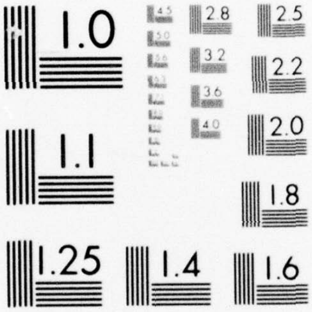
AD-A049 923 MONSANTO RESEARCH CORP DAYTON OHIO DAYTON LAB F/G 11/9
FLAME- AND SMOKE-RETARDANT POLYMER SYSTEMS.(U)
FEB 78 L PARTS, R D MYERS, C A THOMPSON N00024-76-C-5336
UNCLASSIFIED MRC-DA-722 NL

1 OF 2
AD
A049923



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

12

MRC-DA-722

FLAME- AND SMOKE-RETARDANT POLYMER SYSTEMS

Final Report

Issued: 3 February 1978

Period Covered: May 1976 – September 1977

Prepared Under Contract: N00024-76-C-5336

For

Department of the Navy
Naval Sea Systems Command
Washington, DC 20362

Approved for public release; Distribution unlimited.

Leo Parts, Robert D. Myers,
Catherine A. Thompson and Norman F. May

MONSANTO RESEARCH CORPORATION
Dayton Laboratory
Dayton, Ohio 45407

⑭ MRC-DA-722

⑥ FLAME- AND SMOKE-RETARDANT POLYMER SYSTEMS.

⑨ Final Report May 76-Sep 77

Issued: ⑪ 3 Feb~~ruary 19~~78

Period Covered: May 1976 - September 1977

⑫ 143 P.

⑮ Prepared Under Contract N00024-76-C-5336

For

Department of the Navy
Naval Sea Systems Command
Washington, DC 20362

Approved For Public Release; Distribution Unlimited

⑩ Leo/Parts, Robert D./Myers,
Catherine A./Thompson ~~and~~ Norman F./May

MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
DAYTON, OHIO 45407

401 865 JOB

ABSTRACT

Means for enhancing the fire safety of molded polyvinyl chloride (PVC) and neoprene foam were explored. These included incorporation of fire- and smoke-retardant additives into both polymer systems and the use of intumescent coatings with the PVC system.

Ferric and cupric acetylacetonates, used together with magnesium carbonate in PVC, reduced smoke optical density in laboratory tests by ~55%. These additives had no adverse effect on ignitability. The concentrations of NO_x, HCl, and hydrocarbons formed from the flame- and smoke-retardant polymer compositions, burned under laboratory-scale fire test conditions, were generally lower than those observed with the reference polymer composition. However, these additives enhanced carbon monoxide formation and the rate of flame propagation.

Four intumescent coatings of different types were evaluated with the PVC compositions. An alkyd-based intumescent paint exhibited best performance. It had no significant effect on smoke formation, and it reduced the formation of CO and the rate of flame propagation.

Ferric acetylacetonate and poly(ammonium phosphate), incorporated into neoprene foam, induced smoke optical density under flame exposure conditions only 10%.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (cont'd)

LIST OF ILLUSTRATIONS (cont'd)

(APPENDIX)

LIST OF ILLUSTRATIONS (cont'd)

(APPENDIX)

LIST OF ILLUSTRATIONS (cont'd)

(APPENDIX)

LIST OF TABLES

(APPENDIX)

LIST OF TABLES (cont'd)

(APPENDIX)

LIST OF TABLES (cont'd)

(APPENDIX)

LIST OF TABLES (cont'd)

(APPENDIX)

1. INTRODUCTION

The Navy is concerned about injuries and losses caused by unwanted fires on board ships and at shore installations. One approach to reducing these involves the use of materials with improved response-to-fire and fire performance characteristics. The program described in this report was designed to evaluate selected means for enhancing the fire safety of two polymeric materials widely used on board ships. These materials are polyvinyl chloride (PVC) and neoprene.

The means for enhancing the fire safety entailed incorporation of candidate fire- and smoke-retardant additives into both polymer systems and the application of intumescent coatings with PVC. The fire performance characteristics were evaluated by laboratory-scale tests. These included measurement of ignitability, flame propagation, and smoke and gaseous combustion products formation. Some physical properties important for the use of the polymers were determined with the most promising fire- and smoke-retardant PVC polymer compositions.

2. EXPERIMENTAL

2.1 MATERIALS

2.1.1 Unmodified Polyvinyl Chloride Resin

Unmodified, compressed PVC resin (Opalon 650, previously produced by Monsanto Company) was used for ignitability measurements.

2.1.2 Experimental Polyvinyl Chloride Compositions

2.1.2.1 Base Polymer Formulation

The base polymer (BP) formulation for experiments with PVC had the following composition:

Resin (Geon 102EP from Goodrich Chemical Company)	100 parts
Plasticizer (Santicizer® 148 plasticizer from Monsanto Industrial Chemicals Company)	30 phr
Stabilizers	
Dibasic lead phthalate	7 phr
Dibasic lead stearate	0.4 phr
Lubricant (stearic acid)	0.4 phr

®Registered trademark of Monsanto Company.

The ingredients for this formulation were initially dry-blended at room temperature. Subsequently, they were further blended by milling at ~160°C. The 0.0625-in.-thick sheets were compression molded at 130-160°C at a pressure of 1500 psi.

2.1.2.2 Fire- and Smoke-Retardant Polyvinyl Chloride Compositions

The flame- and smoke-retardant polymer (FSP) formulations contained 30 phr $MgCO_3$ (Magcarb L, from Merck Chemical Division). Additionally, formulation FSP-1 contained 5 phr ferric acetylacetonate, and formulation FSP-2 contained 5 phr cupric acetylacetonate. The FSP compositions were processed in the same manner as the base polymer formulation.

2.1.3 Experimental Polyvinyl Chloride Compositions with Intumescent Coatings

Four types of intumescent coatings were used. Their compositional characteristics, manufacturers, and designations are tabulated below.

Coating Identification	Manufacturer	Designation Used In This Report
Alkyd-based intumescent paint No. 110	C. M. Athey Paint Co.	IC-1
Epoxy-based intumescent paint No. 477	Ocean Chemicals, Inc.	IC-2
Mastic No. 34	Ocean Chemicals, Inc.	IC-3
Latex-based intumescent paint No. 330	Ocean Chemicals, Inc.	IC-4

The alkyd- and latex-based coatings are recommended by the manufacturers for interior surfaces (Refs. 1 and 2). The alkyd-based coating is specifically recommended for interior marine applications such as galleys, and engine room bulkheads and overheads (Ref. 1). The mastic coating is generally used for the protection of load-bearing metal structural components. The epoxy-based intumescent paint is recommended by the manufacturer for exterior, marine, and interior applications (Ref. 3).

The coatings were applied onto one side of the molded PVC sheet specimens and onto a 0.019-in.-thick aluminum sheet according to the manufacturers' specifications.

The intumescent paints were applied with a brush in the approximate thicknesses specified in the manufacturers' technical literature. The alkyd and latex coatings were applied at a coverage of ∿200 square feet per gallon in a single application. The epoxy coating is recommended at a thickness of 9 to 10 mils, which is attained in two applications, at a total coverage rate of approximately 130 square feet per gallon. The solids content of the epoxy coating is in excess of 80%.

The mastic was applied with a spatula at a thickness of 0.12 in. After drying, it exhibited poor adhesion to the materials used in this work.

The alkyd, latex and mastic coatings were allowed to dry at room temperature for at least one week, and the epoxy coating for at least two weeks, before specimens were cut for testing. The thicknesses of the alkyd, epoxy and latex coatings were approximately 15 mils, 9 mils and 12 mils, respectively, after drying.

2.1.4 Experimental Neoprene Foam Compositions

Numerous formulations have been used for the preparation of neoprene foam (see Ref. 4 for examples). An isocyanide-modified foam, based on Neoprene Latex No. 357 produced by the Du Pont Company, was used as the base formulation because of its relatively good fire resistance (Refs. 5 and 6). This composition contains aluminum hydroxide as the filler. It has been shown in a recent investigation (Ref. 7) that aluminum hydroxide enhances char formation from neoprene, with a concomitant reduction of heat release during the thermal degradation.

Phos-Chek® P/30 fire retardant was incorporated into the latex formulation to enhance the fire resistance of the foam. This additive was expected to exert fire-inhibiting action by two mechanisms: (1) by supplying flame-inhibiting phosphorus-containing species, and (2) by forming a protective aluminum phosphate coating on the surface of the degrading polymer.

2.1.4.1 Development of a Procedure for the Preparation of Experimental Neoprene Foam Compositions

In exploratory, small-scale experiments with fire- and smoke-retardant additives, the recipe reported in Ref. 5 served as the starting composition. The effects of incorporated fire- and smoke-retardant additives upon foam processing and curing characteristics were investigated. Processing and curing procedures were then modified, based on the effects of the incorporated fire- and smoke-retardant additives. Procedures were established for larger scale preparation of experimental compositions for fire performance testing.

®Registered trademark of Monsanto Company.

The following is a brief description of the base foam (BF) preparation procedure (see Ref. 5 for additional details). One hundred sixty-seven and seven-tenths grams of Neoprene Latex 357 (Du Pont Company, Elastomer Chemicals Department) of 60% total solids content was used. The quantities of the other reagents are given with reference to 100 parts of dry solids in the latex, or 166.7 parts of the water-based latex.

The <u>base liquid compound</u> was <u>prepared</u> by a five-step procedure:

1. The following components were first combined:

Water		1.00
Aquarex WAQ, 30% active		1.2
(Du Pont Company, Elastomer Chemicals Department)		
Triton X-100, diluted to 30% active ingredient		3.00
(surfactant from Rohm and Haas Company)		
Dresinate 91		1.50
(surfactant from Hercules, Inc.)		
Thiocarbanilide, 33%		3.00
(Monsanto Company, Rubber Chemicals Department)		
Ball-milled dispersion prepared from:		
Thiocarbanilide	100	
10% Solution of Daxad 11	30	
10% Solution of ammonium caseinate	30	
Water	140	
(Daxad 11 and ammonium caseinate are surfactants available from Dewey and Almy Chemical Company, and Sheffield Chemical, respectively)		
Tepidone, 23.5% active ingredient, prepared by diluting the 47% commercial composition with water		1.00
(Du Pont Company, Elastomer Chemicals Department)		
Diethanolamine		0.25
Pigment masterbatch		15.83
Ball-milled dispersion prepared from:		
Zinc oxide	100.0	
Antox N	26.6	
(Antioxidant from Du Pont Company, Elastomer Chemicals Department)		
Marasperse N-22, 10% solution	12.7	
(surfactant from American Can Company, Chemical Products Division)		
Water	72.2	
Antimony oxide		4.40

The above components, except for antimony oxide, were agitated until a uniform mixture was obtained. Subsequently, the latter compound was incorporated and the mixture was again stirred well.

2. The blended mixture prepared in Step 1 was added to 166.7 parts of the latex with agitation.

3. Aluminum hydroxide, 20.00 parts (Hydral 710, Aluminum Company of America, Chemical Division), was added while the dispersion was stirred rapidly.

4. N-Methyldiethanolamine hydrochloride solution, 23.8%, was added to bring the pH into the range of 10.8 to 11.2. Subsequently, N-methyldiethanolamine (MDEA, Union Carbide Corporation) was added to bring the total quantity of MDEA to 7.35 grams per 100 grams of latex solid. The resulting suspension was allowed to age for at least two hours at room temperature before further processing.

5. Ammonium caseinate surfactant solution of 10% solids content was added at a ratio of 1 to 100 of latex solids.

The foaming was carried out with a Kitchen Aid mixer. The base liquid composition, whose preparation is described above, was frothed with air at high whipping speed for 8-10 seconds to produce a foam of approximately the desired density. Subsequently, the speed of agitation was reduced for further refining of the foamed dispersion. Finally, polymethylene polyphenyl isocyanate (PAPI) and sodium silicofluoride were added in the following amounts:

PAPI (from Upjohn Company)		14.00
Sodium silicofluoride dispersion		13.33
Ball-milled dispersion prepared from:		
Sodium silicofluoride	100	
Bentonite clay	2	
10% Solution of NaOH	5	
Water	226	

PAPI and the sodium silicofluoride dispersion were distributed rapidly over the entire surface. These ingredients were blended into the foam at the refining speed within 90 seconds. The blended foam, including all ingredients, was poured rapidly into a 5 in. x 10 in. x 4 in. mold in which it was allowed to set up at room temperature for approximately four hours. The water-containing open-pore foam slab was then dried and cured for 12 hours in an oven maintained at 120-125°C.

