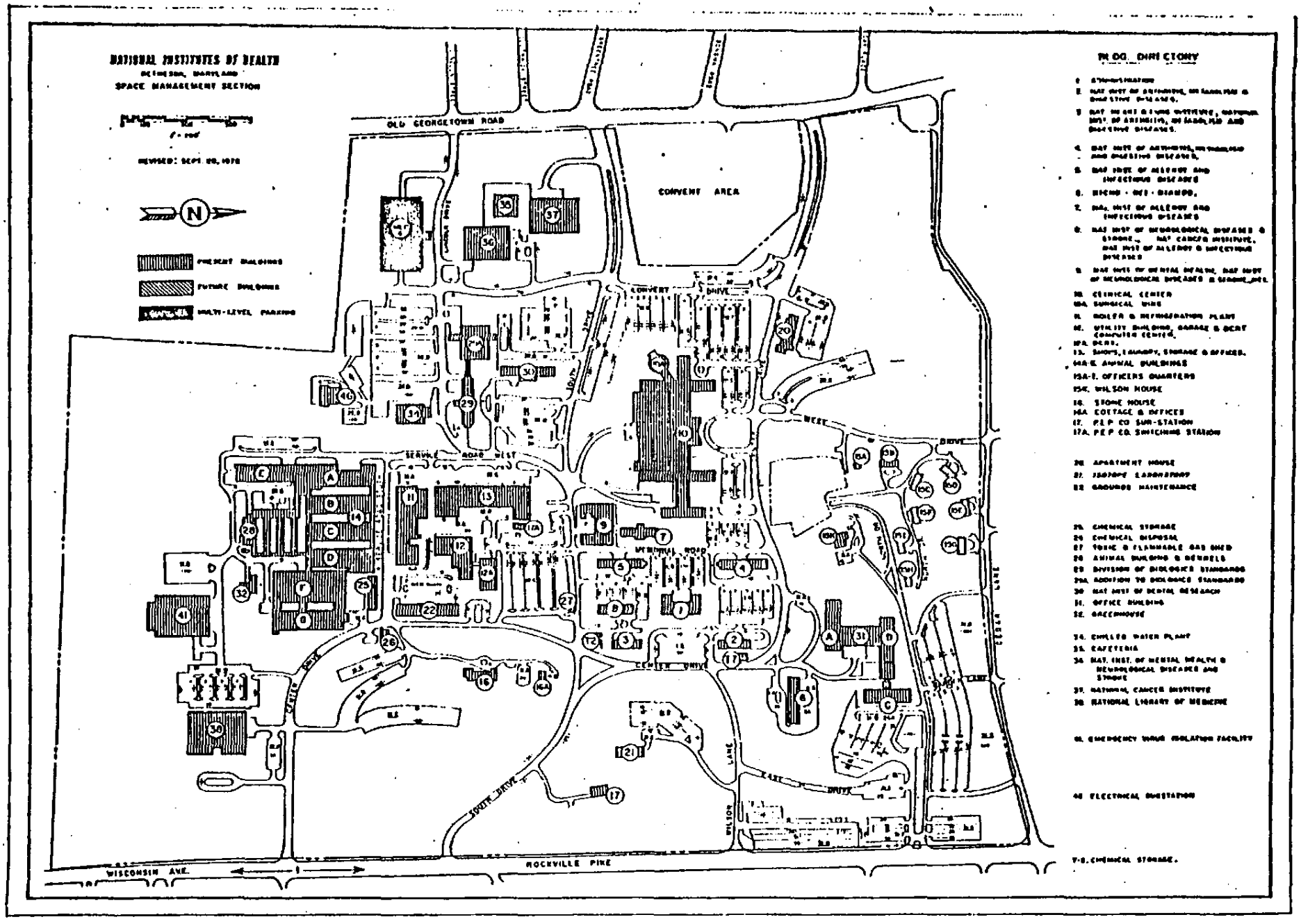

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HOTELS/MOTELS IN THE BETHESDA, MARYLAND AREA

Name/Address/Telephone #	Single Room Rate (Inc. Tax)	Distance from NIH (Approximate)
Bethesdan Motor Hotel 7740 Wisconsin Avenue Bethesda, MD 20014 (301) 656-2100	$28.60	1 mile
	**********	
Holiday Inn (Bethesda) 8120 Wisconsin Avenue Bethesda, MD 20014 (301) 652-2000	$51.70	1 mile
	**********	
Ramada Inn (Bethesda) 8400 Wisconsin Avenue Bethesda, MD 20014 (301) 654-1000	$49.50 $45.10	1 mile
	**********	
United Inn of America 8130 Wisconsin Avenue Bethesda, MD 20014 (301) 656-9300	$41.80 Sun - Thurs $35.20 Fri - Sat	1 mile
	**********	
Holiday Inn (Chevy Chase) 5150 Wisconsin Avenue Chevy Chase, MD 20015 (301) 656-1500	$46.20	1½ miles
	**********	
Intown (Chevy Chase) 6800 Wisconsin Avenue Chevy Chase, MD 20015 (301) 654-1400	$29.70 $27.50*	2 miles
	**********	
Linden Hill Hotel 5400 Pooks Hill Road Bethesda, MD 20014 (301) 530-0300	$51.70 $49.50*	2 miles

*Special Government Rate

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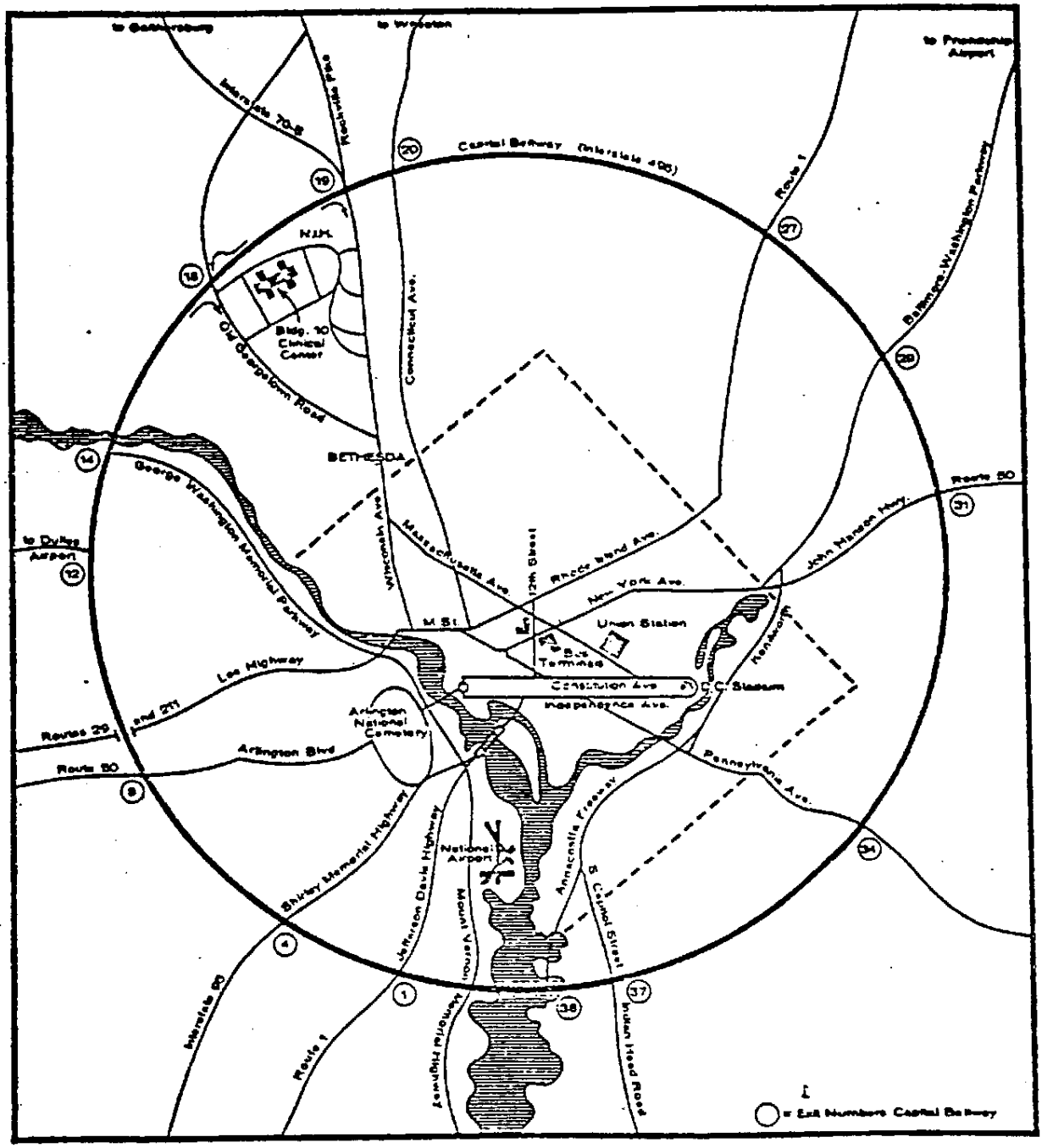
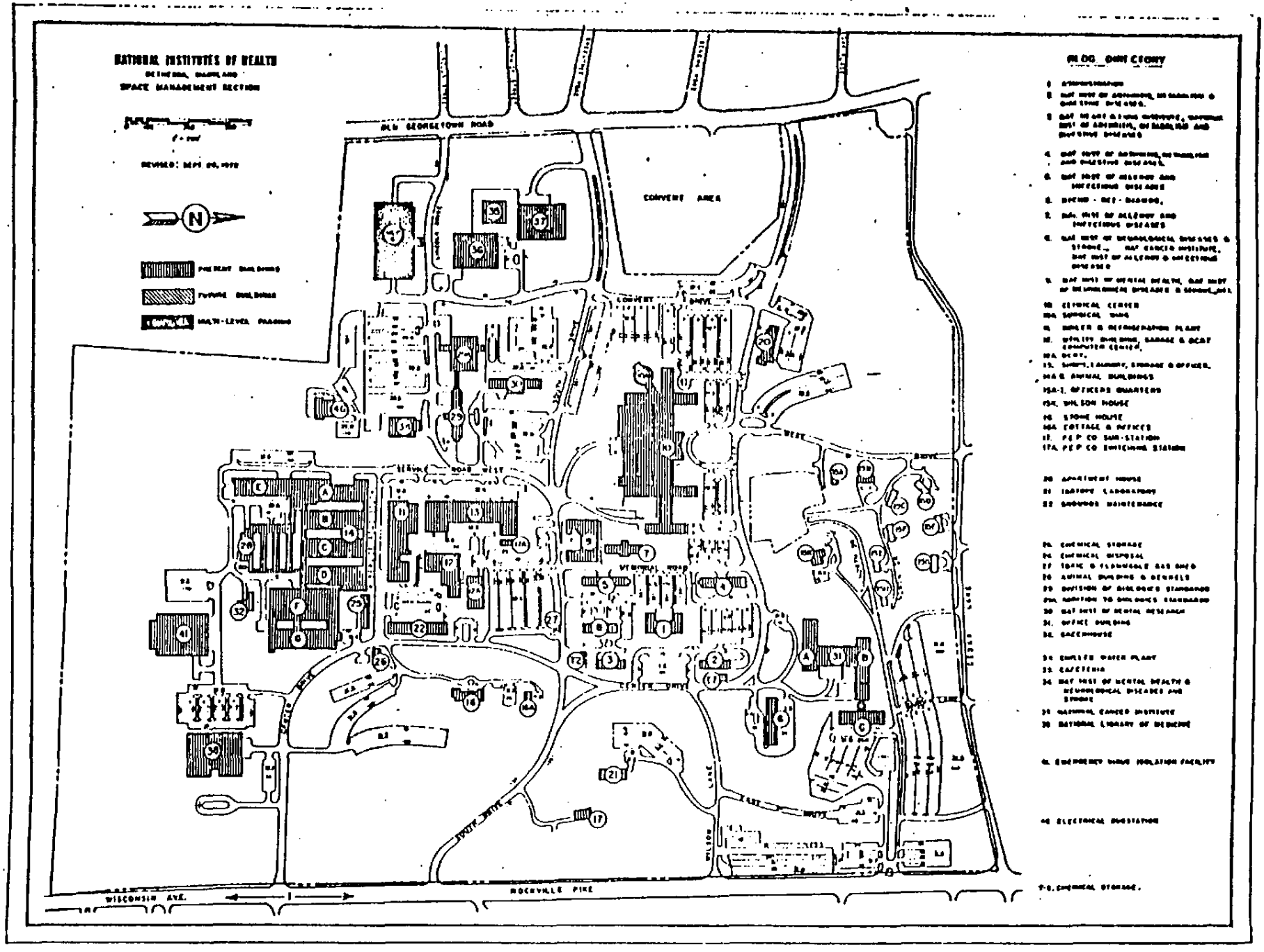
Name/Address/Telephone #	Single Room Rate	Distance from NIH (Approximate)
Connecticut Inn 4400 Connecticut Avenue Washington, D. C. 20008 (202) 244-5600	$39.68 *Steam Bath **********	5 miles
Howard Johnson's Motor Lodge 2715 University Boulevard Wheaton, MD 20902 (301) 933-1300	$33.00 $30.80* **********	7 miles
Hampshire Inn 7411 New Hampshire Avenue Langley Park, MD 20787 (301) 439-3000	$37.40 $24.20* **********	12 miles

*Special Government Rate





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A Literature Study of the Combustion Hazards of Polyvinylchloride (PVC) and Acrylonitrile Butadiene Styrene (ABS)

A Literature Study of the Combustion Hazards of Polyvinylchloride (PVC) and Acrylonitrile Butadiene Styrene (ABS)

by

Judith E. Hall* and Eric L. Tollefson, P.Eng.**
Department of Chemical and Petroleum Engineering
The University of Calgary

June 20, 1981

* Research Associate
**Professor

Table of Content

Summary

The increasing use of plastics to replace traditional materials in, for example, furniture, draperies, carpeting, electrical and thermal insulation as well as piping in plumbing systems has given rise to much concern in the event of a fire. Many plastics are very flammable, burn rapidly and produce intense heat, heavy smoke and toxic gases which together are very dangerous to life. The recent MGM Grand Hotel fire is an example of this type of fire; most of the victims dying from smoke inhalation even though far-removed from the site of the fire.

This report is the result of a literature search on the combustion hazards associated with the use of two plastics widely used in plumbing systems, namely, polyvinyl chloride (PVC) and acrylonitrile-butadiene-styrene (ABS). These two plastics, along with polystyrene, comprise about one third of the total plastics sold in the United States. Of the common plastics these three are most prone to produce extremely dense smoke on combustion. ABS is very flammable and like other nitrogen-containing polymers releases hydrogen cyanide as a combustion product. PVC is much less flammable but will burn if combustion is supported by other fuels. Large amounts of hydrogen chloride gas (HCl) are released by either heating or burning PVC.

Heavy smoke production during a fire is dangerous because: (a) it reduces visibility thus impeding escape, (b) particulates cause difficulties in breathing if inhaled, and (c) toxic or irritant gases not only interfere with vision and breathing but also damage lungs, cause confusion, unconsciousness and death. ABS, PVC, and wood produce comparable amounts of smoke when smouldering but, under flaming conditions, within one to two minutes after ignition the smoke from these two plastics is about 28-40 times as dense as from wood. Ventilation does not decrease the smoke density as it does in the case of wood.

In the case of a rapid electrical overload in PVC-insulated wire, smoke which is usually the first indication of a fire, is only noticeable after significant quantities of HCl have been released. Ionization detectors have been found to be quite insensitive to PVC smoke and have been reported to give an alarm after hazardous levels of HCl had already been exceeded.

The rapid production of very dense smoke in PVC fires, the fact that 70% of the hydrogen chloride vapor which can be produced by a sample occurs in less than one minute at 200-300°C, and the relative insensitivity of ionization

detectors to PVC smoke, all combine to deny a person exposed to such a fire a reasonable escape time.

Loss of hydrogen chloride from PVC is a thermal decomposition beginning between 170 and 190°C and becoming quantitative at about 270°C. The presence of oxygen is not necessary for this reaction to occur. At 500°C and in the presence of oxygen, combustion of PVC produces carbon monoxide as do most other organic materials.

ABS begins to decompose at 300°C, the major toxic product formed being HCN as well as a smaller amount of nitrogen dioxide (NO_2). These gases are produced from the acrylontrile part of ABS so varying the composition of the ABS may affect the amounts of HCN and NO_2 produced its combustion.

The toxicities of smokes produced from different materials have been extensively studied and it is apparent that results can be very sensitive to experimental conditions. For example when "time of death is used PVC and ABS pyrolysis products are apparently less toxic than wood but when the amount of sample which caused 50% of the animals to die was determined ABS and PVC were much more toxic than wood. The relative toxicity of PVC also rises drammatically when air is drawn over the samples towards the test animals. Physiological and histopathological studies indicate that the major toxicant in PVC pyrolysis gases is HCl. It would also seem evident from the few experiments that have been done that HCN is the major toxicant from ABS combustion.

When water is used to trap HCl in smoke toxicity tests, the animals are able to survive five times the amount of PVC pyrolysis products that they can survive without a water trap. This implies that water from sprinkler systems or other sources would be valuable in reducing the HCl content of the atmosphere during escape or in fire-fighting operations.

Carbon monoxide, hydrogen cyanide, nitrogen dioxide and hydrogen chloride all interfere with the body's system for uptake, transport or use of oxygen to reduce their capacities either seriously or fatally. Hydrogen cyanide and nitrogen dioxide are about twenty-five times as toxic as carbon monoxide based on the lethal concentration values and hydrogen chloride is intolerable at levels of 100 ppm or more with 1000 ppm causing lung edema after a very shor

exposure time. The effects of HCl will not be evident immediately and carbon monoxide can cause death as long as 9-15 months after a person apparently has recovered. The situation is further complicated by the fact that inhalation of a complex mixture of toxic gases and smoke in an actual fire situation will result in additive or possibly synergistic (greater than additive) responses that are not well studied or understood.

Information is available concerning the apparent increase in the toxicity of carbon monoxide when blood alcohol is greater than 0.1% (volume). In actual fire victims the carbon monoxide levels are elevated but very often are not sufficiently high to have caused death indicating that other toxic substances are important factors.

In actual PVC fires, even though there was little smoke in their early stages and the fires were small, the firefighters involved exhibited symptoms due to inhalation of HCl and often required medical treatment. The role of cyanide poisoning in fires seems to be less well understood but is nevertheless considered to be serious in terms of its highly toxic effects.

Calculations based on experimental data show that if 100 pounds of ABS pipe was burned in a 10,000 ft^3 apartment it would result in a maximum concentration of HCN approximately 20 times the lethal amount. The same calculations for 100 pounds of PVC pyrolyzed in the same apartment show that a concentration of HCl as high as 57,385 ppm could be reached, about 57 times the concentration that will cause lung edema on very short exposure.

The use of plastic pipe in high-rise buildings is of concern due to the fact that it will melt or burn through thus allowing toxic gases, smoke and fire to penetrate fire partitions. It is evident from this literature search that the use of plastic pipe is not a safe practice in many situations and that metal pipe would be less hazardous.

Choice of materials, and development of building practices that will contain any fire which breaks out, will minimize smoke production, smoke toxicity and smoke exposure are clearly desirable.

1. Introduction

Smoke from smouldering or burning materials is at least as hazardous to life and property as uncontrolled fire (1). Indeed, it is widely recognized that more than half the deaths attributed to fire are caused by smoke inhalation rather than by heat or burns (1). With the increasing use of plastics in buildings, including furnishings, upholstery, piping systems and electrical and thermal insulation, there is increasing concern about the fire- and smoke-producing hazards of these materials. Possible increases in danger to fire fighters and rescue workers resulting from the substitution of plastics for more traditional materials is also a concern (2,3,4).

Such concerns have been reinforced by a number of recent fires. A good example is the November 1980, fire at the MGM Grand Hotel in Las Vegas. In this fire 679 people were injured and 84 people lost their lives. Sixty-four of the victims were found on the upper floors far-removed from the site of the actual fire. The source of ignition was reported to be electrical and large amounts of foam plastic padding and other plastics were included in the fuels (5). All deaths were attributed to smoke inhalation (6) but the lethal component or components of the smoke were not specifically identified. The fact that the concentration of carboxyhemoglobin in most of the victims was not high enough to have caused death (7) indicates that other toxic gases or smoke particles must also have been involved. This opens the question as to whether or not the burning of plastics increases the lethal potential of fires.

Although a detailed consideration of the potential fire hazards of the numerous plastics now in widespread use in beyond the scope of this report, much can be learned about the dangers which can exist from considering two very common plastics, PVC (polyvinylchloride) and ABS (acrylonitrile-butadiene-styrene). The largest single use of both PVC and ABS is for piping systems. PVC is also widely used for electrical conduit, electrical insulation and telephone ducts (8). Lesser amounts are used for wallpaper, window frames, and upholstery.

A thorough search of Chemical Abstracts for information on the combustion and pyrolysis (thermal degradation) of ABS and PVC was carried out. The results are presented in this report.

The Hazards of The Pyrolysis/Combustion Process

The fire hazard a material is described by:

1. its combustibility (how readily and how rapidly it burns or releases heat)
2. the amount of smoke it produces, and
3. the toxic gases released during heating and combustion (9).

These factors are in turn related to the chemical composition and weight of the material which will determine the total heat, smoke and toxic gases that can be released under specified conditions. The exposed surface area, surface characteristics, thermal exposure and the location of the material within the fire system will also affect the fire hazard associated with it. The combustibility can be described by ease of ignition, rate of heat release, and total heat release (9). The ease of ignition and the rate of heat release from some plastics is very high compared with such traditional materials as wood (9,10,11) but other plastics are less combustible than wood (10).

Smoke evolution is a concern relevant to a significant percentage of the plastics used. In the United States 33% of the 14,791,000 metric tons of plastic sold in 1977 were the three types most prone to produce smoke: PVC, ABS and polystyrene (12).

Smoke is hazardous because: (13)

1. if dense it impedes escape, rescue or fire-fighting by obscuring vision
2. it is irritating and can be destructive to tissues of the eyes, nose, throat and lungs
3. it may contain lethal or incapacitating concentrations of toxic or suffocating gases
4. certain of its constituents particularly acid gases, may damage property.

The particulate and gaseous fractions of smoke can be considered separately, and "smoke" in this report refers to the particulates only.

Combustion Properties of ABS and PVC

1. Smoke

Very dense smoke is rapidly produced from both of these plastics and unlike with wood becomes denser under flaming conditions. Indeed for PVC the time until an observer would find it difficult to see an exit sign through 10 ft. of smoke in a 12.5 x 20 x 8 ft. room was extimated to be 2.1

minutes under smouldering conditions, and 0.5 minutes under flaming conditions (14). The corresponding times for ABS (cycolac) have been reported as 2.98 minutes (smouldering) and 0.57 minutes (flaming) (15). This short time would make escape difficult or impossible in many situations. The corresponding values for various woods ranged from 8-15 minutes (smouldering) and 4-10 minutes (flaming) (14).

2. Toxic Gases

In addition to carbon monoxide which is often present when any organic substance burns, the major products of concern from ABS and other nitrogen-containing substances such as wool, nylon, orlon, and acrilan are hydrogen cyanide and nitrogen dioxide (16,17). When PVC is subjected to thermal degradation, under smouldering or combustion conditions, hydrogen chloride gas is produced rapidly and quantitatively sometimes before smoke is evident (18). From one gram of PVC, 0.583 g of hydrogen chloride is produced. This facile production of large quantities of acid gas in fire situations is perhaps the most striking difference between PVC and more traditional materials. Some benzene is formed at the same time (19,20,21).

When acrylonitrile is pyrolyzed or burned, hydrogen cyanide and nitrogen dioxide are formed. If hydrogen cyanide is inhaled, it causes a reflex stimulation of breathing which in turn will lead to a greater concentration of the gas entering the body. It also inactivates certain respiratory enzymes thus preventing the use of oxygen by tissues (22). Concentrations as low as 100 ppm can be lethal.

Safe concentrations of nitrogen dioxide are below 5 ppm. Nitrogen dioxide is irritating to mucous membranes and when inhaled will cause damage to tissues in the upper respiratory tract. Inhalation of very low concentrations may cause little or no damage to the upper respiratory tract but may result in death hours later due to pulmonary edema (abnormal accumulation of serous fluid in the lungs) (23).

If inhaled, hydrogen chloride gas dissolves in water to become hydrochloric acid and will severely damage the upper respiratory tract leading first to breathing difficulties, then to pulmonary edema and death. Hydrogen chloride also acidifies the blood and destroys hemoglobin thereby interfering with transport of oxygen (24). However, when it is first inhaled it will tend to cause the larynx to close (laryngospasm) thus interfering with breathing but

but protecting the lungs. While PVC decomposes, benzene is also formed and it will depress the laryngospasm allowing both solids and aerosols (including acids) to enter the lungs (22).

The main action of carbon monoxide (CO) after it is inhaled, even at low concentrations, is to bind reversibly with hemoglobin (Hb) to form carboxy-hemoglobin (COHb). Thus the % COHb of a person's blood is related to the concentration of carbon monoxide in the atmosphere and the time of exposure. Carbon monoxide displaces oxygen in the blood and leads to anoxia and death, if the reaction is not reversed. In general, most persons will not show toxic symptoms below 20% COHb. Death occurs at approximately 60-70% COHb. (25). When carbon monoxide is inhaled there is also a loss in nerve conduction velocity and a drop in blood pressure which depletes the blood flow to the brain resulting in confusion and failure to respond to stimuli (22). However, even after exposure to a potentially lethal or comatose level of carbon monoxide, 80% of individuals will recover immediately or within a few days. Then perhaps 9-15 months later, 15-20% of those people suddenly develop dementia and the "shakes" dying shortly afterwards (22).

The statement that carbon monoxide is the primary killer in fires has been disputed (22) but about 53% of the fire deaths due to smoke inhalation occur within 12 hours, usually at the fire scene with fairly slight respiratory tract damage. The remainder of the deaths attributed to smoke inhalation occur after the victims are taken to hospital and treated. In these cases the respiratory tract damage continues to develop after they are removed from the fire and would implicate gases other than carbon monoxide and/or the inhalation of particulates as the cause of death (22).

Carbon dioxide is also present in smoke, but not normally in sufficiently high concentrations to cause any toxic symptoms. However, inhalation of carbon dioxide will stimulate respiration which in turn will increase inhalation of any toxic gases present. Organic aldehydes and acids which are both irritating and damaging to mucous membranes are also known to be produced from some materials (26).

Human responses to oxygen depletion and various concentrations of gases relevant to this report are found in Appendix 1 (25).

3. Flammability

In general polymers with an aliphatic backbone such as polyethylene and polypropylene are very flammable, but their tendency to generate smoke is minimal. The addition of flame retardants, especially halogen - containing compounds, while reducing the tendency to burn, increases the evolution of smoke (10) and introduces strong mineral acid gases into combustion products.

Halogen - containing polymers such as PVC are usually relatively non-flammable, with high oxygen indices (40.3% for PVC) but display high smoke generation when combustion is supported by the presence of other fuels which may include plasticizers. The oxygen index is the percentage of oxygen in an oxygen-nitrogen mixture which will support sustained combustion. The lower the oxygen index, the more flammable is the material. Representative oxygen indices are given in Appendix 2.

Polymers with aromatic rings such as polystyrene and ABS not only generate dense smoke (10) but tend to be very flammable. In fact, in several studies, ABS was one of the most flammable polymers tested (11,27).

The burning characteristics and "combustibility" of a sample can be described in terms of rate of heat release as well as ease of ignition, and total heat release. The sudden release of heat indicates a rapid spread of flame across the exposed surface. ABS exhibits a very rapid rate of heat release (see Figure 1), is very easily ignited, and burns quickly compared to wood or PVC (9).

Factors Affecting Survival

An important factor in a fire situation is a person's escape time; that is the time interval between the person being alerted to the existence of the fire and the point at which escape is no longer possible. The rate of production and distribution of smoke and toxic gases is therefore very important (2).

It has been estimated that a sleeping person needs 12-15 minutes to awaken, react to danger and take appropriate action (2). With the very rapid production of smoke (and toxic gases) from ABS and PVC the person will often not have that much time. Judgment may also be impaired on awakening as a result of breathing asphixiants such as carbon monoxide while still asleep.

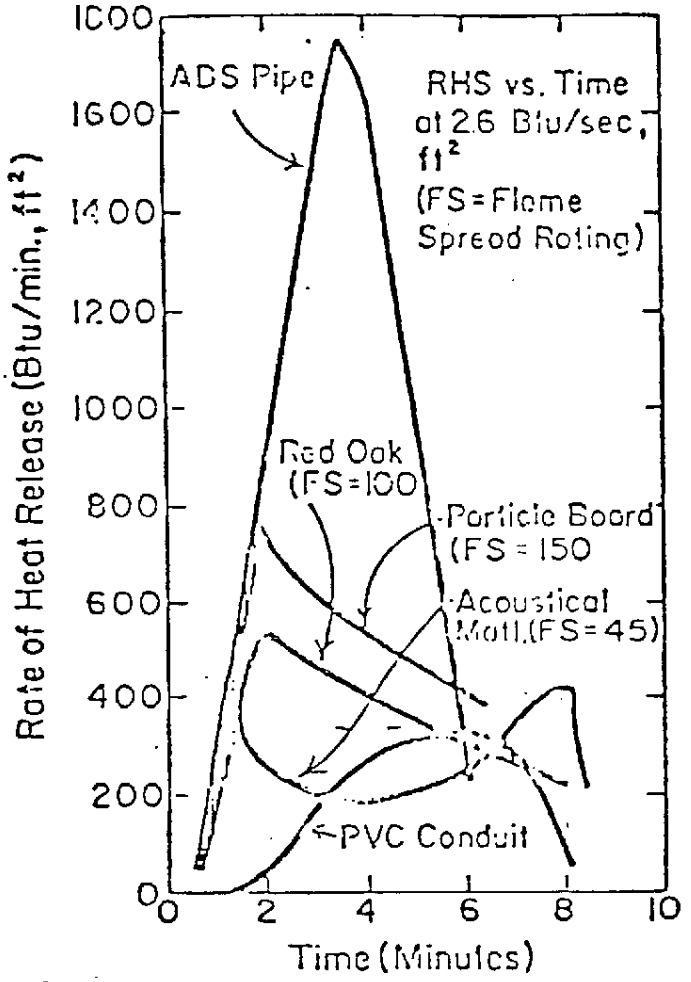


Figure 1. Rate of Heat Release (9).