The following fire- and smoke-retardant experimental foams (FSF) were prepared by the procedure used for the base formulation:

FSF-1, containing 5 phr ferric acetylacetonate
FSF-2, containing 10 phr of Phos-Chek P/30
FSF-3, containing both additives at the indicated concentrations.

The fire- and smoke-retardant additives were incorporated into the frothed formulation before the addition of PAPI and sodium silicofluoride.

The encapsulated Phos-Chek P/30 contained 80 wt-% poly(ammonium phosphate) and 20 wt-% of the encapsulating polymer. The 10 phr Phos-Chek P/30 content of FSF-2 refers to poly(ammonium phosphate).

2.1.4.2 Observations and Conclusions

All additives incorporated into the base formulation affected the set-up and curing characteristics of the foam. Some candidate smoke-retardant compositions containing cupric acetylacetonate were also prepared in the initial phase of the work. This additive accelerated the set-up at room temperature, allowing only 45 seconds for the final mixing as compared with 90 seconds for the base formulation. When it was learned that this additive also catalyzed thermal degradation of the neoprene polymer at the oven curing temperature, its use was abandoned.

Ferric acetylacetonate retarded both gelation and the rate of curing at the elevated temperature. The FSF-1 formulation was mixed for four minutes before pouring into molds. Since 12 hours of curing time were needed for this formulation, other compositions were also cured for the same duration.

Phos-Chek P/30 lowered the pH of the frothed foams and greatly accelerated the gelation. To enable incorporation of this fire retardant, it was encapsulated into partially hydrolyzed ethylene-vinyl acetate polymer. The encapsulation procedure is reported in Section 2.1.4.4. With encapsulated Phos-Chek P/30, a mixing time of 60 seconds could be used for the FSF-2 composition.

In the FSF-3 composition, the effects of ferric acetylacetonate and Phos-Chek P/30 were counteractive. A 90-second final mixing time was used, which is identical with that used for the base formulation (BF).

Higher concentrations of the surfactants Aquarex WAQ and Triton-100 were used for the FSF compositions than those that were found optimal with the base formulation (see Ref. 5). The increased concentrations were essential to stabilize the frothed foam prior to set-up.

It was found during the small-scale preparations that the ambient temperature must be at least 23°C in the room in which the foam is prepared. At lower temperatures, the frothed foam coalesced before setting up.

2.1.4.3 Preparation of Neoprene Foam Specimens for Fire Performance Testing

To prepare test specimens for fire performance testing, the quantities listed for the recipe in Section 2.1.4.1 were quadrupled. The mixing and frothing operations were conducted with a Hobart mixer equipped with a 5-gallon bowl. The frothed foam was poured into 20 in. x 7.5 in. x 2.5 in. cardboard molds lined with polyethylene film. Test specimens were cut from the cured foam slabs using a bandsaw that was equipped with a thin-edged, sharp blade.

The sample frothing and refining times were 13 sec and 10 minutes, respectively, during the preparation of test specimens. The mixing times, after the addition of PAPI and sodium silicofluoride, were as follows: BF, 120 sec; FSF-1, 360 sec; FSF-2, 90 sec; and FSF-3, 90 sec.

Set-up time in the molds was 1 to 4 hours at room temperature. The samples were removed from the molds and air-dried at room temperature overnight. All samples were subsequently cured in an oven at ∿121°C for 12 hours. The densities of cured specimens ranged from 6.3 to 7.7 lb/ft^3.

2.1.5 Encapsulated Phos-Chek P/30 Fire Retardant

The following procedure was used for the encapsulation of Phos-Chek P/30, to prevent coagulation of neoprene latex upon the addition of this phosphorus-containing fire retardant. This procedure was adapted from a patented process (Ref. 8) that utilizes partially hydrolyzed ethylene-vinyl acetate as the encapsulating material.

Three liters of reagent grade toluene, contained in a 4-liter beaker, was heated to 85°C using a water bath. Thirty-five grams of partially hydrolyzed ethylene-vinyl acetate polymer (60/40 E/VA, 44% hydrolyzed) was added. With continuous stirring, the dissolution of the polymer required about two hours.

After the polymer had completely dissolved, 250 ml of cottonseed oil was added. The solution was then allowed to equilibrate thermally with the bath.

Three hundred and fifty grams of Phos-Chek P/30 (sieved previously to >200<100 mesh size) was added while efficient agitation was provided.

The water from the heating bath was drained and an ice bath was prepared to cool the suspension rapidly. Samples of the suspension were removed at intervals and observed under the microscope, to monitor the encapsulation process. Encapsulation began at temperatures below 40°C.

When the capsules had formed and the temperature had been lowered to below 20°C, 50 grams of Mondur CB-75 isocyanate was added to form a crosslinked polymer surface network. Stirring was continued at room temperature for 24-36 hours to attain the desired crosslink density.

After the preparation, the encapsulated Phos-Chek P/30 was allowed to settle. The supernatant solution was decanted. The capsules were washed twice, with agitation, using additional quantities of toluene. They were subsequently dried.

2.2 TEST METHODS

2.2.1 Ignitability

The Setchkin ignition test apparatus was used for ignitability measurements (Refs. 9 and 10). Six-gram samples, instead of the specified 3-gram specimens, were used for the tests. Even with the larger specimens, the rate of pyrolyzate formation was not sufficiently rapid during all tests to yield ignitable compositions in the gas phase.

The linear air flow rate through the chamber was maintained at 20 fpm (10.2 cm/sec) at all temperatures. Calibrated chromel-alumel thermocouples were used for temperature monitoring. The ignition temperatures reported here are those determined at the upper sample surface at the time when ignition was observed.

2.2.2 Formation of Smoke and Gaseous Combustion Products

An analysis system capable of continuous measurement of CO, CO_2, NO_x, total hydrocarbons, and oxygen (Ref. 11) during the burning of polymers was used in conjunction with smoke measurements. This system, designed and constructed at Monsanto Research Corporation (MRC), is connected to the NBS-Aminco smoke optical density chamber (Ref. 12), which is utilized for the burning of samples under controlled conditions. The analysis system is shown in Figure 1, and it is depicted in a simplified schematic manner in Figure 2.

The work described in this report was conducted with 2.5 in. x 2.5 in. (7.6 cm x 7.6 cm) samples of different thicknesses, mounted in vertical position. The imposed energy flux was 16.1 watts/sq. in. (2.5 watts/cm^2) in the center of the sample face. The samples were exposed to radiant heating under both nonflame and flame exposure conditions.

The smoke optical density in the NBS-Aminco chamber is monitored optically. To ascertain representative sampling of the gaseous combustion products, a 3-probe sample acquisition assembly is used for all species, except for HCl. The sample intake ports are located at 1/6, 1/2 and 5/6 of chamber height, parallel to

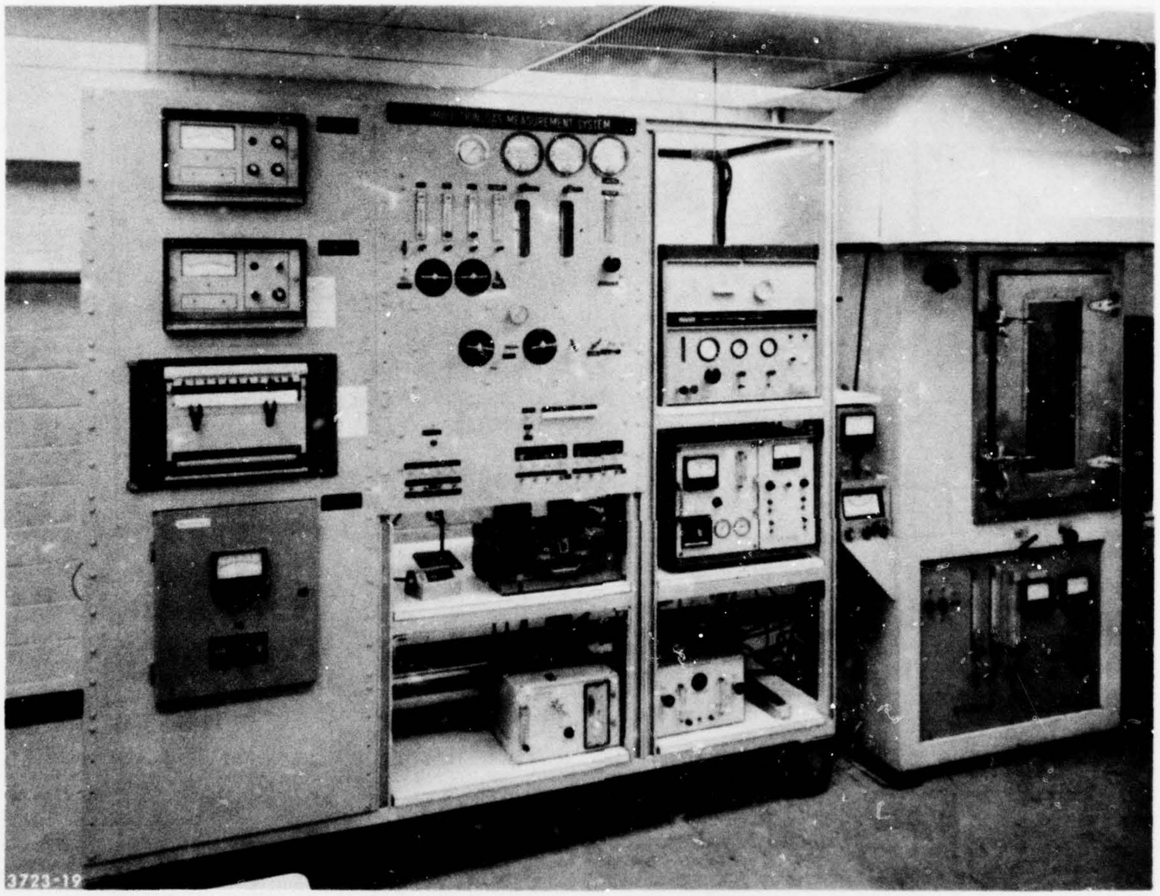


Figure 1. Apparatus for Gaseous Combustion Products and Smoke Optical Density Measurement