Approaches to the Problem

The question of the relative hazards and toxicities of smokes from different sources can be approached in two ways. The most obvious is to study real fires but there are serious difficulties in identifying sources of individual toxicants in such complex situations. One important study of residential fires in Boston employed a sampling system built into the firefighters' turnout coats to determine the concentrations of various gases in the smoke (26).

Some autopsy data are also available on fire victims relating to toxic gases. For instance, the COHb levels and cyanide levels in blood are an indication of the exposure to carbon monoxide and hydrogen cyanide at the fire scene (28). Symptoms described by survivors are also documented in the case of PVC fires and provide an indication of what gases may have been present (2,4).

The importance of the blood alcohol level of fire victims should not be overlooked but often is either not determined or reported. If it is greater than 0.1% volume, there is probably a strong synergistic response with carbon monoxide that increases the apparent toxicity of carbon monoxide (22) and possibly also hydrogen cyanide to the brain. Indeed in one study of fire deaths in Maryland, 36% of the victims had a blood alcohol content of greater than 0.1% (29).

The second approach is to carry out laboratory scale experiments to determine the amount of smoke produced, the concentrations of the toxic gases, and the toxicity to animals of smokes produced from specific materials. There are many papers in the literature on these subjects but findings are often confusing or apparently contradictory and may be difficult to relate to real fire situations.

The wide range of factors involved in a real fire is difficult to reproduce in the laboratory. There are two distinct processes in a real fire: (1) pyrolysis (the thermal decomposition/volatilization of the sample without any flame being present at the immediate pyrolysis site) and (2) combustion (consumption of the sample by burning with a continuous flame). In the laboratory, pyrolysis and combustion are investigated separately.

Hazards associated with the particulate and toxic gas fractions of smoke can be considered separately. Data are not generally available on the biological effects due to the inhalation of smoke particulates but a concentration of about 1,000 mg/m^3 air will cause immediate respiratory difficulty; much lower concentrations of 20-50 mg./m^3 will cause light obscuration and can thereby interfere with escape (26).

II. Smoke Particulates

Tests for smoke-producing characteristics of materials employ one of two measurements techniques: gravimetric or optical. That is, some tests are based on determining the weight of smoke particles deposited on a filter under specified conditions; other tests measure the fraction of light absorbed or obstructed by the smoke. Both methods measure the airborne particulate fraction of the smoke and not the gaseous fraction.

Results are apparatus dependent and are often reported for commercial products for which the composition is not given. Cross comparisons are

difficult but comparisons of materials for each method are valid.

The best known gravimetric methods are the ASTM E162 (30) and the Arapahoe smoke tests (31). The most widely used optical methods are the NBS smoke test (32) and the ASTM D2843 test (also called Rohm and Haas XP2) (33) which measure the density of smoke accumulated in an enclosure. In some experiments a modified NBS chamber is used which allows different levels of ventilation. The ASTM E84 test (34) and the OSU release rate test (35) measure, by optical means, the density of smoke flowing past a specific location.

II-1 Results Using Optical Methods

(1) NBS Test

Specific optical densities (see Appendix 3) which can be measured with this apparatus are independent of exposed area of the specimen, chamber volume, and length of light path, but depend on specimen thickness, chemical and physical properties and exposure conditions. The exposed surface area of the sample is 6.56 square inches; the chamber volume is 18 cubic feet (14). Maximum specific optical densities are shown in Table 1 for a number of materials.

Table 1. Maximum Specific Optical Densities (Dm) for Selected Materials (14)

	Thickness	Dm	
		Smoldering	Flaming
Polyethylene (UCC - DXM - 100)	↑	526	-
PVC (UCC - QYTQ)		315	780
ABS (Cycolac)	250 mils	780	780
Douglas fir	↓	380	156

Note that for woods D_m is lower under flaming conditions compared to smoldering conditions, but exactly the opposite is true for PVC. The maximum measurable optical density was reached under both smoldering and flaming conditions for ABS.

Times at which maximum specific optical density occurred (T_m) and at which the specific optical densities (D_s) would be equal to 16 in a 12.5 x 20 x 8 ft. room, the value at which an observer would find it difficult to see an exit sign through ten feet of smoke are shown in Table 2 (14). Under smouldering conditions the times to obscuration for wood and PVC are very similar but under flaming conditions they are much shorter

for PVC. It is interesting to note that doubling the thickness of the PVC sample did not change the time to obscuration even though it roughly doubled the time to maximum specific optical density. Note also that wood and polyethylene show significantly longer times to reach the specific optical density (Ds = 16) than do the PVC and ABS samples tested, an important matter in terms of escape.

Table 2. Times (in minutes) to Obscuration and Maximum Specific Optical Densities (14)

	Smoldering		Flaming	
	T_m	T for D_s=16	T_m	T for D_s=16
Douglas Fir	20	2.1	19	4.6
Polyethylene	17	5.5	9	4.0
PVC rigid - filled	30	1.6	11	0.5
PVC rigid unfilled - 1/8" thick	14	2.1	5	0.5
PVC rigid unfilled - 1/4" thick	33	2.1	10	0.6
ABS		3.0		0.6
*ABS	11		6.5	

* *Data from reference 36*

Table 3. Effect of Ventilation on Maximum Smoke Densities from Some Smoldering and Burning Materials (14)

Material	Smoke Densities at Specific Ventilation Rates (Air Changes/hr)				
	0	3	6	12	20
Smoldering					
Rigid PVC, filled	490	335	235	160	120
Douglas Fir	380	300	225	150	90
Flaming					
Rigid PVC, filled	530	535	535	475	375
Douglas Fir	155	65	70	60	25

The effect of ventilation rate on the development of maximum smoke density is illustrated in Table 3. It should be noted from the data that ventilation decreased the maximum smoke densities under smouldering conditions but that there was little difference observed under flaming conditions for PVC (14). Similar observations were made by other workers (37,13). SA ALL BY GASKILL

ABS also produced very dense smoke rapidly (27,36) under flaming conditions. At 1.5 minutes after ignition, D_s = 176, already a much denser smoke than that which would cause obscuration of vision.

Specific optical densities are dimensionless but the time required to reach a given smoke density must depend on material surface area and chamber or room temperature. It is therefore, of interest to note that the ratio of sample surface area to chamber volume in the NBS test corresponds to 13 feet of sealed 3-inch pipe in a 4,000 cu.ft. room. Therefore, burning even a short length of ABS or PVC pipe in a room would rapidly produce dense, obscuring smoke.

(2) ASTM D2843 (Rohm and Haas XP2)

This test is limited to flaming conditions. The sample surface-to-chamber volume ratios are similar to the NBS test. It has been reported that the amount of smoke produced is almost proportional to the weight of material consumed (38). The amount of smoke produced is very dense for PVC and ABS (in agreement with NBS results) (15). The times to obscuration (D_s = 16) for PVC sheets (1 in. x 1 in. x 0.0158 in. or 1 in. x 1 in. x 0.0424 in.) were 0.03 and 0.08 minutes shorter than found in NBS tests (15).

Both PVC (QYTQ) and ABS (cycolac) reached the maximum specific optical densities measurable with this apparatus. Various polyethylenes had D_m = 10 - 214. For PVC (QCA - 2460) of 15, 20 and 40 mils thick, the respective maximum specific optical densities were reported to be 99, 82, and 319 (15).

(3) OSU Release Rate Test

This test measures the density of the smoke flowing out of an exhaust stack under flaming conditions. The sample has 100 sq. in. of exposed surface area (9).

Results show that the rate of smoke release and total amount of smoke released for samples of PVC and ABC are many times greater than for oak (12) (Table 4).

Table 4. OSU Release Rate Tests Studies (17)

Material	Orientation	Applied Heat Flux w/cm^2	Max. Smoke Release Rate units/min-m^3	Total Smoke Release Units/m^3 3 min	10 min
Oak, 1"	V	1.0	0.9	0.9	2.3
		2.0	5.5	1.8	4.6
		2.5	6.9	9.1	11.4
PVC rigid pipe	V	1.0	4.6	0.9	22.8
		2.6	114	91.4	457
PVC flexible sheet,	V	1.0	228	228	640
		2.0	336	640	731
ABS sheet, 125 mil	H	0	274	2.3	137
		1.0	366	155	457
		2.5	366	457	548

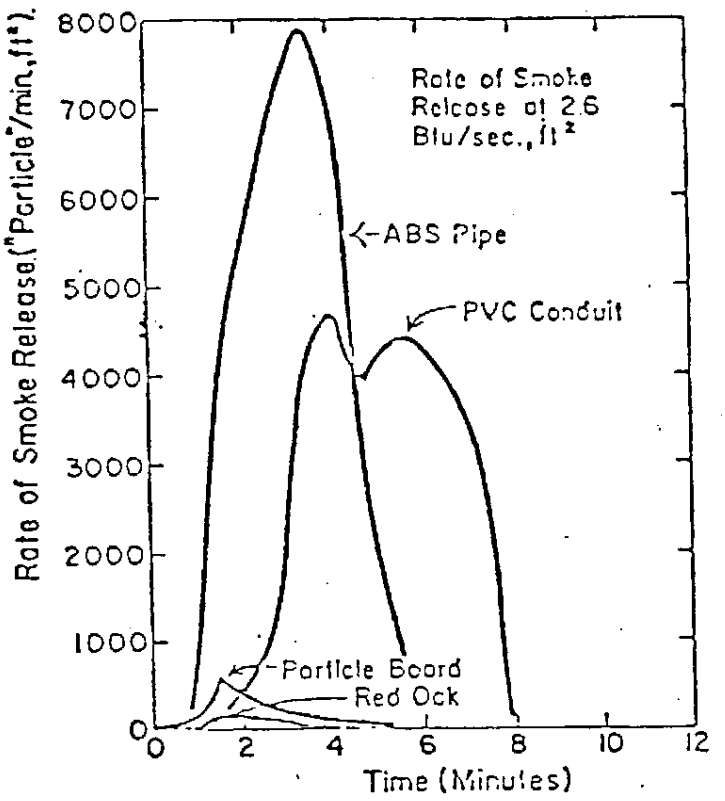
V = Vertical sample

H = Horizontal sample

1 smoke unit in 1 m^3 air will produce an optical density of 1.0 for a light path of 1 metre.

The very large variation in rate of smoke release per ft^2 of exposed surface for different materials is shown in Figure 2. While the maximum rate of smoke release for red oak is less than 200 "particles"/min ft^2 the corresponding value for ABS at the same heat flux is over 7900 and for PVC is about 5,500 (9). The use of piloted ignition and excess oxygen assures that essentially all decompositions vapors are burned and would minimize the smoke release in the case of the oak.

Figure 2. Rate of Smoke Release at 2.6 Btu/sec-ft^2 (9)



(4) Other Experiments

Other workers using different types of apparatus also observed very dense smokes from ABS and PVC compared to wood (39,40,41,42,43).

Mass optical density (MOD) (Appendix 3) relates smoke generation to the weight of sample rather than the area of sample exposed. Results are given in Table 5 (40).

Table 5. Mass Optical Densities of Materials Under Flaming Conditions (40).

Sample	MOD $cm^2 gm^{-1}$
ABS	6900
PVC with 28% plasticizer	5800
PVC	3400
PE	2900
Hardwood (3 thicknesses)	300-800

The results from the different experiments and the various calculations all show that much denser smoke is produced under flaming conditions from ABS and

II-2 Gravimetric Methods

(1) ASTM E162

In this test flaming conditions are used and the particles are collected on filter paper positioned at the top of the stack. Some results for this test are given in Table 6. It will be noted that, as with optical methods, a large difference was observed between wood and PVC (12).

Table 6. ASTM E162 Results (12)
(Flaming Conditions)

Material	Size	Thickness (mils)	Smoke Deposit (mg)
Red Oak	12x18"	750	0.3
Exterior fir plywood	"	250	0.3
PVC	"	147	28.9
PVC, Fire retardant	"	147	10.5

This shows that the optically dense smoke released by these polymers is at least partially due to release of a larger mass of smoke particles.

(2) Arapahoe Smoke Chamber

The sample is exposed to the burner flame for 30 seconds with air flowing through a filter at the top of the stack. The burner is then extinguished and air flow continued for a further 30 seconds to give a total collection time of 60 seconds (44).

Results are reported as percent smoke based on the initial weight of the sample or on the weight loss of the sample (Table 7) (12). Because some cellulosic materials (wood) smoulder for several minutes at the end of the test the calculation based on weight loss for these materials would not be valid and they are best compared to plastics using percent smoke based on initial weight (44). The results confirm that much more smoke is produced from PVC and ABS than from wood.

In conclusion it can be stated that both PVC and ABS produce copious amounts of dense smoke under both smouldering and flaming conditions. Furthermore, in the preceding discussion these plastics were compared with wood which is a traditional building material but is not used for piping or conduit systems. Traditional metal piping does not produce any smoke under normal fire conditions.

Table 7. Arapahoe Smoke Test Results (12)

(Flaming Conditions)

Material	% Smoke based on Initial Weight	% Smoke based on Weight Loss
Cellulose Fibreboard, coreboard	0.57	0.75
Hardboard	0.06	0.08
PVC flooring	0.21	6.23
PVC rigid	1.33	10.52
PVC, flexible, fire retardant	2.36	12.74
ABS, fire retardant	4.02	20.54

II-3 Relative Rates of Smoke and HCl Release From PVC

In the case of a rapid electrical overload of PVC insulated wire, the evolution of HCl preceding the detection of visible smoke is as shown in Figure 3 (18).

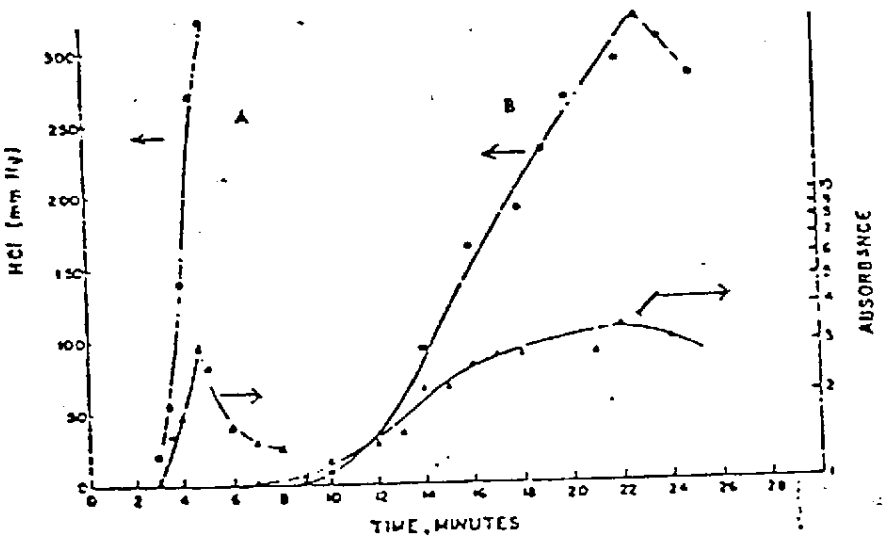


Figure 3. Comparison of Rates of Formation of HCl and Smoke for Different Heating Rates of PVC Insulated Wire. (A=40°C/min and B=15°C/min)

When pure PVC film was used the smoke and HCl evolved at the same time regardless of the heating rate used. To complicate matters further, it was found that a commercial sheet of PVC evolved smoke about half a minute before HCl was detected at a heating rate of 20°C/min, and, that at decreased heating rates smoke was detected before HCl. Under some circumstances, particularly in the case of a rapid electrical overload, HCl could be a significant hazard before a person became alerted to the fire by the presence of smoke. Firefighters should be aware of the fact that dangerous acid gases

can be present in areas involved with electrical fires even though there may be little visible smoke.

II-4 Toxic Gases Adsorbed on Soot

(1) HCl

Irritant gases are found to be adsorbed on soot. HCl adsorbed on soot would gain access to the lungs where, on combination with water, hydrochloric acid would be formed causing a violent inflammatory response, resulting in destruction of lung tissue (2,45).

Hydrogen chloride from PVC combustion was found in the gas phase, and both loosely and tightly bound to the soot. About 2% of the total hydrogen chloride was found adsorbed on soot. The hydrogen chloride that was loosely bound amounted to 19 mg/g soot on soot particle diameters of 300-1100 Å (0.03-0.11 microns). Such particles would agglomerate rapidly to form larger particle clusters. For rigid PVC the size distribution of particles was found to be 0.1-0.2 microns and the mean particle size was smaller for flaming than for smouldering conditions (42). The particle sizes ranging from 0.1 to 2.5 microns diameter (corresponding to soot aged from seconds to one hour) would be retained in the alveolar sacs to an extent of from 20-40% of those inhaled (46).

Assuming there was 1.57 grams of soot/m^3 and no HCl in the gas phase and that the breathing rate of a person is 18 l/min, after one hour of exposure 0.7 grams of soot bearing 13 mg of loosely bound HCl would be retained in the lower lungs (46). If there was a gas phase hydrogen chloride concentration of 150 mg/m^3 with no soot present, at a breathing rate of 18 l/min and an exposure of one hour about 108 mg of HCl would be retained in a person's body (46). (It has been estimated that 62% of the hydrogen chloride gas inhaled is retained in the body (47).] Therefore, it was concluded (47) that gas phase exposure was about eight times as severe as exposure to soot; however the HCl on the soot would cause damage to the lungs.

(2) Polyaromatic hydrocarbons

Polyaromatic hydrocarbons have been detected in small amounts from the combustion of various plastics, including PVC (48,49,50,51). The production of these compounds was relatively lower under flaming than under non-flaming conditions (49) (Table 8) and included the potent carcinogens benzo [a] pyrene and 7,12-dimethylbenz [a] anthracene. As the humidity of the ventilating air increased the production of polyaromatic hydrocarbons

Table 8. Amount of Polyaromatic Hydrocarbons Found in PVC Pyrolysis Products under Simulated Fire Nonflaming and Flaming Conditions (49).

	Amount µg/g of PVC	
	Nonflaming	Flaming
Fluorene	3.6	-
Phenanthrene	29.1	3.6
1-methyl phenanthrene	19.1	3.5
9-methylanthracene	15.5	3.6
9,10-dimethylanthracene	15.6	4.7
Fluoranthene	10.5	-
Pyrene	11.6	6.1
1,2-benzofluorene	35.3	4.5
2,3-benzofluorene	32.8	5.8
Chrysene, 1,2,-benzoanthracene triphenylene	16.0	10.5
7,12-dimethylbenzo [a] anthracene	3.5	-
Benzo [a] pyrene, benzo [e] pyrene	5.3	2.4
Perylene	7.3	2.4

decreased (49). The evolution of benzo [a] pyrene generally increased with increasing temperature but at high temperatures it decreased drastically when a high air supply rate was used (48).

Whilst these compounds are not considered to have acute toxicity they could be of concern to firefighters who are repeatedly exposed to them. It is difficult to assess the dangers due to the amounts of polyaromatic hydrocarbons detected in these experiments. LOW

II-5 Smoke Detectors

With respect to detectors it is interesting to note three papers in the literature (52,53,54). Tests showed that ionization detectors are particularly insensitive to the degradation products from PVC, polyurethane foam, and polyethylene (52). All ionization detectors tested showed a decreasing sensitivity (based on increasing smoke obscuration at alarm) in the order "punk" (a standard calibration source) > polyurethane > polyethylene > PVC (53). PVC cable overloads of ≥ 3.5 times the nominal current were detected by ionization detectors but the alarm was given at 3-10 times the maximum allowable hydrogen chloride concentration (54).

In the case of PVC, evolution of toxic gas is a major threat before there is sufficient smoke released to activate whatever detectors that may be in

place (55).

III-1 Decomposition of PVC

1. Temperature at which decomposition takes place

Dehydrochlorination* of PVC is essentially a thermal decomposition. Flaming and combustion conditions are not required (56). Dehydrochlorination is reported to begin between 150-190°C (57,58,59,60) becoming quantitative at about 270°C (18,61). It was also observed that pyrolysis of PVC at 600°C under helium atmosphere resulted in quantitative recovery of HCl and formation of a chlorine-free ash (62).

Woolley (63) showed that the rate and extent of dehydrochlorination was essentially independent of the amount of oxygen present in the atmosphere. Removing HCl from the reaction zone by evacuation decreases the rate of dehydrochlorination PVC but does not change the rate of benzene formation (64). Until recently the only product reported to be produced during the decomposition of PVC below 220°C was hydrogen chloride (65,66). Voorhees et al (21) established the fact that benzene and hydrogen chloride were formed simultaneously during the thermal decomposition of PVC. At 275°C a very rapid weight loss occurred accounting for 60% of the initial weight. The product was about 95% hydrogen chloride and 5% benzene (20). A second weight loss occurred at higher temperatures (66). In another experiment in which 1.0 g of PVC was burned 583 mg HCl, 729 mg. of carbon dioxide, 442 mg. of carbon monoxide, and 36 mg. benzene were formed (66). Other workers found that burning 3 g PVC in a closed container (0.12 l air) at 400-800° gave a gaseous mixture containing 14.3% HCl, 10.6% CO, 10.6 and 4.0% organic materials (67). Burning PVC in air gave 0.496 g HCl, 0.001 g $COCl_2$ (disputed by others), 0.229 g CO, and 0.433 g CO_2 per gram of PVC (67).

Although a very small amount of phosgene had been reported (67) subsequent workers have been unable to detect either phosgene or chlorine (68,69). A mixture of smaller amounts of saturated and unsaturated hydrocarbons is also formed, in addition to benzene (70,71,60,20,72,73,74,75,69).

At temperatures greater than 300° eighty compounds were formed in relatively small amounts from the combustion of PVC (76). Various chlorobenzenes (77,78) and formaldehyde (75) have also been detected. At 200°C no hydrocarbons were found (77). Carbon monoxide appeared at about 500°C (79,80) and at higher temperatures was the major product (81). The higher the pyrolysis temperature the greater the variety of gases produced (82).

2. Rate at which toxic gases are produced

Several factors affect the rate of dehydrochlorination. The rate increases with increasing temperature (59) and with increasing air flow (83, 72,56).

From the rate constants of decomposition the time required for 20, 40 and 60% dehydrochlorination of PVC in N_2 and air between 200-300°C was calculated (72). These results appear in Table 9.

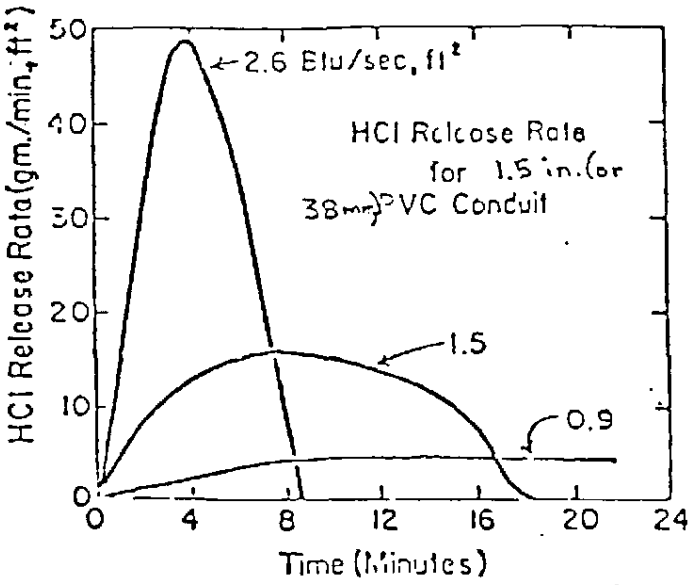
Table 9. Calculated Time (min) for Dehydrochlorination of PVC (72)

Temperature °C	20%		40%		60%	
	N_2	Air	N_2	Air	N_2	Air
200	251.4	114.9	619.8	283.3	1237.8	565.8
220	41.4	24.3	102.1	60.0	204.0	119.8
240	7.9	5.8	19.4	14.3	38.7	28.6
260	1.69	1.55	4.16	3.82	8.31	7.62
280	0.41	0.45	1.00	1.12	2.00	2.23
300	0.11	0.14	0.27	0.36	0.53	0.71

The experimental values were found to correlate well with the calculated values (72). It should be noted that time for 60% dehydrochlorination to occu is less than one minute at 300°C.

The rate of release of hydrogen chloride from 1.5 inch (3.8 cm) PVC condu at different heat fluxes is shown in Figure 4 (9).

Figure 4. Rate of Release of Hydrogen Chloride from 1.5" PVC Conduit (9)



SAL 000070860

The relative rates of smoke and toxic gas release is a matter of some concern. In the case of a rapid electric cable overload the evolution of hydrogen chloride precedes the appearance of a measurable amount of smoke (18). At 385°C heat and smoke release from PVC were very low but significant release of HCl occurred (9). It is of interest to note here that tests with chlorinated PVC water pipe showed that copious amounts of hydrogen chloride were released at about 580°C. Heat and smoke release were very small and increased when obvious burning occurred after nearly all the hydrogen chloride had been released (9).

3. Full Scale Fire Tests

Full scale fire tests have been carried out in a special compartment (3 x 3 x 2.5 m)-corridor (12 m. long x 1.3 m wide x 2.5 m high) facility designed to represent a room attached to a corridor (91). The fire load consisted of wood (120-240 Kg) in the form of a crib with thick PVC wall linings (rigid PVC sheet 0.63-115 Kg) in the compartment or corridor. Even at the corridor end of the test rig the temperature of the fire gases in all tests exceeded a bearable temperature within a few minutes after ignition.

The assessment of the hazard arising from the presence of CO and HCl is difficult because of the very high temperatures of the undiluted gases. In practical situations it is often necessary to consider the dilution of gases as would occur during the discharge of fire gases into the air enclosed within a building. The maximum concentrations of hydrogen chloride and carbon monoxide formed when the compartment and corridor gases are diluted with clean air to a bearable temperature (120°C) are shown in Table 10 (84).

Table 10. Production of CO, HCl and Smoke from Full Scale Fire Tests with PVC Wall Linings, After Dilution to a Bearable Temperature (84).

Fire Load		Compartment		Corridor		Visibility
Wood (kg)	PVC (kg)	CO (ppm)	HCl (ppm)	CO (ppm)	HCl (ppm)	(m)
123	0.9	2,750	3	4,150	8	1.6
123	2.63	232	79	---	67	1.6
120	95.0	2,230	3,230	850	1,460	2.4
120	115.0*	526	360	---	9,690	1.2
240	95.0	2,350	3,920	566	1,890	2.4
240	115.0*	6,730	1,800	3,330	20,500	2.0

*PVC used as corridor lining

Using a 127 g wood crib and 100 kg PVC wall lining in the same apparatus the amounts of HCl and CO were measured and compared to a control experiment in which the wood only was present (72). The results are shown in Figure 5.

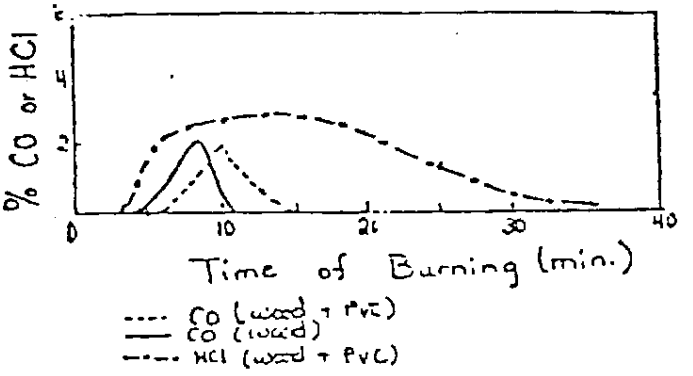


Figure 5. Toxic Gas Production from Wood and PVC Fires (Adapted from ref. 72)

The rapid and facile release of HCl when PVC is heated suggests that PVC should not be used where there is a possiblity of it becoming overheated. In service corridors, for example, if a fire should break out, very high concentratio of HCl vapor are to be expected if PVC piping, conduit and wire insultation have been employed. Firefighters need to be aware of these hazards in fighting such fires.

4. Effect of Composition of PVC on Decomposition Products

The release rate of hydrogen chloride for different PVC materials is fairly uniform (9), however the temperature at which decomposition occurs and the amount of hydrogen chloride released can vary. Certain inorganic fillers in PVC compounds can act as HCl adsorbers during pyrolysis and combustion. For example, $CaCO_3$, a typical filler in PVC wire formulations was shown to adsorb a stoichiometric equivalent of HCl when burned (85). Rigid PVC film containing plasticizer and a small amount of stabilizer completed a major part of dehydrochlorination at less than 300°C, while rigid PVC plate containing about 5% stabilizer evolved maximum concentrations of HCl at 400°C (69). PVC artificial leather evolved about 1/10 the amount of HCl compared to PVC raw material (69,86).

The amounts of aromatic hydrocarbons were found to be dependent on the presence of additivies (78). Heating PVC plasticized with phihalates gave dibutylphthalate (87).

III-2 Decomposition of ABS

When ABS is pyrolyzed in atmospheres of either nitrogen or air (36) a large weight loss begins to occur at about 300°C. The decomposition products which have been reported are hydrogen cyanide (HCN), nitrogen dioxide (NO_2), methane (CH_4), hydrogen and ethylene (C_2H_4) (88,17,89,71).

In 1974, Chaigneau (17) using a sample of ABS (22% acrylonitrile, 19% butadiene and 59% styrene) subjected to temperatures of 500-1200°C under dynamic conditions in air found the HCN and NO_2 production shown in Table 11,

Table 11. Decomposition Products from ABS (17)

Temp °C	500	600	700	800	1000	1100	1200
HCN g/100g ABS	3.00	3.56	4.09	4.62	7.61	4.59	5.42
NO_2 g/100g ABS	0.012			0.015		0.01	

Much less of the nitrogen was found as NO_2 as compared to HCN. The maximum amount of HCN was formed at 1000°C under these conditions.