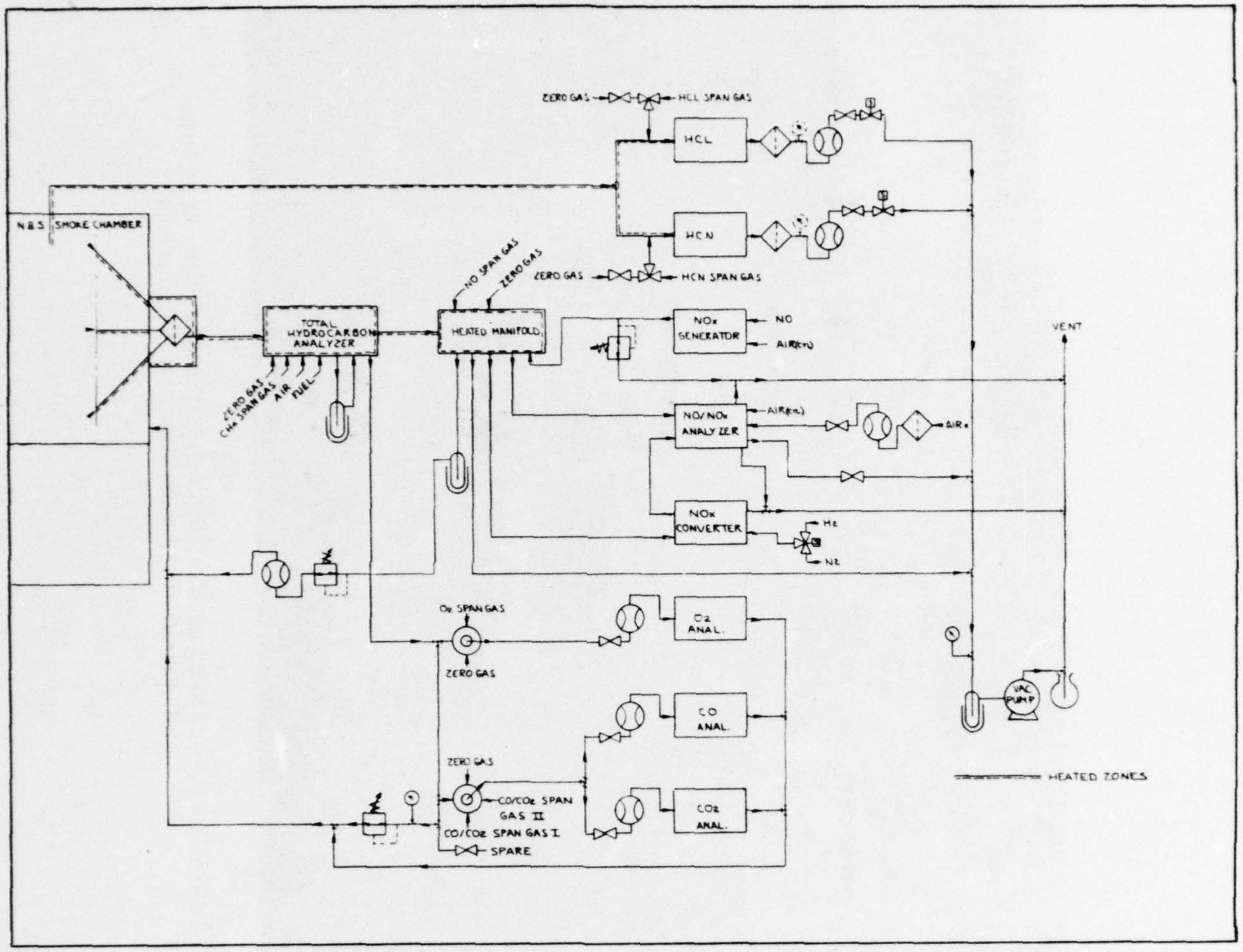


Figure 2. Simplified Flow Diagram of the Combustion Products Analysis System

the optical path used for smoke density measurement. Hydrogen chloride and hydrogen cyanide are sampled through separate Teflon tubes whose openings are 10 cm below the ceiling.

The chamber atmosphere is sampled for gases other than HCl and HCN at the rate of 2200 ml/min. Approximately 37% of the sample is unaffected by the analyzers. That fraction is returned to the chamber. The instruments incorporated into the analysis system and their measurement ranges are listed in Table I.

Table I

ANALYTICAL INSTRUMENTS FOR COMBUSTION PRODUCTS AND OXYGEN ANALYSIS

Species	Operational Principle	Manufacturer and Model	Measurement Limits	
			Lower	Upper
CO_2	Nondispersive IR	Beckman 864	0.05%	20%
CO	Nondispersive IR	Beckman 865	1 ppm	10%
HC	Flame ionization	Beckman 402	50 ppb	25%
NO_x	Chemiluminescence	TECO 10A	0.1 ppm	1%
O_2	Paramagnetic susceptibility	Beckman F3	0.05%	25%

The continuous analyzers for gaseous combustion products and smoke provide an on-site record during the experiments through a Texas Instruments Model FMWS 24-point recorder, operated in 8-point cycles. The analysis instruments are also connected to a General Automation SPC-16/65 computer for real-time data acquisition and processing. The control terminal is located in the fire safety laboratory. The computed results are available after the completion of experiments in tabular and graphical form.

Samples for HCl and HCN analysis are withdrawn intermittently. For 4-minute durations, with sampling times centered at 5-, 15-, and 30-minute time points, chamber air is pumped at the rate of 140 ml/min through impingers containing 25 ml of 0.2 molar aqueous KOH solution.

One-milliliter samples of the impinger contents were used for chloride analysis by a colorimetric method (Ref. 13) in the early phase of this work. The method entails release of SCN^- anions upon reaction with $Hg(SCN)_2$ and their reaction with Fe^{3+} to yield colored complex species. In the later stage of this work, chloride determinations were made by an ion chromatographic method

(Ref. 14). A Dionex Model 10 instrument was used for these measurements.

2.2.3 Flame Propagation

Flame propagation measurements were conducted by the procedure specified in ASTM Standard Method E 162-76 (Ref. 15). Either duplicate or triplicate measurements were performed with each material, depending upon the repeatability of results.

2.2.4 Tensile Strength and Elongation Measurements

An Instron Model TTC testing machine was used for the tensile strength and elongation measurements. It was equipped with serrated, Type 10F grips whose separation was 4.5 in. The specimens were cut with a Type I die. Their cross-sectional dimensions ranged from 0.041 in. x 0.500 in. to 0.073 in. x 0.500 in.

2.2.5 Electrical Measurements

The volume resistivity was measured with a Rohde-Schwartz Company tera ohmmeter. The dielectric constant and dissipation factor measurements were conducted with a General Radio Company capacitance bridge, Type 716C. A Type 1690A sample holder was used for the latter determinations. All electrical measurements were conducted at 25°C.

3. RESULTS AND DISCUSSION

3.1 EXPERIMENTAL POLYVINYL CHLORIDE COMPOSITIONS

3.1.1 Ignitability

Ignitability measurements were conducted with the base polymer composition designated as BP, and with the $Fe(acac)_3$- and $Cu(acac)_2$-containing fire- and smoke-retardant compositions, FSP-1 and FSP-2. Tests were also conducted with samples of the compressed, unmodified PVC resin and with the plasticizer used in the first three compositions. The results and observations are summarized in Table II.

Table II

FLASH IGNITION TEMPERATURES OF PVC COMPOSITIONS

	Number of Determinations			
Material	Total	When Ignition Occurred	Flash Ignition Temperature (°C)	Remarks
PVC	2	2	429[a,b]	
BP	9	7	271[a,c]	Smoke evolution without ignition observed at temperatures from 420°C to 510°C
FSP-1	5	1	296[d]	Experiment discontinued at 330°C
		3	459[e]	Smoke evolution observed at 202°C to 300°C
FSP-2	4	1	450	Smoke evolution observed at 217°C to 242°C
Santicizer 148 plasticizer[f]	2	2	289[g]	

[a] Average value for all measurements.

[b] Ignition observed at 426°C and 432°C. Opalon 650, previously produced by Monsanto Company, was used for these measurements. Other polymer compositions contained Geon 102EP PVC, produced by Goodrich Chemical Company.

[c] Ignition observed at temperatures ranging from 254°C to 294°C.

[d] Temperature at which ignition observed in one experiment.

[e] Average value for ignitions observed at 447°C, 464°C, and 465°C.

[f] Plasticizer in BP, FSP-1 and FSP-2.

[g] Ignition observed at 283°C and 295°C.

The unmodified PVC resin ignited at ∿430°C. The ignition of PVC occurs as a consequence of a two-step degradation process of the resin (Ref. 16). Upon heating at a constant rate, the resin begins to decompose at a readily detectable rate above 220°C (see Figure 3). The initial weight loss is caused mainly by the elimination of HCl from the polymer chain. The low slope in the thermogram at 350-380°C occurs when the chlorine has been almost completely lost from the polymer and a thermally unstable char of the approximate composition $(CH)_n$ remains (Ref. 17). Further heating causes degradation of that char with concomitant volatilization of some degradation products and the formation of a more stable, hydrogen-poorer char. Flash ignition takes place when the heating at this stage occurs under ventilation conditions that allow the lower flammability limit of the volatile organic degradation products to be exceeded.

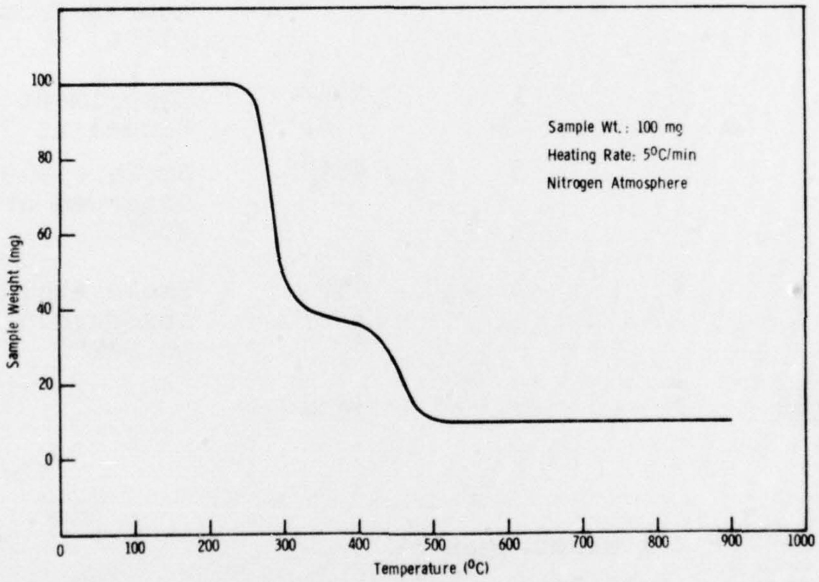


Figure 3. Thermogram of Polyvinyl Chloride (Opalon 650) Degradation

The ignition temperature (∿290°C) of the plasticizer, isodecyl diphenyl phosphate, was determined under the same conditions as those used for the plasticized PVC compositions.

Flash ignition temperatures of the plasticized PVC compositions were found to fall into two ranges: 254-296°C and 426-465°C. Some samples did not ignite; however, these samples generated high concentrations of smoke in temperature ranges at which the other samples of the same compositions ignited.

Different samples of FSP-1 exhibited ignition in both temperature ranges. Four of the five samples tested underwent flash ignition; one did not ignite. One sample ignited at 296°C and three samples ignited in the 447-465°C temperature range.

Flash ignition of the BP and FSP-1 in the 254-296°C temperature range is attributed to the ignition of thermal degradation products of the plasticizer on the basis of measurements conducted with the pure plasticizer and the unmodified PVC resin. On the same basis, the flash ignition temperatures of the FSP compositions in the 447-465°C range are attributed to the hydrocarbon degradation products formed from the PVC resin.

The data in Table II indicate that the transition metal-containing additives incorporated into the plasticized PVC compositions for the enhancement of char and reduction of smoke formation have no adverse effect on the ignitability of the base polymer compositions.

3.1.2 Formation of Smoke

The primary objective of the program was to lower smoke formation by burning PVC and neoprene polymer composition. Concomitantly, enhancement of other fire performance characteristics (e.g., reduction of the rate of flame propagation) was sought.

During the combustion of organic materials, smoke is formed because of incomplete combustion of volatile pyrolysis and thermo-oxidation products. The formation of smoke thus constitutes a competing path to thermo-oxidation of the carbon-containing species in the flame.

Two general approaches were investigated for reducing smoke formation during combustion and for enhancing other fire performance characteristics of PVC and neoprene:

- Reduction of the rate of volatile, combustible pyrolyzate formation.

- Catalysis of the oxidation of solid particulate smoke during flaming combustion.

The following means for reducing the rate of volatile, combustible pyrolyzate formation were investigated with PVC:

- Use of additives that catalyze or cause condensation reactions under fire-associated pyrolysis conditions.

- Use of intumescent coatings.

The effectiveness of the first of the above means was also investigated with neoprene rubber foam. Additives that were expected to form an insulative glass foam upon heating under conditions prevailing in fire environments were incorporated into neoprene compositions.

The second of the above general approaches for smoke retardance entails the incorporation of materials into the polymers that will serve as precursors for catalysts that will oxidize carbonaceous soot particles. This approach to smoke retardance is based on the demonstrated ability of some metals to catalyze the oxidation of graphite (Refs. 18-20).