Sumi and Tsuchiya (16) also using dynamic conditions and temperatures ranging from 400-800°C found that the amount of HCN produced from ABS pipe increased as the temperature increased in agreement with Chaigneau. They also observed that the yield of HCN was highest in a 50% air - 50% nitrogen atmosphere.

IV Toxicology

When an animal or man is placed in contact with a chemical agent it can produce an acute toxic effect by acting as a primary irritant upon the skin and/or mucous membranes or by being absorbed into the blood stream. Absorption of very low concentrations may affect mental functions.

The most common syndromes associated with exposure to combustion products are those resulting from impaired oxygen delivery or transport caused by impaired pulmonary function, decreased ambient oxygen or carbon monoxide binding to hemoglobin.

Animal experiments are done in several different ways. Behavioural endpoints, for example, time to incapacitation, are sometimes determined. This is considered to be directly related to escape capability as incapacitation is defined as the onset of staggering, prostration, collapse or convulsions (90). Physiological changes can be monitored by recording

changes in respiratory rate, heart rate and rhythm (EKG), brain wave activity (EEG) and blood pressure (24). The time to death for animals exposed to decomposition products under specified conditions has also been used to determine their toxicity (91,92,93,94,55). This does not allow for consideration of slow-acting toxicants such as HCl. The traditional toxicological approach is through determination of the dose required to cause death in 50% of the animals (LD50). It can be determined for a single toxicant but combustion or pyrolysis atmospheres are complex and may contain many varied toxicants making it impossible to determine a true "dose-response" relationship. The LC50 (sample weight lethal to 50% of the animals) is sometimes used to assess toxicity (95). It has also been defined in the literature as the concentration of material in the atmosphere inhaled that will produce 50% mortality (96,97). Apparent lethal concentration (ALC50) is defined as that concentration of gaseous pyrolysis products in the atmosphere being inhaled which will produce 50% mortality (96).

Histopathological studies have been carried out (98,99). The type and extent of damage in the tissues of different parts of the animals is a good indication of the toxic substances that were inhaled before death.

According to Hilado (100) 85.66% of the plastics sold in the United States are less toxic than wood. These results were based on "time to death" data for mice in an unvented chamber, and carbon monoxide and methane were the only gases for which analyses were done. It was noted that, in the case of ABS, the concentration of carbon monoxide was too low to have caused death (100,90,101,102,103). On the basis of these tests PVC was said to be less toxic than wood (100). These results have been questioned on the basis that much HCl probably did not reach the animals due to condensation and the fact that it is not a fast-acting toxicant (24). The latter point is important because only deaths occurring during exposure were recorded (100).

When wood is exposed to a 2.5 W/cm^2 radiant heat flux in a non-flaming mode, animals are incapacitated at a carbon monoxide level of 7% (22). This is likely due to inhalation of a mixture of aldehydes including acrolein, an extremely strong lachrymator which is lethal to humans at concentrations of 10 ppm (see Appendix 1). At a higher heat flux (7.5 w/cm^2) which is just below the ignition point the animals do not develop symptoms until a much highe carboxyhemoglobin level is present (22). Under these conditions the aldehydes would form and then be rapidly destroyed.

Quite different toxicities were observed using dynamic air flow conditions

and temperatures from 400 - 800°C. Toxicity factors, based on the concentrations fatal to man in 30 minutes, the weight of sample, and the volume of each toxic gas produced were calculated and are shown in Table 12 (16). From these data it can be seen that the toxicity of the decomposition products is primarily due to HCN and HCl in the case of ABS and PVC, respectively, with carbon monoxide playing a minor role.

Table 12 (16)

Calculated Toxicity Factors (l/g)

Materials	CO	CO_2	HCN	HCl
Polyacrylonitrile	7	1	1201	-
Nylon 6	17	1	931	-
ABS pipe	10	1	267	-
PVC	12	1	-	343
White Pine	47	3	-	-

A study of 72 residential fires in Boston (26) in the early 1970's using a sampling system built into the firefighters' turnout coats, showed that acrolein, benzene, hydrogen chloride, hydrogen cyanide, nitrogen dioxide and carbon dioxide were present at real fires. The carbon monoxide concentration in only 29% of the fires exceeded 500 ppm. At this concentration people would experience hallucinations after 30-120 minutes (Appendix 1). A lethal concentration to man in 30 minutes would be about 4,000 ppm (16). Carbon dioxide at the levels observed in these fires would not have been sufficient to be a significant hazard in contrast to engineered burns where high carbon dioxide concentrations were observed. In only six fires did the oxygen concentration fall below 18%. A further study in 1976 (26) again showed that low oxygen concentrations were not generally significant. This also is in contrast to results from model fires which consistently showed low oxygen concentrations (26).

An investigation of 185 fire injuries and deaths, carried out by paramedics taking blood and breath samples from the victims immediatly after their removal from the fire showed that many had low carboxyhemoglobin levels (COHb) (22); 24% had COHb greater than 50%, 36% had COHB of 11-45% and 11% had COHb of 7-10%. Clearly carbon monoxide alone did not cause a high percentage of these deaths. What did cause them remains unanswered in many cases.

When a mixture of toxic gases is inhaled synergism (meaning more than

that is not well understood. There appears to be a strong synergistic response between blood alcohol and carbon monoxide. If a person has a blood alcohol content greater than 0.1% (volume) his COHb need not be higher than 30% for death to occur (22,29). It is interesting to note that both alcohol and carbon monoxide interfer with the availability of oxygen to the brain. It is therefore, a reasonable expectation that hydrogen chloride which interfers with breathing and hydrogen cyanide which interfers with use of oxygen by tissues may be members of the same synergistic complex.

The ratio of the percentage of carbon monoxide in the blood to the percentage of carbon monoxide in the atmosphere is always higher with fumes from the combustion of materials than it is with carbon monoxide alone (24). It is possible that this is due to increased respiration caused by other gases present such as carbon dioxide or hydrogen cyanide. A statistical analysis of data on the combined lethal effects of carbon monoxide, carbon dioxide and oxygen depletion showed that generally the effect of a combination of these factors was additive and even when synergism occurred its contribution was minor (104).

An increase in the ambient temperature which is likely to occur during a fire has been reported to lower human resistance to toxic fumes (105). This is an area where much work remains to be done if we are to understand what is occurring. In time such studies may indicate why people die in atmospheres in which the maximum tolerance levels for various gases known to be present have not been exceeded.

IV-1 PVC Toxicology

1. Physiological Responses

a). Changes in Respiratory Rate

Physiological changes accompanying the decrease in respiratory rate have been well-documented in laboratory animals and humans (106).

The irritant nature of pyrolysis gases from PVC was assessed using the decrease in the respiratory rate of mice (98). The animals were exposed under dynamic air flow conditions. For mice the RD_{50} in mg/l of pyrolysis products were found to be: (106) (RD_{50} is the sample weight that caused at 50% reduction in the respiratory rate)

RD_{50} mg/l	Material pyrolyzed
0.24	Douglas Fir
0.50	PVC (no plasticizer or fire retardan
0.19	PVC (plasticizer)
0.45 (275 ppm)	HCl

The concentration of chemicals which caused RD_{50} in mice were found to be intolerable to man. The 0.1 RD_{50} value for mice was uncomfortable but tolerated by man (107).

b). Other Physiological Responses

Thermal decomposition of polymers can produce chemical species that may contribute little towards sensory irritation but which would have a significant lethal potential. For example, benzene which has been shown to be produced from PVC at the same time as hydrogen chloride (20,21) is a powerful sensitizer of the heart to epinephrine. Thus cardiac arrhythmias (irregularity of the heart) and ventricular fibrillation (rapid and erratic contraction of the individual muscle fibres of the ventricular walls of the heart producing weak and irregular heartbeats) could be induced, particularly if a person was also experiencing a deficiency of oxygen. Such effects on the heart during exposure of rats to thermal decomposition products of various polymers have been noted (106). The maximum rate of decrease in respiratory rate is not as important as the time of onset of irritation and its duration. The total response was quantitatively related to the total stress imposed on the animals by the Sensory Irritation Stress Index (SISI) (98). On this basis PVC was more toxic than douglas fir and polyurethane. A comparison of PVC with HCl suggested that the sensory irritation response was due primarily to HCl (98).

Rabbits were exposed to PVC pyrolysis products under smouldering (400°C) and flaming (800°C) combustion for thirty minutes and the arterial pO_2, pCO_2, pH, central nervous system (EEG) and cardiovascular system (EKG) were monitored (24). As in the respiratory rate studies, the intoxication syndrome due to combustion of PVC was found to resemble the results of exposure to HCl. The concentrations of carbon monoxide present were insufficient to have killed the animals. The rabbits died during the recovery period, sometimes after 15-30 days.

With carbon monoxide alone, the EEG activity decreased and cardiovascular modifications were not large (24). On the other hand, both HCl and PVC

decomposition products caused great decay of the cardiovascular system, lowering of the EEG and rapid appearance of acute pulmonary edema (abnormal accumulation of serous fluid in the lungs). When a water trap to remove HCl was present only the effect of carbon monoxide was observed in the rats and they survived exposure to the pyrolysis products from about five times as much PVC (24).

With wood fumes the effects were the same as for carbon monoxide for the first fifteen minutes, but just after this period a dramatic decay of the cardiovascular system occurred. Death followed at about the end of the thirty-minute intoxication period, and acute pulmonary edema was observed. Acrolein and other aldehydes known to be present in wood decomposition products (127) could be responsible for this effect (24).

Kishitani (108) reported that EKG (cardiovascular) abnormalities in mice exposed to PVC degradation products appeared prior to the generation of large quantities of smoke. This is a similar effect to that experienced by firefighters at PVC fires (see Section IV-4), and is more evidence that HCl is evolved before detectable amounts of smoke. The COHb of dead mice exposed to PVC degradation products averaged 21.2% which is much below the lethal amount of about 70% (109).

Workers acutely intoxicated by inhalation of the combustion gases from PVC had moderately elevated venous COHb chloride is known to cause this, whereas carbon monoxide results in high pO_2 (24).

The results of all of these physiological experiments seem to indicate that the toxicity of PVC degradation products is mainly due to hydrogen chloride.

2. Mortality

a). Time to Death and Lethal Concentration

Time to death is a very poor index of toxicity because extremely toxic chemicals are not necessarily fast-acting (111,22). Using time to death as a toxicity index PVC was less toxic than wood (55,112,113). However, when the sample weights lethal to 50% of mice during a 30-minute exposure period and a 10-minute recovery period are determined the values were 12-15 grams of PVC and 64 g of douglas fir (114). Dynamic conditions were used and PVC is clearly much more toxic than wood in this case. Whether static or dynamic conditions were used was found to make a significant difference to the toxicities of materials, with irritant gases such as HCl playing a much greater role under the dynamic conditions (45).

It is interesting to note that when HCl, CO and CO_2 are removed from PVC pyrolysis products the time to death for mice is about twice as long (94).

3. Histopathological Studies

Based on pathological changes observed in mice PVC is much more hazardous than douglas fir or polyurethane (98). It must be noted that the mouse is an obligate nose breather and man is a voluntary nose breather. When irritation occurs, man will convert immediately to mouth breathing and the first susceptible epithelium would be the larynx. Damage to this area comparable to that seen in the nose of the mouse exposed to HCl or PVC pyrolysis products would markedly obstruct the airway either killing the victim or necessitating immediate surgical therapy (115). A comparison of the damage to tissues from exposure of animals to HCl and PVC degradation products led to the conclusion that HCl was the principal contributer to the toxicity in the case of PVC (99,24,22).

After exposure to PVC combustion products, the development of completely abnormal cells was observed in rats (22). If the PVC contains antimony a massive haemorrhage may occur 4-5 days later (22).

IV-2 ABS Toxicology

1. Behavioural Endpoints and Mortality

Nearly all the experiments with ABS have been done using a method developed at the University of San Francisco referred to as the "USF test" (93). A second method, the Federal Aviation Administration-Civil Aeromedical Institute (FAA-CAMI) method has also been used (116, 117). The times to various behavioural endpoints and to death were determined. In these experiments the exposure chamber atmosphere was never analyzed for HCN or NO_2, but it was noted that the concentration of carbon monoxide was insufficient to have caused death (118,90,101,102,103). This is in contrast to the case of polyethylene where the major toxicant is carbon monoxide (116,119).

When the "USF" methods were used the introduction of forced air flow (G,H,I) caused a marked reduction in deaths in the case of polyethylene but it resulted in decreased times to incapacitation and death in the case of ABS. Table 14 (120,116,119). The times to these endpoints also depended on the rate at which the sample was heated, and were shorter when ABS was exposed to a fixed temperature of 800°C than when a rising temperature program was used (Table 14) (121,122,120,103). The relative toxicities of the pyrolysis products appeared to be fairly insensitive to the temperature program used (97). The effect of oxygen depletion was not discussed in any of these papers although in a control experiment using methods B,E, and F (see Table 14) the oxygen concentration was reduced to 12% after 30 minutes

Table 14

Results for "USF" Tests on Mice (120,116,119,118,113,55)

Method	Temp. °C	Air Flow (l/min)	Sample	Time to Incapacitation (min.)	Time to Death (min)	Mortality
B	200-800	0	PE	16.68	22.60	8/8
			ABS	13.52	17.62	20/20
			woods	10.34	14.72	
			PVC	5.95	16.37	
E	600	0	PE	9.95	16.62	8/8
			ABS	5.83	18.52	8/8
F	800	0	PE	3.57	11.72	8/8
			ABS	3.09	9.51	16/16
			woods	3.23	6.16	
G	800	1	PE	2.91	no deaths	0/8
			ABS	1.69	3.80	8/8
H	800	3	PE	5.11	no deaths	0/8
			ABS	1.47	3.47	8/8
I	600	1	PE	5.31		1/8
			ABS	2.84	4.53	8/8
J	600	3	PE	4.08	9.69	7/8
			ABS	2.80	5.69	8/8

(96). Using the apparent lethal concentration values as a toxicity index for mice in a sealed chamber ABS and PE appear to be more toxic than wood in contrast to the results using time to death. The ALC_{50} values in mg/l were (116,123,96):

ABS,2	10.45
PE	11.81
ABS,1	20.32
Douglas Fir	22.40
Red Oak	64.00

The large discrepancy in results for the two ABS samples probably is due to their composition. Varying the ratio of acrylonitrile: butadiene: styrene gives a tremendous variety of ABS products. This results in confusion as many papers do not state the composition of the ABS used.

The lethal dose (LD_{50}) based on the quantity of material which after combustion caused 50% mortality in mice in 10 minutes was determined and the relative toxicities were ABS > polyethylene > PVC, under these conditions Table 15 (124].

In the case of ABS and other polymers containing nitrogen, as the char yield increased from 0-20% the time to death increased but at char yields greater than 20% time to death decreased (93). The higher the char yield, theoretically the higher the fraction of the original carbon retained in the char and consequently the lower the concentration of carbon monoxide produced (101]. Thus it would seem that the toxicity due to ABS is related to toxicants other than carbon monoxide as already observed in other experiments.

Hydrogen cyanide and nitrogen dioxide, both detected and measured in ABS pyrolysis gases (17], are, on the basis of LC_{50} values, about twenty-five times as toxic as carbon monoxide (125].

Table 15 (124]

LC_{50} Values for Plastics

ABS	0.034 g
PE	0.052 g
PVC	0.140 g

IV-3 Real Fires Involving PVC

In PVC fires a study of the medical histories of over 100 firemen showed that they became disoriented and that their COHb was usually less than 20% (22). In another study it was observed that at 17% COHb some subjects had a momentary lapse of attention and failed to respond to all the stimuli presented (2). This could explain the fact that firefighters, having detected the sharp odor of HCl do not always seem capable of escaping from the vapors.

Several PVC fires have been investigated (19). In one case less than one pound of electrical insulation (plasticized PVC) burned yet five of the eight firefighters experienced shortness of breath, eye irritation, loss of balance, loss of co-ordination, numbness and chest pains and had to be treated in emergency. All exhibited a rapid irregular pulse and developed a wheezing condition and coughs during the postexposure period.

A second fire involving a small amount of PVC pipe and plasticized PVC, resulted in firefighters experiencing respiratory difficulty immediately upon entering the building although a very limited amount of smoke was observed. After the fire was extinguished they experienced the same symptoms as above. Upon returning to the station these firefighters complained of a burni sensation of the neck, wrists and elbows. Twenty-four hours after exposure they experienced a sloughing of skin where they had experienced the burning sensation (19). A third fire involving plasticized PVC electrical insulation also resulted in the incapacitation of the firemen (19).

Several important features of these fires and those reported by Esch and Dyer (2) were that all of them were small and easily extinguished, the level of smoke was described as low to moderate, and the intoxication syndrome described by all of the firefighters was essentially the same.

On a larger scale, a PVC fire in 1975 in the New York Telephone Company installation generated smoke so dense that it hindered all phases of fire-fighting operations and resulted in over 200 people being treated for smoke inhalation (4).

It is clear that smoke and toxic gases from burning or heating PVC are dangerous to people and that the use of PVC in buildings is a significant concern.

It is also apparent once again that those involved in fighting fires in which plastics are consumed should be extremely cautious. Such fires, depending upon the conditions, may cause relatively little to extremely dense smoke.

Both extremes are dangerous. On the one hand, toxic gases may be quite concentrated with little smoke; on the other hand both toxic gases and the effects of dense smoke can be very damaging to the people involved unless proper precautions are taken.

IV-4 Real Fires Involving ABS and Plastics Known to Produce Hydrogen Cyanide

In 1977 a fire in a Tennessee jail resulted in 42 deaths. The only thing which burned was the cell padding which was styrene-butadiene rubber covered with neoprene-covered nylon fabric. It had been patched with toluene-diisocyanate polyether-polyurethane covered with PVC-nylon fabric. In this case, the cyanide could not account for the deaths not already explained by CO in the 10 victims autopsied. In spite of the relative simplicity of this fire, the toxicological significance of elevated HCN in fire fatalities was not resolved (28).

In the case of the MGM fire, blood cyanide in one victim was 7-9 µg/ml and COHb was 22.2%. Several other victims with blood cyanide levels of 1-2 µg/ml had COHb 18.2-48.2%. One with cyanide levels of 2-3 µg/ml had COHb 40%. None of these COHb levels is considered high (7). In fact an analysis of the data in (7) showed that the COHB was below the accepted lethal concentration in all but one case (Table 16). Whether the cyanide levels in conjunction with the CO levels in the victims were sufficient to have caused death is unknown with one exception. Blood alcohol for these victims was not reported (7).

Cyanide toxicity is a difficult problem. Just what the toxic concentrations are is not agreed upon. Normal blood cyanide levels for humans range from 0 to 0.22 µg/ml, with an average of 0.05 µg/ml for non-smokers (128). These higher background levels are attributed to cigarette smoking. The above results were obtained on 32 living subjects and 22 non-fire related deaths (128). In acute cyanide poisoning, the blood level is likely to be 5 µg/ml and inhalation of HCN results in signs and symptoms of acute toxicity at blood concentrations at or above 0.2 µg/ml blood (129).

Blood cyanide in fatal cases may be below 1 µg/ml when HCN gas is inhaled (130). By contrast Caplan et al. (126) considered 0.26-1.0 µg/ml as being sub-toxic concentrations in a report on cyanide concentrations in 25 fire fatalities. Elevated blood cyanide has generally been found with significantly elevated COHb in fire victims, in contrast to the autopsy results from the MGM fire.

Table 16

COHb Concentrations in Victims of the MGM Grand Hotel Fire (7)

% COHb	No. of Victims	(% of Victims)
≤ 10	4	(5.6)
11-20	9	(12.9)
21-30	17	(23.9)
31-40	24	(33.8)
41-50	7	(9.9)
51-60	9	(12.7)
≥ 60	1	(1.4)

V-1 Rates of Smoke and Acid Gas Release in Rooms

Two examples taken from an article in the literature by E.E. Smith are instruct on this topic (9). The release rate of HCl is such that 2.0 ft (60.96 cm) of 1.5 inch (3.81 cm) PVC conduit when exposed to a temperature of 1,000°F (538°C) will release over 0.1 lb (45.4 g) of HCl per minute. At this rate the air in a 10 x 10 x 100 ft (3.05 x 3.05 x 30.5 m) corridor in which the combustion occurs would reach an average concentration (assuming rapid mixing) of 100 ppm HCl in less than 45 seconds. This concentration of HCl would be intolerable to breathe.

The use of PVC in ducts is also a matter of concern should it suddenly become exposed to fire or intense heat (9). Assume that 100 ft^2 (9.30 m^2) of vinyl-covered fibrous glass duct liner is in the concealed space above a 4,000 ft^3 (113.49 m^3) compartment and that it is suddenly exposed to a heat flux of 2.6 Btu/sec.ft^2 (2.95 watts/cm^2). It is assumed that the ventilation system pulls 10% of the compartment's air (400 ft^3 or 11.35 m^3) per minute into a corridor. In less than one minute 775 "particles"/ft^2 x 100 ft^2 (8,333 "particles"/metre^2 x 9.3 m^2) or 77,500 "particles" will be released into the compartment reaching a maximum of 18.5 "particles" per ft^3 (660.7/m^3). The rate of smoke "particle" emission when there is 90% transmissic of light (O.S.U. Apparatus - Section II-1) was determined to be 198 "particles" per minute (9). In the first minute following the "flash" fire, over 7,000 smoke "particles" will be discharged into the corridor. If these "particles" were uniformly distributed along a 10 x 10 x 50 ft (3.05 x 3.05 x 15.25 m) or 5,000 ft^3 (141.86 m^3) corridor the concentration would be 7,000/5,000

or 1.4 "particles"/ft^3 (7000/141.86 = 49.34 "particles" per m^3). This concentration produces a degree of obscuration which would make it impossible to see an exit sign at a distance of 5.5 feet (1.68 m).

The major hazard from the duct material would be from the HCl released. During the first minute of exposure 7.5 g/ft^2 x 100 ft^2 (80.65 g/m^2 x 9.3 m^2) (9) or 750 g (1.65 lb) of HCl would be released. Over the next minute, 75 grams (0.17 lb) of HCl would be discharged into the corridor where the average concentration could reach 400 ppm, making it unsafe as an escape route.

If the same surface area of red oak were present in the same concealed space the smoke concentrations reached in the corridor would be very different (9). Because of the larger mass of red oak present the total amount of smoke could be larger, but, because of the slower release rate, the maximum number of "particles" per minute discharged into the corridor would be less than 25% of the number from the duct liner (9).

Using the amounts of HCN and NO_2 measured when ABS is pyrolyzed at 800°C (17), we can calculate the concentrations of these gases in an average apartment taken to be 10,000 ft^3, assuming that there are 100 lb of DWV* pipe and fittings in that apartment. These calculations also assume the composition of the ABS to be 22% acrylonitrile, 19% butadiene and 59% styrene as in (17). From 100 lbs of this ABS at 800°C, assuming that all of it burned, 1,739 l of HCN and 3.3 l of NO_2 (at STP) would be produced. Thus the average concentration of HCN in the 10,000 ft^3 apartment would be 6,140 ppm, about 22 times the concentration (280 ppm) that would be immediately fatal (see Appendix 1). The concentration of NO_2 would be 11.7 ppm, a level which would be mildly irritating to the eyes, nose, and respiratory tract (see Appendix 1).

V-2 Behaviour of PVC and ABS Pipes in Fire Tests

Opposition to the use of plastic pipe in high-rise buildings particularly, is based on the fact that it will burn through and thus might allow fire gases, smoke, and possibly flames to penetrate fire partitions. A paper by P.C. Attwood (109) in which an extensive series of small scale tests are described using a positive pressure of 5 mm within the fire compartment and either a horizontal or vertical penetration of the partitions is quite informative. He discusses several possible situations involving the use of plastic pipe.

*Drain, waste, vent.

Horizontal Pipes

1. Unprotected

The wall was 5/8-in. type X gypsum board mounted on both sides of 2 x 6-in. pine studs. The exposed side of the plumbing consisted of a 2-in (50.8 mm) lateral with a water-filled P-trap. This lateral penetrated the wall and joined the stack within the wall cavity. The exposed gypsum was backed by a sheet of 24 ga. sheet metal and the PVC wall section was fire-stopped at the top. (104)

ABS laterals sagged and collapsed within 7 minutes; the pipe burned through in 10 minutes for ABS and 19 minutes for PVC, completely exposing the penetration and igniting the pipe and studs within the wall cavity.

2. Steel-Sleeved Laterals at a 45° Angle

With both 1.5-in (38 mm) and 3-in (75 mm) PVC pipe penetrating walls at a 45° downward angle protection was provided for up to two hours by the formation of a plug due to the intumescent nature of PVC and to char formation. A 3-in diameter pipe would be the largest one that would form such a plug. Pipe above the plugs had been totally consumed.

The same test with 1.5-in ABS pipe resulted in the pipe being totally consumed leaving an open path for fire gases. A test with ABS pipe penetrating a wall upwards at a 45° angle gave similar results.

With 1.5-in PVC pipe, penetrating the wall upwards at a 45° angle, it was found that a barrier against flame and gas propagation was formed due to swelling and charring of the pipe as long as the unexposed end of the assembly was unvented. (104)

3. Mechanical Shut-Off Devices

Mechanical shut-off devices which relied on the softening behaviour of thermoplastics at elevated temperatures were also tested. To be effective the closure device should shut as the plastic collapses, creating a seal. A variety of single shut-off devices were tested with failure times ranging from 28 minutes to 115 minutes. Such devices were generally unsatisfactory, and the 115 minute duration of one test was only a result of severe blistering of the metal assembly presumably caused by acidic products (HCl) from combustion of PVC. A double shut-off device was more successful and provided protection for up to two hours, although with ABS, combustion products vented through the plumbing system until the second device pinched off the pipe after 60-70 minutes.

Vertical Pipe Assemblies

1. Unprotected Pipe

A 4-inch (10.2 mm) pipe extending seven feet (2.13 m) above a concrete slab and 4 inches below it was used for the tests. A twelve-inch, long steel sleeve was around the pipe. The 4-inch end of the pipe was heated in the furnace. After 14 minutes for ABS and 22 minutes for PVC the pipe had softened sufficiently to collapse in a heap around the sleeve on top of the slab creating a temporary seal. The ABS ignited immediately whereas the PVC burned through after 35 minutes. (104)

2. Stacks Within Vented Chases

In each test damage was substantial: a remnant of pipe remained in the top of the chase, the rest of the pipe having collapsed into the bottom of the chase. In one PVC test and the ABS test the pipe in the chase was totally consumed. In two PVC tests the furnace gases had created a path through the PVC ash, thus exposing the penetration. (104)

3. Mechanical Shut-Offs

In the time before a seal is created (30 minutes and 25 minutes for 3-inch (75 mm) PVC and ABS and 22 minutes for both 4-inch PVC and ABS) hot combustion gases and smoke are vented through the plumbing system. (104)

4. Unvented Applications

Three-inch copper, ABS and PVC drain pipes were connected to water closets with the trap filled with water. In the PVC and ABS tests the pipe within the furnace was consumed and a small amount of smoke and fume seepage was evident around the ungrouted base of the water closet. By the end of two-hour tests all ABS and PVC pipe, flanges and rubber seal rings had been consumed. In the copper tests, the system remained intact except for the seal ring. Severe cracking of the water closet base occurred in each test, but only on surfaces not contacting water. There was no loss of water in any test but smoke seepage occurred through the cracks in the water closet.

Considering the rapid rate of dehydrochlorination of PVC at reasonably low temperatures there is a possibility that significant amounts of HCl would be vented through the plumbing system before any mechanical shut-offs would have sealed the pipe, or through the cracks in the case of water closet Unprotected plastic pipes, both horizontal and vertical are obviously hazardous (1

It must be concluded on the basis of the above that integrity of fire partitions penetrated by either ABS or PVC pipe is indeed compromised and that the mechanical shut-off devices tested were generally ineffective despite the author's conclusion (104) that plastic pipe can penetrate fire separations without propagating fire beyond the separation.

Conclusions

Some conclusions derived from this literature search are the following:

1. The main product of pyrolysis or combustion of PVC is hydrogen chloride vapor which is not only extremely irritating to the eyes and nose but causes extensive lung damage when inhaled.

2. ABS is a very flammable plastic which on combustion produces deadly hydrogen cyanide as well as carbon monoxide.

3. The length of time between the initiation of combustion of ABS or PVC in a room and the point at which concentrations of smoke and toxic gases become overpowering to a victim is short probably about one minute.

4. ABS and PVC under test conditions produce many times more smoke under flaming conditions than a number of woods that were tested.

5. Ionization detectors are relatively insensitive to the products of combustion of PVC sometimes giving a warning after the concentration of hydrogen chloride has built up to several times the tolerable concentration.

6. Use of plastic pipe plumbing systems in high rises and multi-unit dwelling places can contribute to the rapid production of dangerous levels of smoke and toxic gases as well as spreading of flames should the components of such a system catch fire. On the basis of experiments described in the literature it is evident that fire proof penetration of fire partitions by plastic pipe has not yet been achieved.

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References

1. Gaskill, J.R., "Smoke Development During Pyrolysis or Combustion" in Smoke and Products of Combustion, Vol 2. fire and flammability series edited by C.J. Hilado, Technomic Publishing Co. Inc., Westport, Conn. 1973, p. 1.

2. Dyer, R.F. and Esch, V.H., "Polyvinylchloride Toxicity in Fires, Hydrogen Chloride Toxicity in Fire Fighers", J. Am. Med. Assoc. 1976, 235, 393.

3. Woolley, W.D., " The Hazard of Building Contents in Fires", Second Symposium on Combustibility and Plastics, Ottawa, Canada, October 30-1, 1979, p. 117.

4. Clark, P.R., "Plastics and Fire: A Fire Fighter's View", Second Symposium on Combustibility and Plastics, Ottawa, Oct. 30-1, 1979, p. 218.

5. "Fire at the MGM Grand, a preliminary report", Fire Journal, March 1981, p. 33.