The additives and coatings used in such an approach must meet certain requirements. They must be oxidatively and hydrolytically stable under the normal use conditions of the polymers into which they are incorporated. Additionally, the metal-containing ingredients that serve as precursors for the oxidation catalysts of carbonaceous smoke particles must meet the following requirements:

- The oxides formed from these additives in the flame zone must function as catalysts for the oxidation of smoke.
- The additives must either be thermally stable at the polymer pyrolysis temperatures, or they must react in the condensed phase to yield volatile, metal-containing compounds that will volatilize with the polymer degradation products. It is desirable that the metals be volatilized with the pyrolyzate at rates proportional to the pyrolyzate formation.

Ready reversibility of oxidation reactions, i.e., the absence of strong thermodynamic driving forces in the direction of any valence state that is involved in the oxygen transfer reactions, is believed to be a major prerequisite for catalytic effectiveness of the metals in the oxidation of graphite (Refs. 18-20) and soot.

It has been demonstrated in earlier studies at Monsanto Research Corporation (MRC) (Refs. 17, 21 and 22) that iron- and copper-containing transition metal compounds lower smoke formation both in PVC compositions and in other polyolefins. These are incorporated in the form of coordination compounds that have to meet the above-described stability requirements.

In this investigation, ferric and cupric acetylacetonates were incorporated into PVC as precursors for the active smoke-retardants. At elevated temperatures, upon interaction with HCl formed in polymer degradation, these coordination compounds are expected to yield the respective metal chlorides that would function as crosslinking catalysts. These chlorides are also sufficiently volatile to be vaporized in an intense fire environment.

Thereby, the incorporated iron and copper acetylacetonates function also as precursors to vapor phase oxidation catalysts for the oxidation of soot particles in flames.

Santicizer 148 (isodecyl diphenyl phosphate) was selected as the plasticizer for these compositions because of its known low propensity for contributing to smoke from plasticized PVC compositions (Ref. 17, 23 and 24). The plasticizer content (30 phr) was selected to correspond to values frequently used in wire and cable insulation.

Magnesium carbonate was incorporated as the reactive filler. It is presumed to react at high temperatures with phosphate type plasticizers, yielding foamed glassy materials that will lend protection to the polymer.

The results of sample mass and smoke optical density measurements are summarized in Tables IX and X, respectively, in the Appendix. Smoke optical density values as functions of time for the base polymer composition and for the compositions containing Fe(acac)$_3$ and Cu(acac)$_2$ (FSP-1 and FSP-2, respectively) are presented in Figure 4. Similar rate information for samples coated with alkyd- and epoxy-based intumescent paints, and for these paints on an aluminum foil base, are included in Figures 28 through 31 in the Appendix.

3.1.2.1 Smoke From FSP Compositions

Significant reduction of smoke formation has been attained with additives used in FSP-1 and FSP-2 under both flame and nonflame exposure conditions (see Figure 5). The maximum smoke optical density under flame exposure conditions was reduced 61% and 68% with the iron- and copper- containing additives, respectively. Under nonflame exposure conditions, the corresponding values were 42% and 52%. The copper(II)-containing additive was approximately 20% more effective in reducing smoke than its iron(III) analog.

The times that transpired until maximum smoke densities developed with the FSP compositions were a little longer than those for the base polymer composition under flame exposure conditions; under nonflame exposure conditions, these times did not change significantly.

It is noteworthy that the maximum smoke optical densities developed during the exposure of 1/4-in.-thick samples were not much higher than the respective values for 1/16-in.-thick samples (see Figure 5). The times required for the development of the maximum densities were longer with thick samples. The percentage char residue values were also higher with the thick samples (see Table IX in the Appendix). The disproportionately low smoke optical density developed by thick samples is attributed to both physical

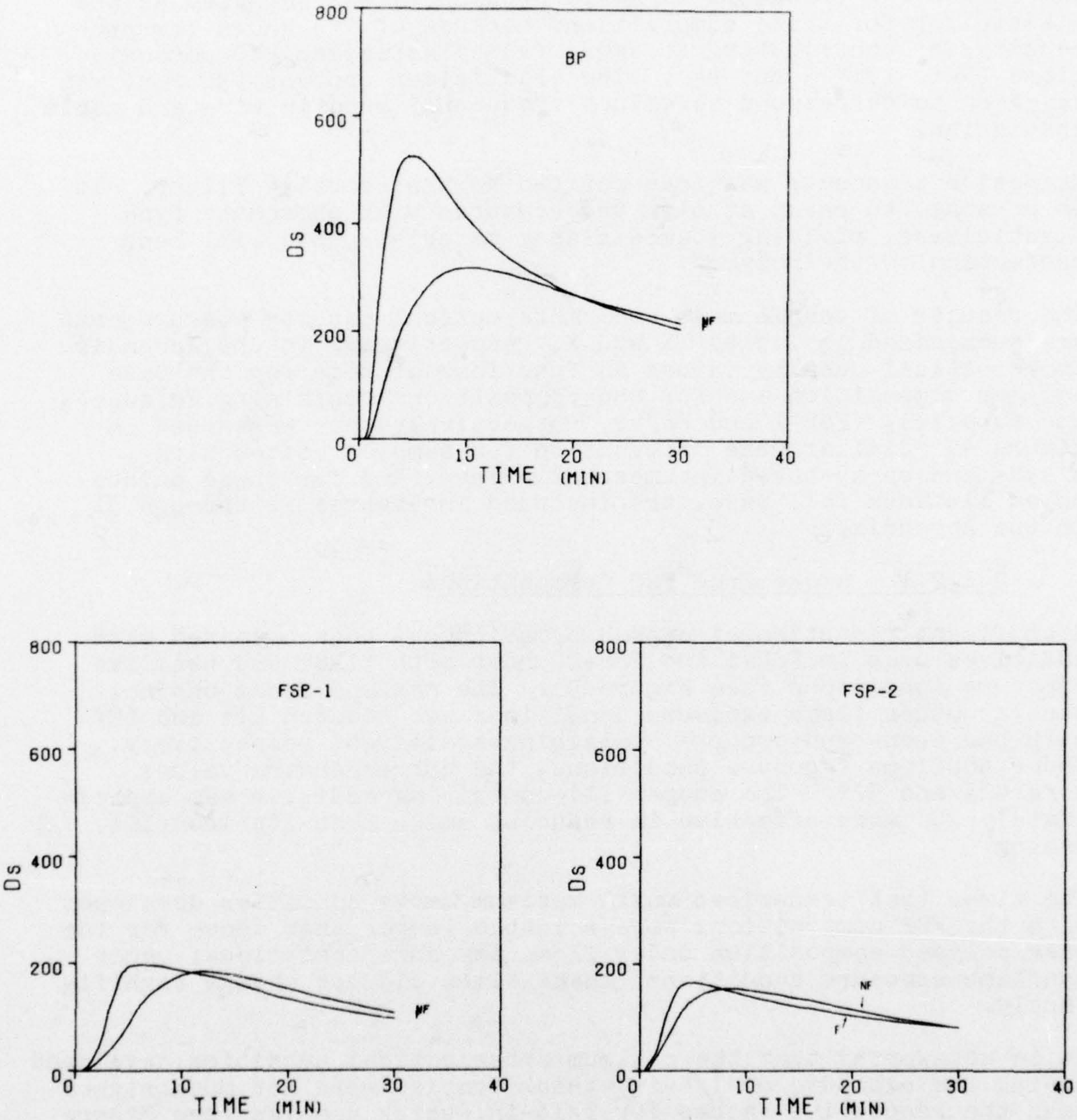


Figure 4. Smoke Optical Densities During the Burning of 1/16-in.-Thick Samples of PVC Compositions in the NBS-Aminco Chamber

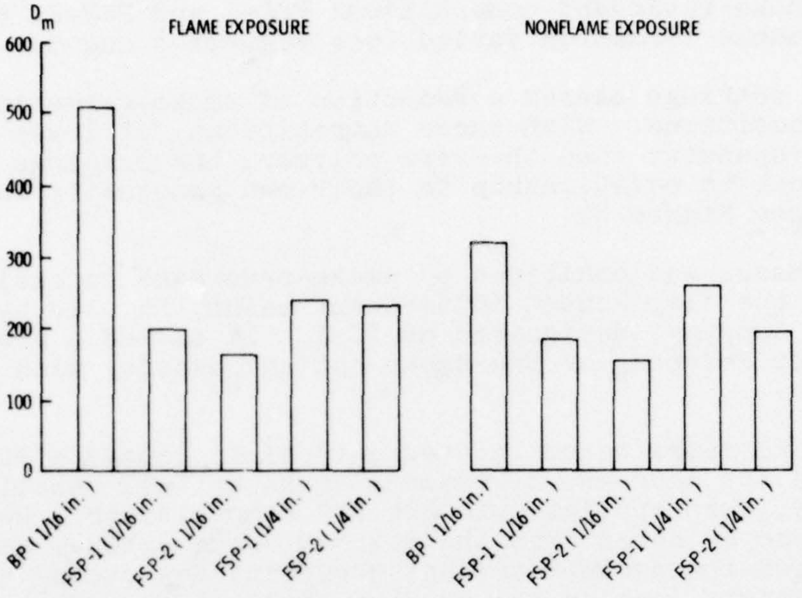


Figure 5. Maximum Specific Smoke Optical Densities of FSP Compositions

and chemical factors. The char formed from the PVC resin is cellular, voluminous and insulating. Because of the larger mass, the thick samples are heated more slowly. Presumably, more extensive crosslinking occurs during the slower heating, causing a reduction of the amount of volatile (combustible and/or condensable) degradation products. Also, more extensive agglomeration of aerosol particles can occur during the prolonged degradation, causing an increase of light transmittance through the smoke.

3.1.2.2 Smoke From Coated Samples and From the Coatings

Previous work at MRC (Refs. 25 and 26) and elsewhere (Ref. 27) has demonstrated the effectiveness of intumescent coatings for enhancing the fire performance of some polymers. Upon exposure to heat, the intumescent coatings expand 100-fold to 300-fold of their original thicknesses, forming insulating, cellular structures that afford protection to the substrate. Reductions of smoke formation and of flame propagation have been attained with intumescent coatings. In the present work, the effectiveness of this approach with the FSR PVC compositions was investigated.

Both types of intumescent coatings (IC-1 and IC-2) used in the present work with the base polymer reduced smoke formation from this composition, in terms of its maximum optical density, by approximately 20% (see Table IX in the Appendix). However, when these and other coatings (IC-3 and IC-4) were applied onto the fire- and smoke-retardant compositions FSP-1 and FSP-2, their effects on smoke formation varied (see Figures 6 and 7).

None of the coatings caused a reduction of smoke formation from the FSP compositions. With these compositions, of lower smoke formation propensity than the base polymer, the coatings contributed smoke in relationship to their own propensity for smoke formation (see Figure 8).

Best performance was exhibited by smoke-retardant compositions coated with the alkyd-based intumescent paint, No. 110 by C. M. Athey Paint Company, designated as IC-1. It caused a practically insignificant increase of the smoke optical density with the FSP compositions.

The epoxy- and latex-based intumescent paints caused a 90% increase and a 60% increase of maximum smoke optical density, respectively, when applied onto the FSP compositions. However, it should also be noted that the maximum smoke optical densities developed from the smoke-retardant compositions, coated with the latter two paints, are on the average still 24% lower than the value for the reference polymer sample of identical thickness (1/16 in.).

The mastic coating (IC-3), applied in a greater thickness than the intumescent paints, contributed more to smoke than did the latter. This is very evident from smoke optical density data obtained on coatings alone, applied onto aluminum foil supports (see Figure 8).

It was found that the rates of smoke formation were generally reduced by the intumescent coatings.

The above results indicate the need for intumescent coatings of very low propensity for smoke formation, to utilize fully the effectiveness of smoke-retardant additives incorporated into the PVC compositions.

3.1.3 Formation of Gaseous Combustion Products

The potential hazards resulting from the evolution of gaseous combustion products cannot be expressed well only by their concentrations at a few specific points in time. It is more useful to have data regarding the evolution of the different major combustion products during the progression of the exposure (Ref. 11). Such information was recorded with the experimental compositions prepared in this program. However, because of financial constraints, some of the analog output data of the analyzers were not digitized nor converted into uniform graphical format.