6. Bush, V.R., "MGM Grand Hotel Fire, Las Vegas, Nevada", Building Standards, Jan-Feb. 1981, 6.

7. Clark-County Coroner-Medical Examiner, MGM Grand Hotel Fire Report.

8. Modern Plastics Encyclopedia 1980, p. 4.

9. Smith, E.E., "Fire Hazard Characteristics of Duct Materials", ASHRAE 1972, 14(7), 29.

10. Imhof, L.G. and Stueben, K.C., "Evaluation of Smoke and Flammability Characteristics of Polymer Systems", Polym. Eng. Sci., 1973, 13(2), 146.

11. Kourtides, D.A. and Parker, J.A., "Flammability Properties of Some Thermoplastic and Thermoset Resins", SAMPE Q. 1978, 9(3), 36.

12. Hilado, C.J., Cumming, H.J., and Machado, A.M., "Screening Materials for Smoke Evaluation", Modern Plastics 1978, 55(7), 61.

13. Gaskill, J.R., "Smoke Development of Plastics Under Various Fire Parameters", Soc. Plast. Eng., Tech. Pap., 1972, 18(Pt.1), 264.

14. Gaskill, J.R. and Veith, C.R., "Smoke Opacity from Certain Woods and Plastics", Fire Technol. 1968, 4, 185.

15. Hilado, C.J., "The Effect of Chemical and Physical Factors on Smoke Evolution from Polymers" in Flammability of Solid Plastics Vol. 7 fire and flammability series ed. by C.J. Hilado, Technomic Publishing Co. Inc. 1974, 93.

16. Sumi, K. and Tsuchiya, Y. "Toxicity of Decomposition Products -

Polyacrylonitrile, Nylon 6 and ABS", Build. Res. Note - Natl. Res. Counc. Can. Div. Bldg. Res., 1976, 1 ..

17. Chaigneau, M. and LeMoan, G., "Pyrolysis of Plastic Materials VII. Polyacrylonitrile and Co-polymers", Ann. Pharm. Fr., 1974, 32, 485.

18. Comeford, J.J. and Birky, M., "Measurement of Smoke and Hydrogen Chloride Evolution from PVC", Fire Technol. 1972, 8(2), 85.

19. Einhorn, I.N. and Grunnet, M.L., "The Physiological and Toxicological Aspects of Degradation Products Produced During Combustion of PVC Polymers", Spec. Rep. - Electr. Power Res. Inst. (Palo Alto) 1980, EPRI EL - 1263, Flammability Solid Polym. Cable Dielectr., 3/1 - 3/47.

20. O'Mara, M.M., "Combustion of PVC", Pure Appl. Chem. 1977, 49(5), 649.

21. Voorhees, K.J., Ryan, P.W., Hickelson, R.W., Einhorn, I.N. and Futrell, J.H., Proceedings 23rd Annual Conference on Mass Spectrometry and Allied Fields, Houston, Texas, 1975, p. 200.

22. Einhorn, I.N., "Methodology for the Study of Toxicology in Combustion : Application to PVC, J. Macromol. Sci., Chem. 1977, A 11(8), 1519.

23. Deichmann, W.B. and Gerarde, H.W., Toxicology of Drugs and Chemicals, Academic Press, N.Y. and London, 1969.

24. Boudene, C., Jouany, J.M. and Truhaut, R., "Protective Effect of Water Against Toxicity of Pyrolysis and Combustion Products of PVC and Wood, J. Macromol. Sci., Chem., 1977, A 11(8), 1529.

25. Hilado, C.J., Flammability Handbook for Plastics, 2nd edition, Technomic, Westport, Conn., 1974.

26. Trietman, R.D., Gold, A., and Burgess, W.A., "Air Contaminants Encountered by Firefighters", Second Symposium on Combustibility and Plastics, Ottawa, Canada, October 30-1, 1979, p. 28.

27. Kourtides, D.A., Gilwee Jr., W.J. and Parker, J.A., "Thermochemical Characterization of Some Thermally Stable Thermoplastic and Thermoset Polymers",Thermosets High Perform. Thermoplast. 1977, 113.

28. Birky, M.M., Paabo, M. and Brown, J.E., "Correlation of Autopsy Data and Materials Involved in the Tennessee Jail Fire", Fire Safety J., 1980 2(1), 17.

29. Berl, W.G. and Halpin, B.M., "Fire-Related Fatalities: An Analysis of Their Demography, Physical Origins and Medical Causes", Fire Standards and Safety, A.F. Robertson, editor, ASTM Symposium, Gaithersburg, Md., April 5-6, 1976.

30. "Standard Test Method for Surface Flammability of Materials Using a Radiant Energy Source", ASTM E 162-176, ASTM Standards, Part 18, 1977.

31. Hilado, C.J. and Cumming, H.J., "Studies With the Arapahoe Smoke Chamber",

J. Fire Flammability, 1977, 8, 300.

32. Lee, T.G., "Smoke Density Chamber Method for Evaluating the Potential Smoke Generation of Building Materials", NBS Technical 757, Jan. 1973.

33. "Standard Method for Measuring the Density of Smoke from the Burning or Decomposition of Plastics", ASTM D2843-70, ASTM Standards, Part 35,(1977).

34. "Standard Test Method for Surface Burning of Building Materials", ANSI/ ASTM 84-77, ASTM Standards, Part 18 (1977).

35. Smith, E.E., "Measuring Rate of Heat, Smoke and Toxic Gas Release", Fire Tech, 1972, 8, 237

36. Kourtides, D.A., Parker, J.A. and Hilado, C.J., "Thermochemical Characterization of Some Thermoplastic Materials", J. Fire Flammability, 1977, 8(1), 59.

37. Gaskill, J.R., "How Plastics Smoke", Soc. Plast. Eng. J., 1972, 28(10), 43.

38. Saito, F., Research Institute (Japan), Research Paper No. 33, 1968.

39. Calcraft, A.M., Green, R.J.S. and McRoberts, T.S., "Burning of Plastics .1. Smoke Formation", Plast. Polym., 1974, 42(16), 200.

40. Meisters, M., "More Realistic Testing of Smoke Generation", Plast. Eng. 1976, 32(8), 49.

41. Bankston, C.P., Powell, E.A., Cassanova, R.A. and Zinn, B.T., "Detailed Measurment of Physical Characteristics of Smoke Particulates Generated by Flaming Materials", J. Fire Flammability, 1977, 8(4), 395.

42. Zinn, B.T., Powell, E.A., Cassanova, R.A. and Bankston, C.P., "Investigation of Smoke Particulates Generated during the Thermal Degradation of Natural and Synthetic Materials", Fire Res., 1977, 1(1), 23.

43. Christopher, A.J., "Some Aspects of Smoke and Fume Evolution from Overheated Non-Metallic Materials", J. Combust. Toxicol. 1976, 3, 89.

44. Hilado, C.J. and Machado, A.M., "Smoke Studies in the Arapahoe Smoke Chamber", J. Fire Flammability 1978, 9, 240.

45. Cornish, H.H., Hahn, K.J. and Barth, M.L., "Experimental Toxicology of Pyrolysis and Combustion Hazards", Environ. Health Perspect. 1975, 11, 191.

46. Stone, J.P., Hazlett, R.N., Johnson, J.E. and Carhart, H.W., "The Transport of Hydrogen Chloride by Soot from Burning PVC", J. Fire Flammability 1973, 4, 42.

47. Henderson, Y. and Haggard, H.W., Noxious Gases, 2nd ed., Reinhold Publishing Corp., N.Y. (1943), p. 71.

48. Morikawa, T., "Evolution of Soot and Polycyclic Aromatic Hydrocarbons in Combustion", J. Combust. Toxicol. 1978, 5, 349.

49. Liao, J.C. and Browner, R.R., "Determination of Polynuclear Aromatic Hydrocarbons in PVC Smoke Particulates by High Pressure Liquid Chromatography and Gas Chromatography - Mass Spectrometry", Anal. Chem. 1978, 50(12), 1683.

50. Morikawa, T., "Evolution of Soot and Polycyclic Aromatic Hydrocarbons in Combustion", Shobo Kenkyusho Hokoku 1978, 45, 13.

51. Chaigneau, M., "Formation of Some Polycyclic Hydrocarbons in the Course of the Thermal Degradation of PVC", C.R. Hebd. Seances Acad. Sci. Ser. C. 1978, 286(8), 257.

52. Wagner, J.P., "Smoke Detector Characteristics", Proc. Int. Conf. Fire Safety, 1977, 2, 432.

53. Welker, R.W. and Wagner, J.P., "Particle Size and Mass Distribution of Selected Smokes: Effect on Ionization Detector Response", J. Fire Flamm. 1977, 8(1), 26.

54. Purt, G., "Fire Protection for Fires With PVC", Ver. Foerder. Deut. Brandschutzes Z. 1969, 18(4), 156.

55. Hilado, C.J., Cummings, H.J. and Casey, C.J., "Toxicity of Pyrolysis Gases from Natural and Synthetic Materials", Fire Technol. 1978, 14(2), 136.

56. Woolley, W.D., "Dehydrochlorination of PVC in Nitrogen and Air", Plast. Polym. 1972, 40(148), 203.

57. Chaigneau, M., "On the Evolution of Various Pollutants from the Thermal Degradation of PVC", C.R. Hebd. Seances Acad. Sci. Ser. C. 1976, 282(13), 583.

58. Bradt, P. and Mohler, F.L., "Mass Spectra of Thermal Degradation Products of Polymers", J. Research Natl. Bur. Standards 1955, 55, 323-7.

59. Paulik, J., Paulik, F. and Erdey, L., "Combined Derivatographic an. Thermal Gas - Analytical Studies", Mikrochim. Acta. 1966, 886.

60. LeMoan, G. and Chaigneau, M., "Pyrolysis of Materials in Plastics .I. PVC Characterization of Possible Volatile Toxic Compounds", Ann. Pharm. Fr. 1969, 27, 97.

61. Carel, A.B., "Pyrolysis of PVC and Experimental P(VC) Compounds Using a Thermal Gravimetric Analysis Furnace and Oven Technique with Recovery Studies of Hydrogen Chloride", Proc. Int. Wire Cable Symp. 1978, 27, 299.

62. O'Mara, M.M., "High Temperature Pyrolysis of PVC : gc-ms Analysis of the Pyrolysis Products from PVC Resins and Plastisols", J. Polym. Sci. Part A-1 1970, 8, 1887.

63. Woolley, W.D., "Decomposition Products of PVC for Studies of Fires", Paper CP 11/74 Building Research Establishment, Fire Research Station, Borehamwood WPG 2BC, Great Britain.

64. Neiman, M.B., Papko, R.A. and Pudov, R.A., "Thermal Degradation of PVC (I),

Vysokomol. Soedin, Ser. A. 1968, 10, 841.

65. Forstier, M., "Combustion Products of Synthetic Materials", Rev. Tech. Feu. 1975, 16, 24.

66. Autain, J., "Toxicologic Aspects of Flammability and Combustion of Polymeric Materials" in Smoke and Products of Combustion; Vol 2.fire and flammability series, ed. C.J. Hilado, Technomic Publishing Co. Inc., Westport, Conn., 1973, p. 57.

67. Imoto, M., "Products by Pyrolysis of PVC", Setchaku 1974, 18, 540.

68. Michal, J., "Evaluation of the Assumed Toxicity of Some Plastics", Nehorlavost. Polym. Mater. 1976, 129.

69. Kobayashi, Y., Hori, M. and Murata, H., "Combustion Gases Generated from PVC and its Products. Model Experiments Simulating Fire", Jap. Plast. 1971, 5, 40.

70. Chang, E.P. and Salovey, R., "Pyrolysis of PVC", J. Polym. Sci., Poly. Chem. Ed. 1974, 12, 2927.

71. Ball, G.L. and Boettner, E.A., "Toxic Gas Evolution from Burning Plastics", Polym. Prepr., Am. Chem. Soc. Div. Polym.Chem. 1973, 14, 986.

72. Woolley, W.D., "Toxic Products from Plastics Materials in Fires", Plast. Polym. 1973, 41, 280.

73. Noffz, D., Benz, W. and Pfab, W., "Pyrolytic Gas Chromatography Study of High Polymers", Fresenius Z. Anal. Chem. 1968, 235, 121.

74. Hiramatsu, K., "Pyrolysis Products of Polymeric Materials by Mass Spectrometry. IV, Mass Spectrometry of Pyrolysis Products of Poly(vinyl alcohol) and PVC", Shitsuryo Bunseki 15, 29.

75. Hagen, E., "Composition of Pyrolysis Gases of Plastics", Plaste. Kaut. 1968, 15, 711.

76. Takahashi, T. and Serizawa, M., "Pyrolysis of PVC", Enka. Biniiru To Porima 1971, 11, 26.

77. Iida, T., Nakanishi, M. and Goto, K., "PVC.I. Evolution of Aromatics on Pyrolysis of PVC and Its Mechanism", J. Polym. Sci., Polym. Chem. Ed. 1974, 12, 737.

78. Goto, K. and Iida, T., "Pyrolysis of PVC . Formation of Aromatic Compounds", Enka. Biniiru To Porima 1973, 13, 18.

79. Koichi, K. and Nakamura, K., "Toxicities of Combustion Products", J. Fire Flammability/Combustion Toxicology Suppl. 1974, 1, 104.

80. Kishitani, K. and Nakamura, K., "Study on Toxicities of Combustion Products of Building Materials at Initial Stage of Fire", J. Fac. Eng., Univ. Tokyo, Ser. B. 1977, 34, 295.

81. Dotreppe-Giscard, N., "Compounds Obtained by Combustion of Plastics", Trib. Centre Belge Etude Doc. Eaux 1968, 21, 247.

82. Schriesheim, A., "Method for the Controlled Burning of Combustible Materials and Analyses of the Combustion Gases", J. Research Natl. Bur. Standards 1956, 57, 245.

83. Gordon, G.Ya., "Thermal Dehydrochlorination of Chlorine Containing High Polymers", Plasticheskie Massy 1964 (4), 6.

84. Woolley, W.D., "Behaviour of PVC in Fires", J. Macromol. Sci. Chem. A 11, 1977, 1509.

85. O'Mara, M.M., "Pyrolysis Gas Chromatography Analysis of PVC.II. In Situ Absorption of HCl During Pyrolysis and Combustion of PVC", J. Polym. Sci., Part A-1 1971, 9, 1387.

86. Eitingon, A.I., Solov'eva, T.V., Gribunova, G. and Naumova, L.S., "Toxicity of Volatile Products Emitted During the Burning of Polymer Materials Synthesized from a PVC Base", Gig. Sanit. 1975, 2, 104.

87. Antonyuk, O.K. and Aldyreva, M.V., "Substantiation of the Maximum Permissible Concentration of Dibutyl Phthalate in the Air of Industrial Premises", Gig. Tr. Prof. Zabol. 1973, 8, 26.

88. Chaigneau, M., "Mass Spectrometry Analysis of Compounds Formed by Pyrolysis of Polyacrylonitrile and Copolymers", Analusis 1977, 5, 223.

89. Chaigneau, M., "Gas Emitted by the Pyrolysis of Different Plastic Materials at 1,000°C.", C.R. Acad. Sci., Ser. C. 1974, 278, 109.

90. Hilado, C.J. and Brauer, D.P., "Concentration-Time Data in Toxicity Tests and Resulting Relationships", J. Combust. Toxicol. 1979, 6, 136.