Some analysis results for the combustion products formed from PVC compositions are shown graphically in Figures 32 through 55 in the Appendix. These include data for the following compositions: BP, FSP-1, FSP-2, BP-IC-1, BP-IC-2, FSP-1-IC-1, FSP-1-IC-2,

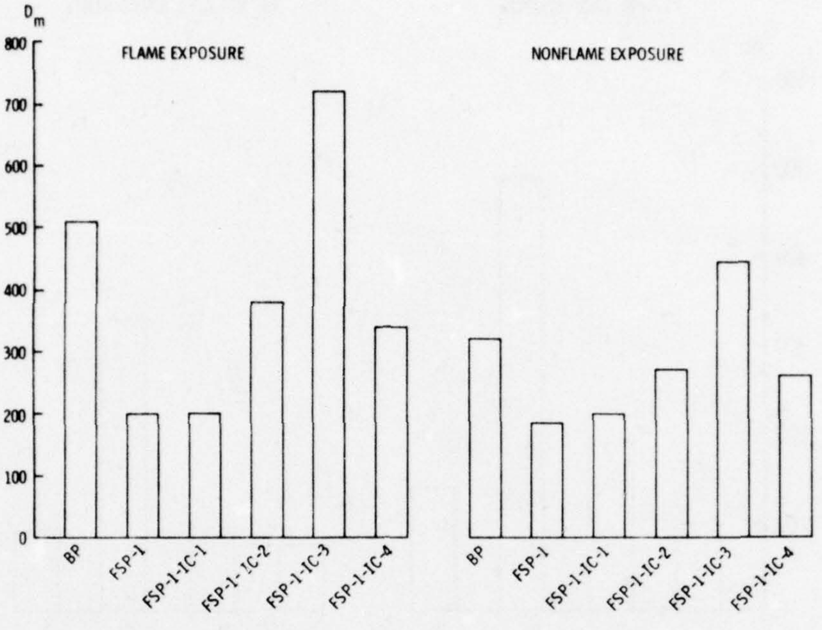


Figure 6. The Effect of Intumescent Coatings on Smoke Formation from 1/16-in.-Thick Samples of FSP-1

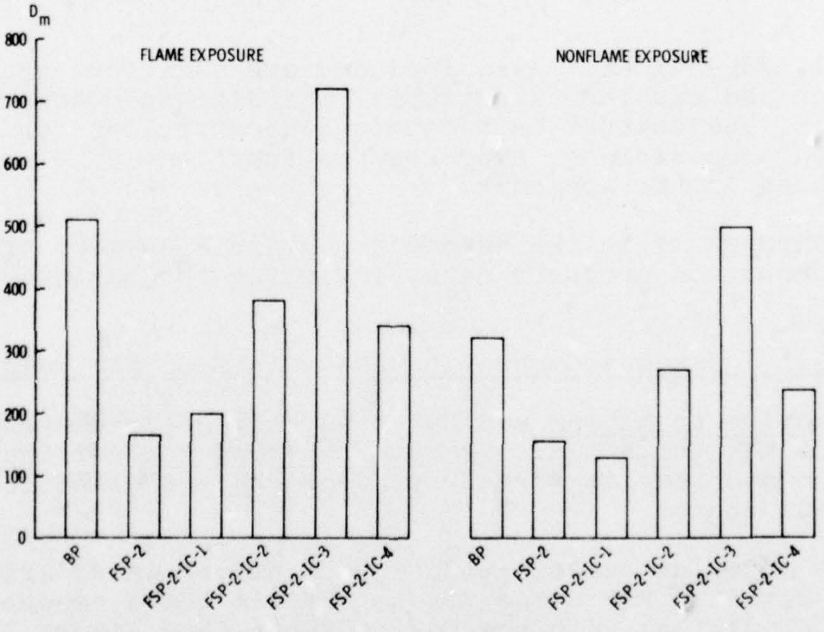


Figure 7. The Effect of Intumescent Coatings on Smoke Formation from 1/16-in.-Thick Samples of FSP-2

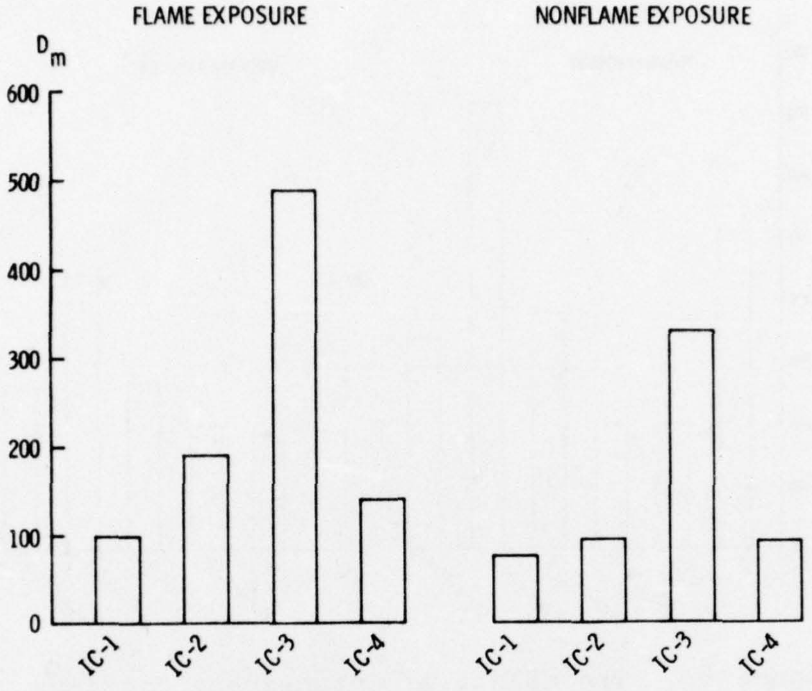


Figure 8. Maximum Smoke Optical Densities Generated from Intumescent Coatings, Applied Onto Aluminum Foil

FSP-2-IC-1, FSP-2-IC-2. Also included are data for intumescent coatings on the aluminum substrate. The digitized computer printouts of the combustion products concentrations for the above-cited compositions, expressed as functions of time, are also included in the Appendix.

Tables X through XV in the Appendix contain a summary of the gaseous combustion products data, including the maximum concentrations.

3.1.3.1 Gaseous Combustion Products from FSP Compositions

Carbon monoxide formation was detected only after charring of the samples had commenced. We have observed earlier (Ref. 17) that carbon monoxide is formed primarily by the oxidation of the carbonaceous chars.

The carbon monoxide concentrations were higher in experiments conducted with the FSP compositions than in those conducted under identical conditions with the base polymer (see Figure 9). The enhancement of carbon monoxide formation from the FSP compositions could arise from increased char formation from these compositions. Furthermore, the incorporated transition metals may also catalyze the oxidation of the char to carbon monoxide.

Carbon dioxide concentration increased progressively during the entire 30-minute duration of the experiments. In experiments conducted under flame exposure conditions, a significant fraction of the total carbon dioxide was formed by the propane flame.

The rate data indicate that the evolution of HCl, nitrogen oxides (NO_x), and hydrocarbons occurs to a large extent during the first five minutes of the exposure (see Figures 34 through 35 in the Appendix). The concentrations of HCl and NO_x were generally found to diminish in the gas phase during the second half of the experiments, presumably because of condensation on the chamber walls and reactions with organic polymer degradation products. The concentrations of NO_x were very low.

The concentrations of NO_x, HCl and hydrocarbons formed from the FSP compositions were generally lower than those observed in experiments with the base polymer under identical conditions (see Figures 34 through 36 in the Appendix and Table III in this section).

Table III

SUMMARY OF CO, NO_x, AND HCl CONCENTRATION DATA DURING TESTS WITH BP, FSP-1 AND FSP-2

		Gas Concentration (ppm)						Time to Maximum Gas Concentration (min)	
		Flame Exposure			Nonflame Exposure				
Gaseous Combustion Product	Material	10 min	20 min	Max. Conc	10 min	20 min	Max. Conc	Flame Exposure	Nonflame Exposure
CO	BP	810	1450	1900	120	310	570	30	30
CO	FSP-1	1190	1850	2200	170	960	1350	30	30
CO	FSP-2	1030	1700	2100	220	700	850	30	30
NO_x	BP	12.6	9.4	18.7	2.9	2.2	4.6	5	4
NO_x	FSP-1	2.5	2.8	3.3	1.5	1.4	1.8	30	5
NO_x	FSP-2	5.9	5.3	7.7	1.5	1.4	1.6	5	4
		5 min	15 min	30 min	5 min	15 min	30 min		
HCl	BP	2100	2400	1050	1900	2600	2200		
HCl	FSP-1	1900	2200	1500	1650	2400	2100		
HCl	FSP-2	1350	900	490	1500	2300	1900		

The evolution of HCl during the early exposure of samples to the radiant energy source and flames is related to the first stage of the resin degradation process (see Figure 9) at temperatures below 350°C. The rapid concomitant evolution of hydrocarbons is attributed to thermal degradation of the plasticizer, which presumably produces hendecene as the major volatile organic species.

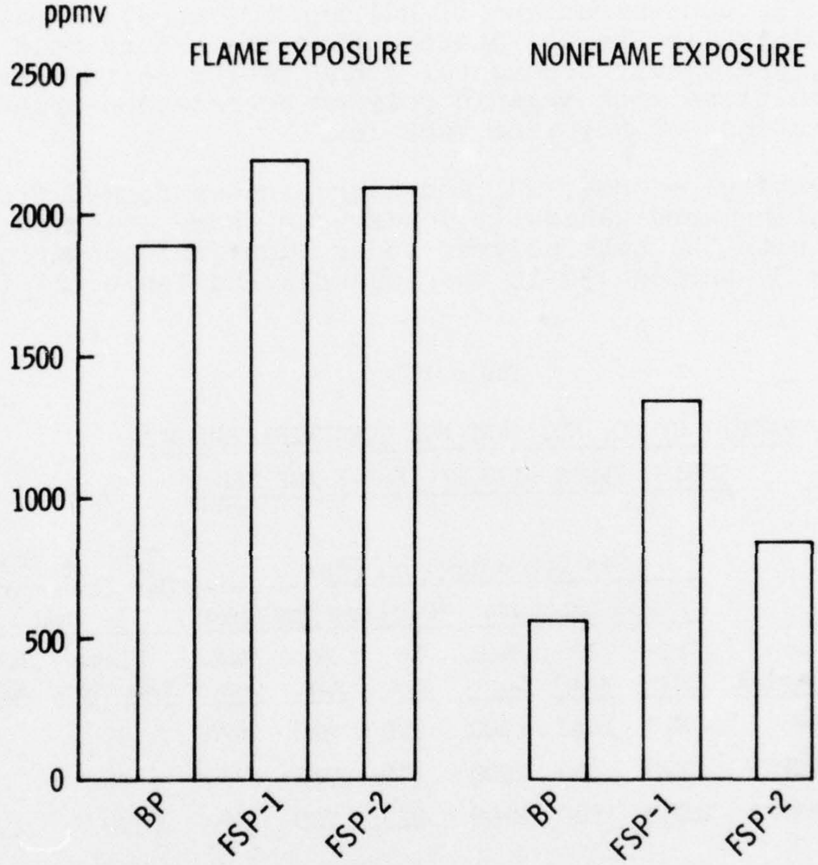


Figure 9. Maximum CO Concentrations Generated From BP and From the FSP Compositions

3.1.3.2 Gaseous Combustion Products From Coated Samples and From the Coatings

The intumescent coatings reduced significantly the formation of carbon monoxide under nonflame exposure conditions (see Table XI in the Appendix and Figures 10 through 13). This effect was especially noticeable with the FSP-1 composition.

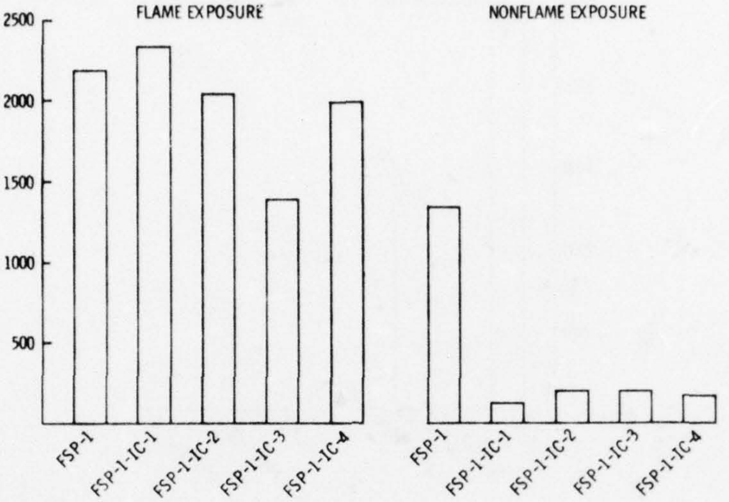


Figure 10. The Effect of Intumescent Coatings on Maximum CO Concentrations Developed from 1/16-in.-Thick Samples of FSP-1

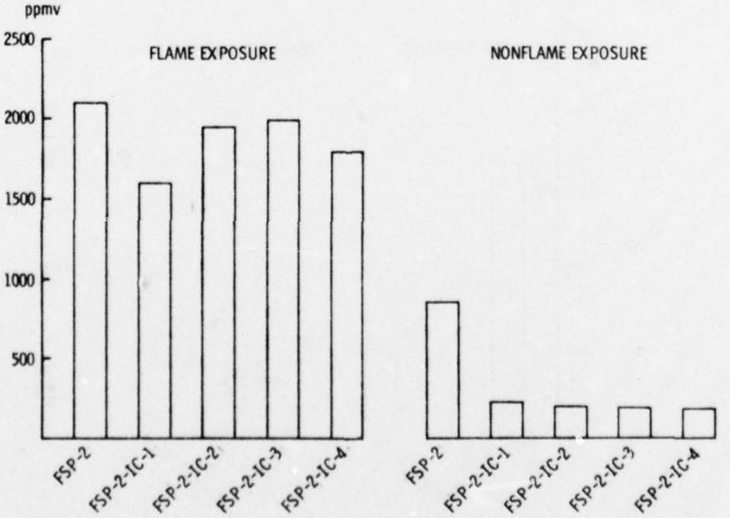


Figure 11. The Effect of Intumescent Coatings on Maximum CO Concentrations Developed from 1/16-in.-Thick Samples of FSP-2

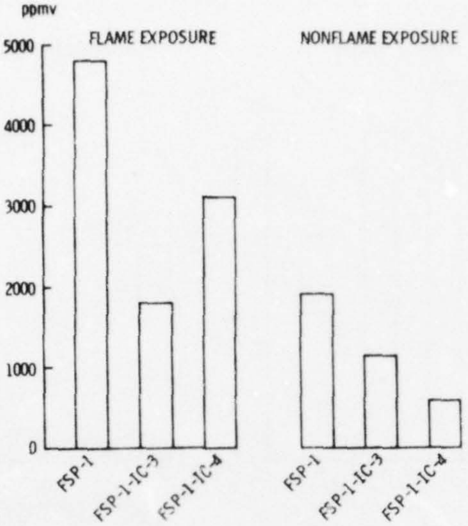


Figure 12. The Effect of Intumescent Coatings on Maximum CO Concentrations Developed from 1/4-in.-Thick Samples of FSP-1

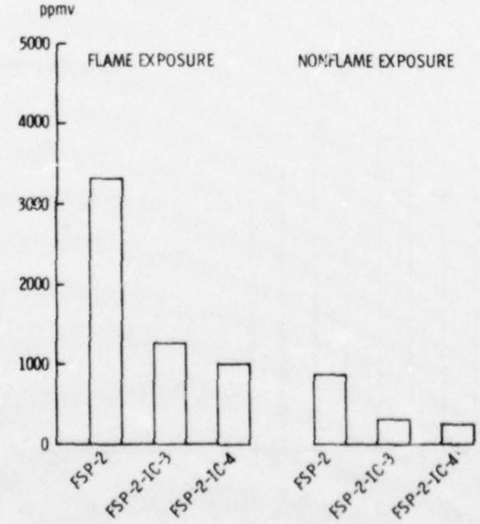


Figure 13. The Effect of Intumescent Coatings on Maximum CO Concentrations Developed from 1/4-in.-Thick Samples of FSP-2

The maximum concentrations of carbon monoxide formed under flame exposure conditions were not greatly affected by the coatings when they had been applied onto 1/16-in.-thick specimens. It should be noted that significant carbon monoxide concentrations were generated under flame exposure conditions from the intumescent coatings used in this work (see Figure 14). The formation of carbon monoxide from these coatings is attributed to the oxidation of the initially formed carbonaceous chars in the flame.

The latex-based intumescent paint and the mastic were also applied onto 1/4-in.-thick panels of FSP-1 and FSP-2. They were found to reduce CO formation from these thick panel specimens not only under nonflame exposure but also under flame exposure conditions (see Figures 13 and 14); the average reduction with these samples was 65%.

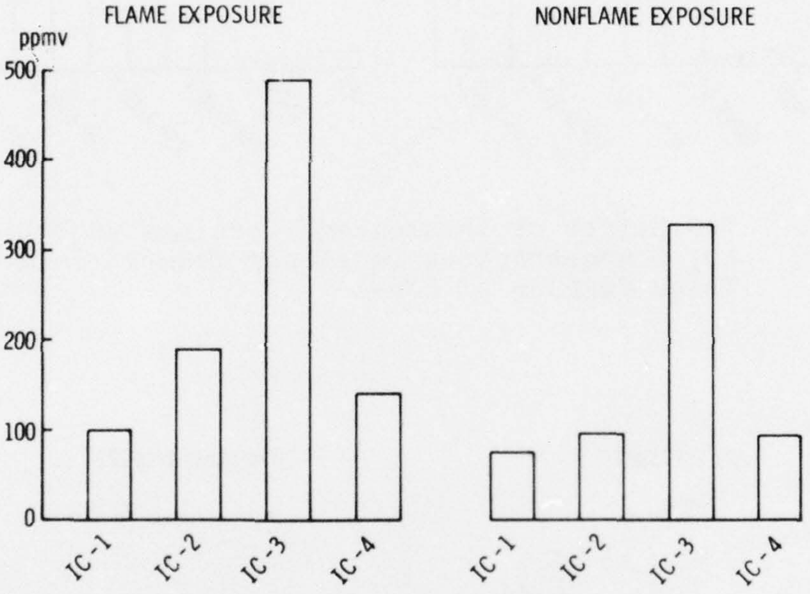


Figure 14. Maximum CO Concentrations Generated From Intumescent Coatings

The <u>formation of carbon dioxide</u> from the FSP compositions was retarded by all intumescent coatings under the nonflame exposure conditions (see Table XII in the Appendix). The reduction of CO and CO_2 formation is an indication of the effectiveness of intumescent coatings for reducing the oxidation of the PVC compositions.

All intumescent coatings increased the <u>NO_x content</u> in the test chamber atmosphere under both types of exposure conditions; however, they delayed the times when the maximum concentrations were reached (see Table XIII in the Appendix and Figures 15 and 16 in this section). The alkyd-based coating made the smallest contribution to the nitrogen oxides in the gaseous degradation

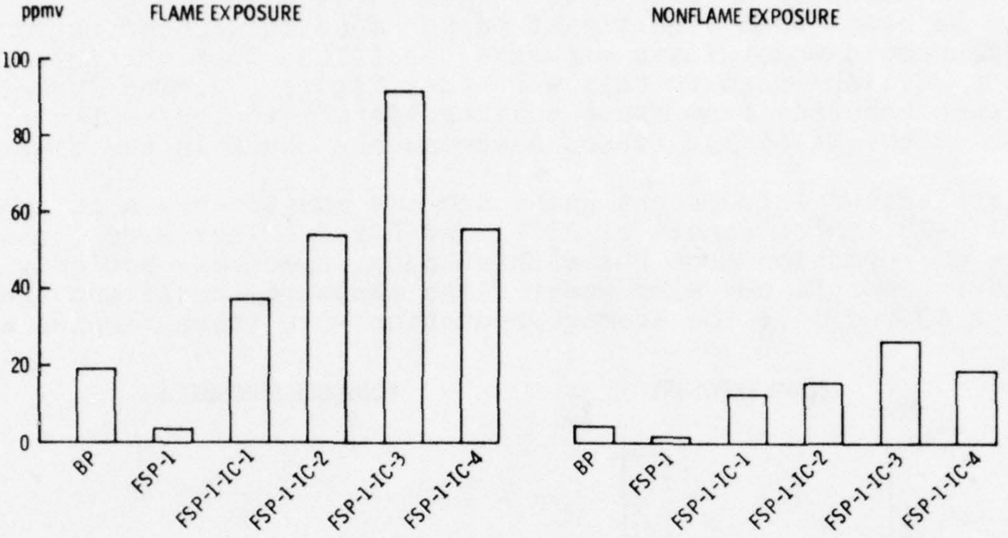


Figure 15. The Effect of Intumescent Coatings on Maximum NO_x Concentrations Developed from 1/16-in.-Thick Samples of FSP-1

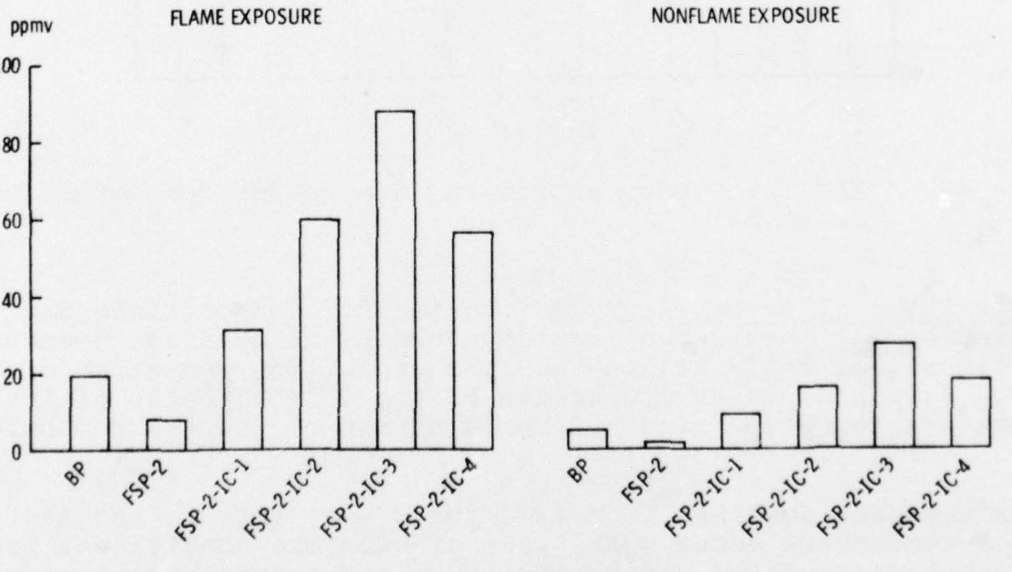


Figure 16. The Effect of Intumescent Coatings on Maximum NO_x Concentrations Developed from 1/16-in.-Thick Samples of FSP-2

and combustion products. The formation of nitrogen oxides from the intumescent coatings (see Figure 17) is attributed mainly to the oxidation of the incorporated nitrogen-containing blowing agents.