91. Hilado, C.J. and Machado, M., "Toxicity of Pyrolysis Gases from Some Cellular Polymers", J. Combust. Toxicol. 1978, 5, 162.

92. Hilado, C.J., Huttlinger, N.V. and O'Neill, B.A., "Effect of Heating Rate on Toxicity of Pyrolysis Gases from Some Wood Products", J. Combust. Toxicol. 1978, 5, 25.

93. Hilado, C.J. and Casey, C.J., "Pyrolysis of Polymeric Materials.I. Effect of Chemical Structure, Temperature and Heating Rate and Air Flow on Char Yield and Toxicity", J. Fire Flammability 1979, 10, 140.

94. Chaigneau, M. and LeMoan, G., "Toxicity of Plastics Combustion Products.II.", Ann. Pharm. Fr. 1977, 35, 153.

95. Barrow, C.S., Alarie, Y. and Stock, M.F., "Sensory Irritation and Incapacitation Evoked by Thermal Decomposition Products of Polymers and Comparison with Known Sensory Irritants", Arch. Envir. Health 1978, 33, 79.

96. Hilado, C.J., Marcussen, W.H. and Furst, A., "Apparent Lethal Concentrations of Pyrolysis Products of Some Polymeric Materials," J. Combust. Toxicol. 1976, 3, 345.

97. Hilado, C.J., Solis, A.N., Marcussen, W.H., and Machado, A.M., "Effect of Temperature and Heating Rate on Apparent Lethal Concentrations of Pyrolysis Products," J. Combust. Toxicol. 1976, 3, 381.

98. Barrow, C.S., Lucia, H., Stock, M.F. and Alarie, Y.C., Am. Ind. Hygiene Assoc. J. 1979, 40, 408.

99. Barrow, C.S., Lucia, H. and Alarie, Y.C., "A Comparison of the Acute Inhalation Toxicity of Hydrogen Chloride vs the Thermal Decomposition Products of PVC", J. Combust. Toxicol. 1979, 6, 3.

100. Hilado, C.J., Cumming, H.J. and Casey, C.J., "Toxicity of Pyrolysis Gases from Plastics and Elastomers", J. Elastomers Plast. 1979, 11, 3.

101. Hilado, C.J. and Machado, A.M., "Effect of Char Yield and Specific Toxicants on Toxicity of Pyrolysis Gases From Synthetic Polymers", Fire Technol. 1979, 15, 51.

102. Hilado, C.J. and Huttlinger, N.V., "Concentration - Response Data on Toxicity of Pyrolysis Gases from Six Synthetic Polymers", J. Combust. Toxicol. 1978, 5, 81.

103. Hilado, C.J., Soriano, J.A. and Kosola, K.L., "Effect of Heating Rate on Toxicity of Pyrolysis Gases from Some Synthetic Polymers", J. Combust. Toxicol. 1977, 4, 533.

104. Attwood, P.C., "Penetration of Fire Partitions by Plastic Pipe", Second Symposium on Combustibility and Plastics, Ottawa, October 30-1, 1979 p. 272.

105. Origgi, P., "Flammability of Plastic Materials", Mater. Plast. Elastomeri. 1976, 120.

106. Barrow, C.S., Alarie, Y.C. and Stock, M.F., "Sensory Irritation and Incapacitation Evoked by Thermal Decomposition Products of Polymers and Comparison with Known Sensory Irritants", Arch. Envir. Health 1978, 33, 79.

107. Kane, L.E., Barrow, C.S. and Alarie, Y.C., "A Short-Term Test to Predict Acceptable Levels of Exposure to Airborne Sensory Irritants", Am. Ind. Hygiene Assoc. J. 1979, 40, 207.

108. Kishitani, K., "Study on Injurious Properties of Combustive Products of Building Materials at the Initial Stage of Fire", J. Faculty of Engineering, U. Tokyo (B), 1971, 31, 1-35.

109. Sakai, T., "Intake of Carbon Monoxide in the Mouse Exposed to a Mixture of Carbon Monoxide and Hydrogen Chloride", Igaku To Seibutsugaku 1977, 94, 475.

110. Colardyn, F. van der Straeten, M., Lamont, H. and van Peteghem, T., "Acute Inhalation - Intoxication by Combustion of PVC", Int. Arch, Occup. Environ. Health 1976, 37 121.

111. Anderson, R.C. and Alarie, Y.C., "Approaches to the Evaluation of the Toxicity of Decomposition Products of Polymeric Materials Under Thermal

Stress", J. Combust. Toxicol. 1978, 5, 214.

112. Hilado, C.J., Cumming, H.J., Kourtides, D.A. and Gilwee Jr., W.J., "Relative Toxicities of the Pyrolysis Products From Some Thermoplastic and Thermoset Polymers", Thermosets High Perform. Thermoplast. 1977, 150.

113. Kourtides, D.A., Gilwee Jr., W.J. and Hilado, C.J., "Relative Toxicity of the Pyrolysis Products from Some Thermoplastic and Thermoset Polymers", Polym. Eng. Sci. 1978, 18, 674.

114. Alarie, Y.C., "Toxicologic and Acute Lethal Hazard Evaluation of Thermal Decomposition Products of Synthetic and Natural Polymers", presented at Second Symposium on Combustibility of Plastics, Ottawa, October 30-1, 1979, p. 56.

115. Lucia, H.L., Barrow, C.S., Stock, M.F. and Alarie, Y.C., "A Semi-Quantitative Method for Assessing Anatomic Damage Sustained by the Upper Respiratory Tract of the Laboratory Mouse, Mus musculis", J. Combust. Toxicol. 1977, 4, 472.

116. Hilado, C.J., Cumming, H.J., Machado, A.M. and Schneider, J., "Comparison of Animal Responses to the Combustion Products Generated by Two Test Procedures, the USF/NASA Methodology and the FAA/CAMI System", J. Combust. Toxicol 1977, 4, 325.

117. Hilado, C.J. and Crane, C.R., "Comparison of Results with the USF/NASA and FAA/CAMI Toxicity Screening Test Methods", J. Combust. Toxicol. 1977, 4, 56.

118. Hilado, C.J., Cumming, H.J. and Casey, C.J., "Toxicity of Pyrolysis Gases from Plastics and Elastomers", J. Elastomers Plast. 1979, 11, 3.

119. Hilado, C.J. and Cummings, H.J., "The Effect of Test Conditions on Relative Toxicity of the Pyrolysis Products from Some Plastics", Fire Technol. 1977, 13, 325.

120. Hilado, C.J. and Cumming H.J., "Relative Toxicity of Pyrolysis Gases from Materials: Effects of Chemical Composition and Test Conditions", Fire Mater. 1978, 2, 68.

121. Hilado, C.J., Soriano, J.A., Kosola, K.L., Solis, A.N. and Furst, A., "Effect of Heating Rate on Pyrolysis Gas Toxicity of Synthetic Polymers and Elastomers", Proc. West Pharmacol. Soc. 1978, 21, 171.

122. Hilado, C.J., "Toxicity of Pyrolysis Gases from Materials", Natl. Symp. Exhib. 1978, 23, 925.

123. Hilado, C.J., Cumming, H.J. and Furst, A., "The Effect of Test Conditions on Relative Toxicity Test Results and Rankings", Aerosp. Med. Res. Lab. (Tech. Rep.) AMRL-TR (U.S.) 1977, AMRL-TR - 77-97; Proc. Annu. Conf. Envir. Toxicol. 8th; AD - A051.334, 77-85.

124. Chaigneau, M. and LeHoan, G., "Toxicity of Plastic Combustion Products III. Rapid Evaluation Method by Determination of LD50 in Mice", Ann.

Pharm. Fr. 1977, 35, 461.

125. Hilado, C.J. and Cumming, H.J., "A Review of Available LC50 Data", J. Combust. Toxicol. 1977, 4, 415.

126. Caplan, Y., Thompson, B. and Altman, R., to be published. Reported in reference 28.

127. Lipska, A.E. and Alvares, N.J., "Chemical Constituents of Smoke and Conjecture as to Their Role in Foam Destruction" in Smoke and Products of Combustion, Vol 2 fire and flammability series ed. C.J. Hilado, Technomic Publishing Co. Inc., Westport, Conn. 1973, p. 171.

128. Caplan, Y. and Altman, R., "Microdetermination of Cyanide in Fire Fatalities", 28th Annual Meeting American Academy of Forensic Sciences, Wash. D.C. 1976.

129. Sunshine, I and Finkle, B., "The Necessity for Tissue Studies in Fatal Cyanide Poisoning", Int. Arch. Gewerbepathol. Gewerbehyg. 1964, 20, 558.

130. Reiders, F. and Sunshine, I., Methodology for Analytical Toxicology, CRC Press, 1971, p. 115.

131. Sumi, K. and Tsuchiya, K., "Combustion Products of Polymeric Materials Containing Nitrogen in their Chemical Structure", in Smoke and Products of Combustion Vol. 2 fire and flammability series ed. C.J. Hilado, Technomic Publishing Co. Inc., Westport, Conn., 1973, p. 92.

132. Isaacs, J.L., "The Oxygen Index Flammability Test", Flammability of Solid Plastics, Vol. 7 fire and flammability series, Technomic Publishing Co. Inc., Westport, Conn., 1974, p. 1.

APPENDIX 1

HUMAN RESPONSE TO OXYGEN DEPLETION AND TOXIC GASES (25)

Oxygen Depletion

Signs and Symptoms of Toxicity of Reduced Levels of Oxygen

% Oxygen in Air	
20%	No symptoms
12-15%	Muscular co-ordination for skilled movements lost
10-14%	Nausea and vomiting, faulty judgment, rapid fatigue
6-8%	Collapse and unconsciousness, rapid treatment can prevent death
6% or below	Death in 6-8 minutes
2-3%	Death in 45 seconds

Toxic Gases

The combined effects of breathing a mixture of gases is not well understood. The information presented here applies to each gas as the sole toxicant.

Carbon Monoxide

Concentration of CO (ppm)	Symptoms
100	No poisoning symptoms even after 8 hours.
200	Headache after 2-3 hours; collapse after 4-5 hours.
300	Headache after 1.5 hours; distinct poisoning after 2-3 hours; collapse after 3 hours.
400	Distinct poisoning, frontal headache and nausea after 1-2 hours; collapse after 2 hours; death after 3-4 hours.
500	Hallucinations felt after 30-120 minutes.
800	Collapse after 1 hour; death after 2 hours.
1000	Difficulty in ambulation; death after 2 hours.
1500	Death in 1 hour.
2000	Death after 45 minutes.
3000	Death after 30 minutes.
8000	Immediate death
12800	Unconsciousness after 2-3 breaths; death in 1-3 minutes.

COHb (Carboxyhemaglobin), % in the blood		Symptoms
20-30	----------	Headache, throbbing in the temples.
30-40	----------	Severe headache, weakness, dizziness, dimness of vision, nausea, vomiting, collapse.
40-50	----------	As above, increase in pulse and breathing rates , greater possibility of asphixiation, collapse.
50-60	----------	As above, coma, intermittent convulsions and Cheyne-Stokes respiration.
60-70	----------	Coma, intermittent convulsions, depressed heart action and respiratory rate, possible death.
70-80	----------	Weak pulse, slowing of respiration leading to death within a few hours.
80-90	----------	Death in less then an hour.

Carbon Dioxide Concentration (ppm)		Symptoms
250-350	----------	Normal concentration in air.
900-5000	----------	No effect.
18,000	----------	Ventilation increased by 50%.
25,000	----------	Ventilation increased by 100%.
40,000	----------	Ventilation increased by 300%, headache, weakness.
80,000	----------	Dizziness, stupor, unconsciousness, distinct dyspnoea, lowered blood pressure, congestion, death within 4 hours.
100,000	----------	Headaches and dizziness.
120,000	----------	Immediate unconsciousness, death in minutes.
200,000	----------	Narcosis, immediate unconsciousness, death by suffocation.

Hydrogen Chloride Concentration (ppm)		Symptoms
1-5	----------	Limit of detection by odor.
5-10	----------	Mild irritation of mucous membranes.
35	----------	Irritation of throat on short exposure.
50-100	----------	Barely tolerable.
1,000	----------	Danger of lung edema after short exposure.

Hydrogen Cyanide (23 and 25)

Concentration (ppm)		Symptoms
18-36	----------	Slight symptoms, headache after several hours.
45-54	----------	Tolerated for 1/2-1 hour without difficulty.
100	----------	Fatal after 1 hour.
110-135	----------	Fatal after 1/2-1 hour.
135	----------	Fatal after 1/2 hour.
181	----------	Fatal after 10 minutes.
280	----------	Immediately fatal.

Nitrogen Dioxide (25)

Concentration (ppm)		Symptoms
10-20	----------	Mildly irritating to eyes, nose and upper respiratory tract.
50	----------	Distinct irritation.
80	----------	Tightness of chest after 3-5 minutes.
90	----------	Pulmonary edema after 30 minutes.
100-200	----------	Very dangerous within 30-60 minutes.
250	----------	Death after a few minutes.

Acrolein (CH_2=CHCHO) (25)

Concentration (ppm)		Symptoms
0.8	----------	Lachrymation, irritation of mucous membranes.
1.0	----------	Irritation
5.5	----------	Intense irritation.
10+	----------	Lethal in a short time.

Benzene (25)

Concentration (ppm)		Symptoms
500	----------	Slight irritation.
1500-4000	----------	Dangerous to life after several hours.
8000	----------	Fatal after 30-60 minutes.
20000	----------	Fatal after 5 minutes.

Parts per million (ppm) is defined as the volume of the gas in one million parts air-vapor at 25°C and 760 mm Hg.

APPENDIX 2

Oxygen Index[1] (Defined as the Percentage of Oxygen in an Oxygen-Nitrogen Mixture Which Will Just Support Sustained Combustion.) (10)

Polyethylene, high density	17.4
ABS, Cycolac T, (Marbon)	18.2
ABS/polycarbonate Alloy (Cycoloy 800)	20.2
PVC, Plaskon 2005	40.3
Chlorinated PVC, Geon 101	45.0
Polytetrafluoroethylene (Teflon)	95.0
Various Woods	22 - 24.5

(1) More complete Indices are given by Isaacs (132) and by Hilado (25).

Effect of Composition of PVC on the Oxygen Index

Plastic	Oxygen Index (10)
PVC	40.3
PVC with 9% ABS impact modifier	35.3
PVC with 41% dioctyl phthalate	21.6
PVC (50%)/ABS (50%)	23.6
PVC (48%)/ABS (48%) with 4% Sb_2O_3	33.0
PVC/ABS alloy Cycovin KA	27.0

APPENDIX 3

OPTICAL DEFINITIONS

Optical Density

$$\text{Optical Density } D = \log_{10} \frac{I_o}{I_t}$$

Optical density is directly proportional to the length of the light path.

Specific optical density, $D_s = \frac{V}{AL} \log_{10} \frac{I_o}{I_t}$, where

V = volume of smoke chamber.
A = area of burning or smouldering material.
K = length of the light path.
I_o = initial light intensity.
I_t = transmitted light intensity.

D_s is dimensionless.

Mass Optical Density, $MOD = \frac{V}{L_m} \log \frac{(100)}{T}$, where

m = mass loss of sample up to T.
T = minimum light transmittance (%) (40).