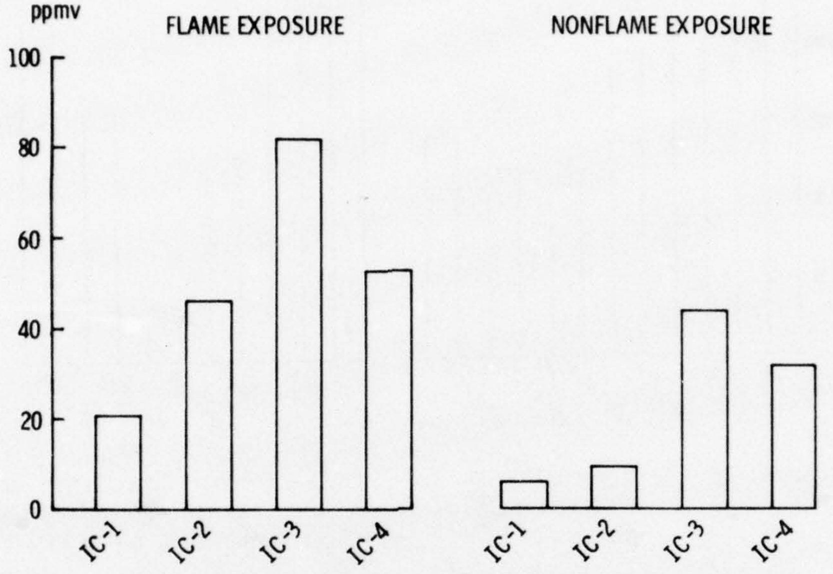


Figure 17. Maximum NO_x Concentrations Generated from Intumescent Coatings

Most intumescent coatings reduced the rates of <u>hydrogen chloride evolution</u> and the maximum concentrations developed during sample exposures (see Table XIV in the Appendix and Figure 18 in this section). The coatings were especially effective in reducing HCl formation from thick samples (see Figure 19). Apparently, by retarding the rate of sample degradation, they cause the released HCl to have a longer residence time in the polymer matrix. Thereby, more time is available for reaction with the incorporated magnesium carbonate.

Intumescent coatings caused a modest increase of <u>hydrocarbons</u> evolution from the thin (1/16-in.) FSP compositions under flame exposure conditions (see Table XV in the Appendix and Figures 20 and 21 in this section). The reason is believed to be twofold. First, hydrocarbons are generated from these coatings upon exposure to radiant heating and to a flame (see Figure 22). Secondly, the oxidation of the volatile organic degradation products from the FSP compositions to CO and CO_2 is retarded by the coatings.

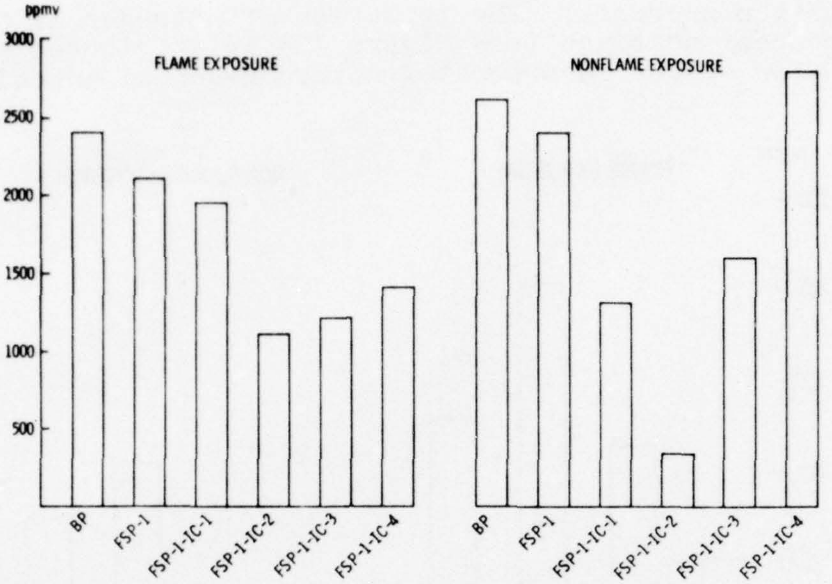


Figure 18. The Effect of Intumescent Coatings on Maximum HCl Concentrations Developed from 1/16-in.-Thick Samples of FSP-1

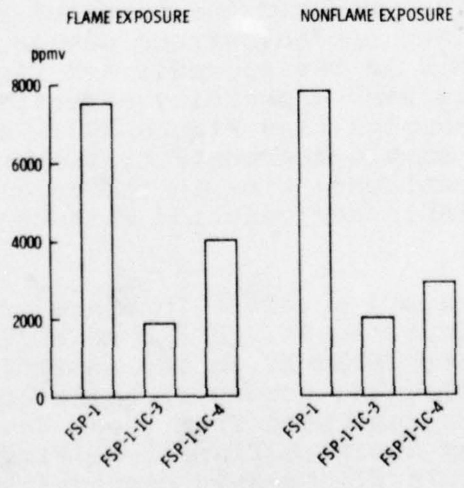


Figure 19. The Effect of Intumescent Coatings on Maximum HCl Concentrations Developed from 1/4-in.-Thick Samples of FSP-1

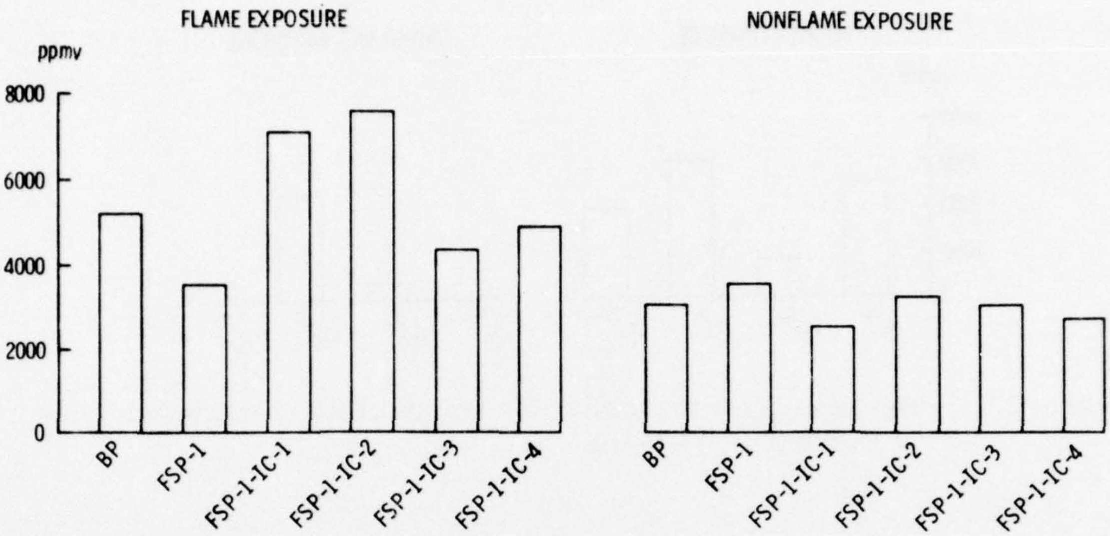


Figure 20. The Effect of Intumescent Coatings on Maximum Hydrocarbons Concentrations Developed from 1/16-in.-Thick Samples of FSP-1

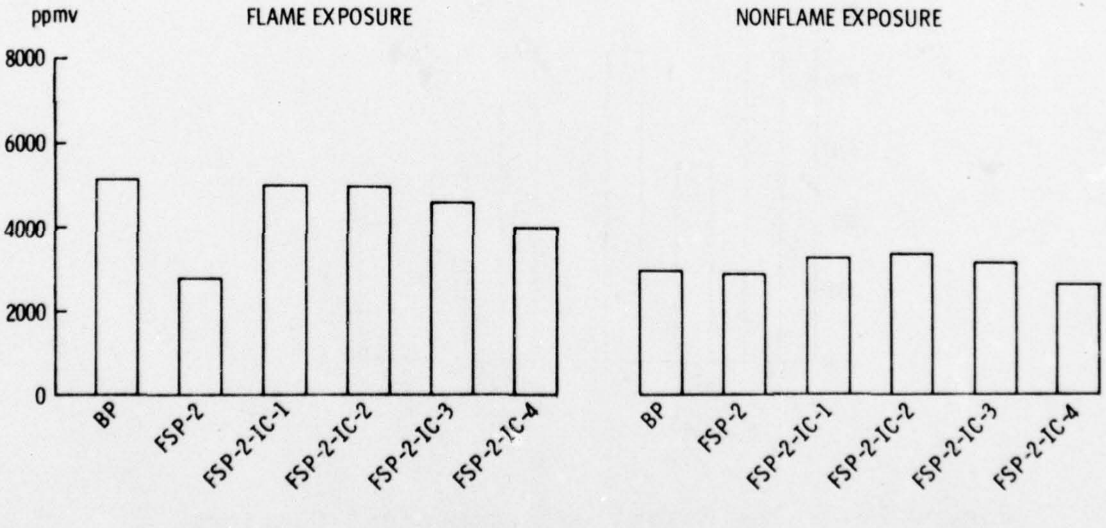


Figure 21. The Effect of Intumescent Coatings on Maximum Hydrocarbons Concentrations Developed from 1/16-in.-Thick Samples of FSP-2

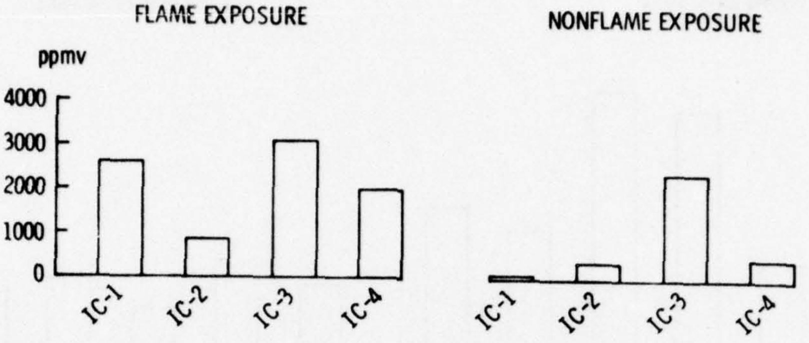


Figure 22. Maximum Hydrocarbons Concentrations Generated from Intumescent Coatings

With thick (1/4-in.) samples of FSP compositions, the mastic and the latex-based coatings retarded hydrocarbons formation by 20% under flame exposure and 35% under nonflame exposure conditions (see Table XV in the Appendix and Figures 23 and 24 in this section). The reduction of hydrocarbons formation from the thick specimens is attributed to significantly reduced pyrolysis.

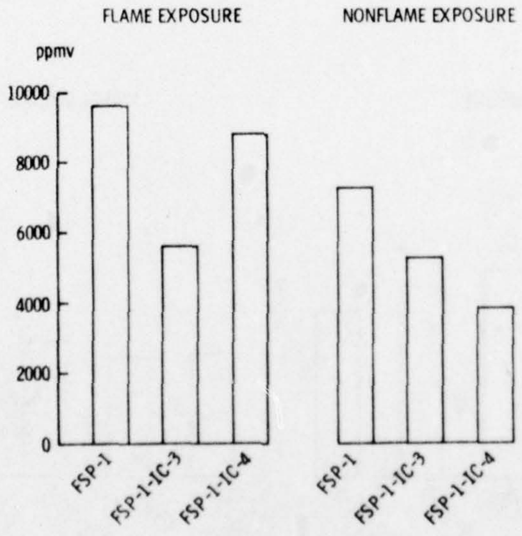


Figure 23. The Effect of Intumescent Coatings on Maximum Hydrocarbons Concentrations Developed from 1/4-in.-Thick Samples of FSP-1

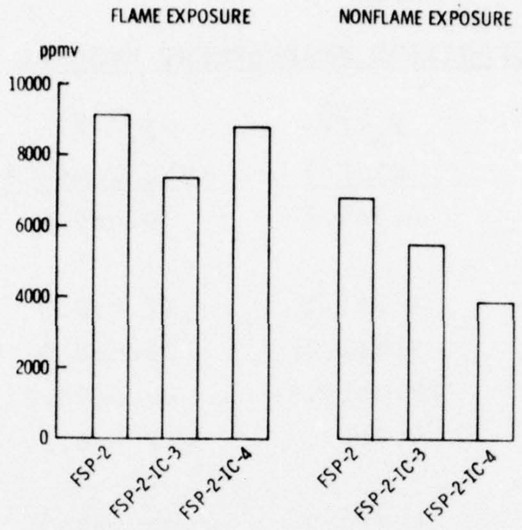


Figure 24. The Effect of Intumescent Coatings on Maximum Hydrocarbons Concentrations Developed from 1/4-in.-Thick Samples of FSP-2

3.1.4 Flame Propagation

Vertically downward flame propagation rates for samples exposed to irradiative heating were measured by the ASTM Standard Test E 162-76. The data are summarized in Table IV, and the results for the individual tests are presented in Table XVI in the Appendix. The mean distances of flame propagation for the different compositions, as functions of time, are presented in Figures 25 and 26.

According to this test (Ref. 15), the flame spread index, I_s, of a specimen is expressed as the product of the flame spread factor, F_s, and the heat evolution factor, Q.

$$I_s = F_s Q$$

The flame spread factor is defined in terms of the times in minutes ($t_3, \ldots\ldots, t_{15}$) that transpire from the initial specimen exposure until the arrival of the flame front at the position 3,....., 15 in. from the ignited sample edge.

$$F_s = 1 + \frac{1}{t_3} + \frac{1}{t_6 - t_3} + \frac{1}{t_9 - t_6} + \frac{1}{t_{12} - t_9} + \frac{1}{t_{15} - t_{13}}$$

Table IV

FLAME PROPAGATION MEASUREMENT RESULTS

Material	F_s[a,b] (min^{-1})	I_s[b,c] (Btu x min^{-2})
BP	2.7±0.2	9.6±4.6
FSP-1-IC-1	5.2±1.1	11.4±2.3
FSP-1-IC-2	9.6±1.0	21.6±8.9
FSP-1-IC-3	22.0±19.4	92.6±78.2
FSP-1-IC-4	5.7±0.1	12.5±0.2
FSP-2-IC-1	4.1±0.9	32.2±20.1
FSP-2-IC-2	6.5±1.8	33.2±7.1
FSP-2-IC-3	8.9±1.3	51.4±2.0
FSP-2-IC-4	3.9±1.3	15.7±7.2

[a] Flame spread factor, as defined in Ref. 15.

[b] Mean value and standard deviation for duplicate or triplicate measurements.

[c] Flame spread index, as defined in Ref. 15.

The heat evolution factor is defined in terms of ΔT, the maximum stack temperature rise in degrees Fahrenheit with reference to that observed with an asbestos-cement board specimen, and the experimentally determined constant β:

$$Q = 0.1 \frac{\Delta T}{\beta}$$

Physically, the constant β represents the maximum stack thermocouple rise in degrees Fahrenheit for unit heat input rate (Btu/min) of the calibration burner. The factor 0.1 in the above equation is an arbitrary constant.

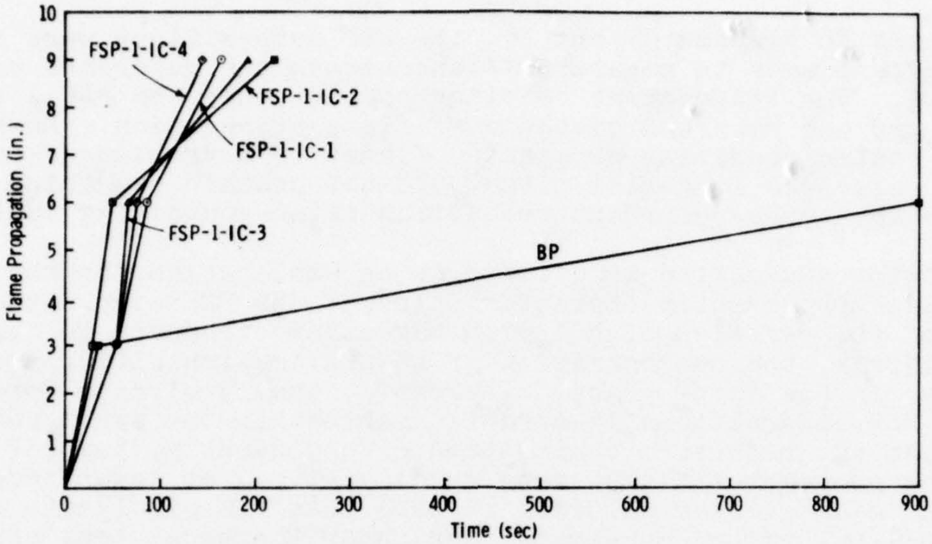


Figure 25. Flame Propagation by FSP-1 Compositions

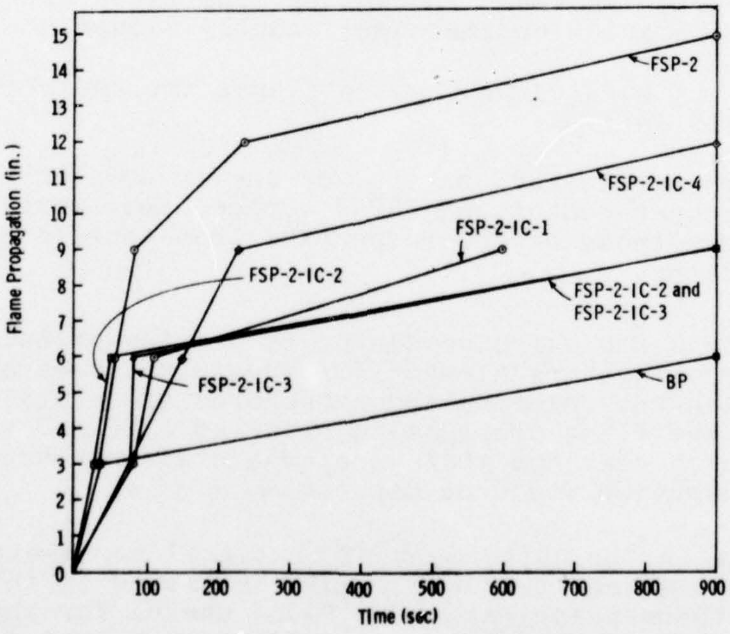


Figure 26. Flame Propagation by FSP-2 Compositions

As indicated in Figures 25 and 26, the FSP compositions were found to propagate flames to greater distances than the reference composition, BP. The intumescent coatings applied onto the FSP-2 surface reduced the rate and distance of flame propagation. However, even the coated specimens propagated flames to a greater distance than the reference composition that did not contain magnesium carbonate and smoke-retardant transition metal-containing additives.

The following suggestion is offered as an explanation for the enhanced flame propagation characteristics of the FSP compositions. Because of the reaction of HCl with magnesium carbonate in the polymer matrix, the concentration of this flame-inhibiting species is reduced in the vapor phase. Therefore, the pyrolyzate formed from the FSP compositions is more flammable than the pyrolyzate formed from the reference composition. Consequently, the FSP pyrolyzate propagates flames more readily (i.e., at lower temperatures, and with greater dilution by air) than the pyrolyzate formed from the reference composition under identical test conditions.

The following additional observations regarding flame propagation measurement results are of interest:

- Subsequent to the initial heating, most specimens propagated flames at a rapid rate from the 6 in. to the 9-in. distance from the point at which the samples were ignited. Thereafter, the rates of flame propagation became significantly slower.

- None of the samples propagated flames the entire length (18 in.).

- The flame spread factors (F_s) of the intumescent-coated copper-containing FSP-2 compositions were lower than those of the respective iron-containing compositions.

The compositions for which we sought to provide protection with intumescent coatings are already fire-resistant because of the manner in which the chlorine and phosphorus are contained. Some reduction of the flame propagation rate was attained with the four intumescent coatings that were evaluated; however, more effective protection would be desirable.

Two approaches to the attainment of that goal merit evaluation. First, the intumescent coatings should be tested in thicknesses greater than those which have been found useful for the relatively more flammable wood substrates. Secondly, when needed for added protection of fire-resistant materials, the intumescent coatings should contain higher than the normally used concentrations of the fire-retardant ingredients.

3.1.5 Tensile Strength and Elongation

The results of tensile strength and elongation measurements are summarized in Table V. The mean values and the standard deviations are based on five determinations with each composition.

Table V

TENSILE STRENGTH AND ELONGATION DATA

FOR SOME PVC COMPOSITIONS

Material	Yield Strength (psi)	Ultimate Strength (psi)	Elongation at Failure (%)
BP	--	3560±220	220±60
FSP-1	2930±70	3160±100	210±30
FSP-2	2930±100	2750±40	87±50

The base composition did not exhibit a yield point; the samples stretched until, ultimately, rupture occurred.

The ultimate tensile strengths of the FSP-1 and FSP-2 compositions were 11% and 23%, respectively, lower than the value for the base polymer.

Whereas the value for elongation at failure for the FSP-1 composition was nearly identical with that for the base polymer, the samples of FSP-2 ruptured at lower elongation.

3.1.6 Electrical Properties

Volume resistivity, dielectric constant and dissipation factor measurements were conducted with the base polymer and with the two FSP compositions without intumescent coatings. The following results were obtained:

Table VI

ELECTRICAL PROPERTIES

Material	Volume Resistivity (ohm-cm x 10^{13})	Dielectric Constant	Dissipation Factor
BP	68	4.05	0.079
FSP-1	14	4.44	0.059
FSP-2	12	4.05	0.056

3.2 EXPERIMENTAL NEOPRENE FOAM COMPOSITIONS

3.2.1 Formation of Smoke

Ferric and cupric acetylacetonates had been found to be effective smoke-retardant additives with the experimental PVC compositions in the present work. On the basis of these results, the smoke-retardant effectiveness of these additives was also evaluated with the neoprene base formulation (BF) selected for the program.

Additionally, Phos-Chek P/30 fire retardant [i.e., poly(ammonium phosphate)] was incorporated as a fire-retardant additive and as a source of phosphate for glass formation during exposure to intense heat fluxes. The latter additive caused coalescence of the neoprene foam prior to curing. To prevent foam coalescence, a procedure was developed for encapsulating the phosphate salt in a coating of partially hydrolyzed ethylene-vinyl acetate polymer.

Ferric acetylacetonate by itself and in combination with Phos-Chek P/30 reduced the smoke optical density generated from the neoprene foam base formulation (BF) under flame exposure conditions by approximately 10%. Under nonflame exposure conditions, the smoke optical density was slightly increased by the incorporated additives. The results of smoke optical density measurements with the neoprene compositions are presented in Figure 27 and in Table VII.

It is apparent from these results that more effective crosslinking catalysts for the thermal degradation stage are needed than the iron acetylacetonate used in the present work. These catalysts cannot cause degradation of the polymer under curing and use conditions.

3.2.2 Formation of Gaseous Combustion Products

The results of gaseous combustion products measurements are summarized in Table VIII and presented graphically in Figures 28 through 61 in the Appendix. The following are noteworthy findings pertaining to these measurements.

Ferric acetylacetonate alone increased carbon monoxide formation from neoprene foam under the conditions of nonflame exposure by ∿40%. However, when this char formation catalyst precursor was used together with Phos-Chek P/30 in FSF-3, the catalytic effect for CO formation was destroyed. Ferric acetylacetonate had no adverse effect on CO formation under flame exposure conditions.

Carbon dioxide formation was slightly enhanced by the incorporated additives under both flame and nonflame exposure conditions.

The formation of hydrocarbons was reduced by ∿45% by the incorporated additives in tests conducted under flame exposure conditions.

Table VII

SMOKE OPTICAL DENSITY RESULTS SUMMARY FOR NEOPRENE FOAM COMPOSITIONS[a]

Material	Smoke Optical Density						Time to Maximum SOD (min)	
	Flame Exposure			Nonflame Exposure				
	10 min	20 min	Maximum	10 min	20 min	Maximum	Flame Exposure	Nonflame Exposure
BF	560	510	560	490	460	490	9	9
FSF-1[b]	490	400	500	500	400	510	12	12
FSF-2[c]	530	470	530	480	440	480	12	11
FSF-3[d]	500	460	510	520	440	530	13	12

[a] Measurements conducted with 3 in. x 3 in. x 1 in. (7.6 cm x 7.6 cm x 2.5 cm) specimens in vertical orientation. Imposed energy flux in the center of the samples 16.4 watts/sq. in. (2.5 watts/cm^2). Foam density 7.0±0.7 lb/ft^3

[b] Contained 5 phr ferric acetylacetonate.

[c] Contained 10 phr encapsulated Phos-Chek P/30.

[d] Contained 5 phr ferric acetylacetonate and 10 phr encapsulated Phos-Chek P/30.

Small amounts of hydrogen cyanide were formed from the neoprene foam compositions used in this work. The incorporated polymethylene polyphenyl isocyanate may have been the major source of this degradation product. It is noteworthy that ferric acetylacetonate, in the absence of Phos-Chek P/30, reduced the formation of hydrogen cyanide without a concomitant increase of nitrogen oxides.

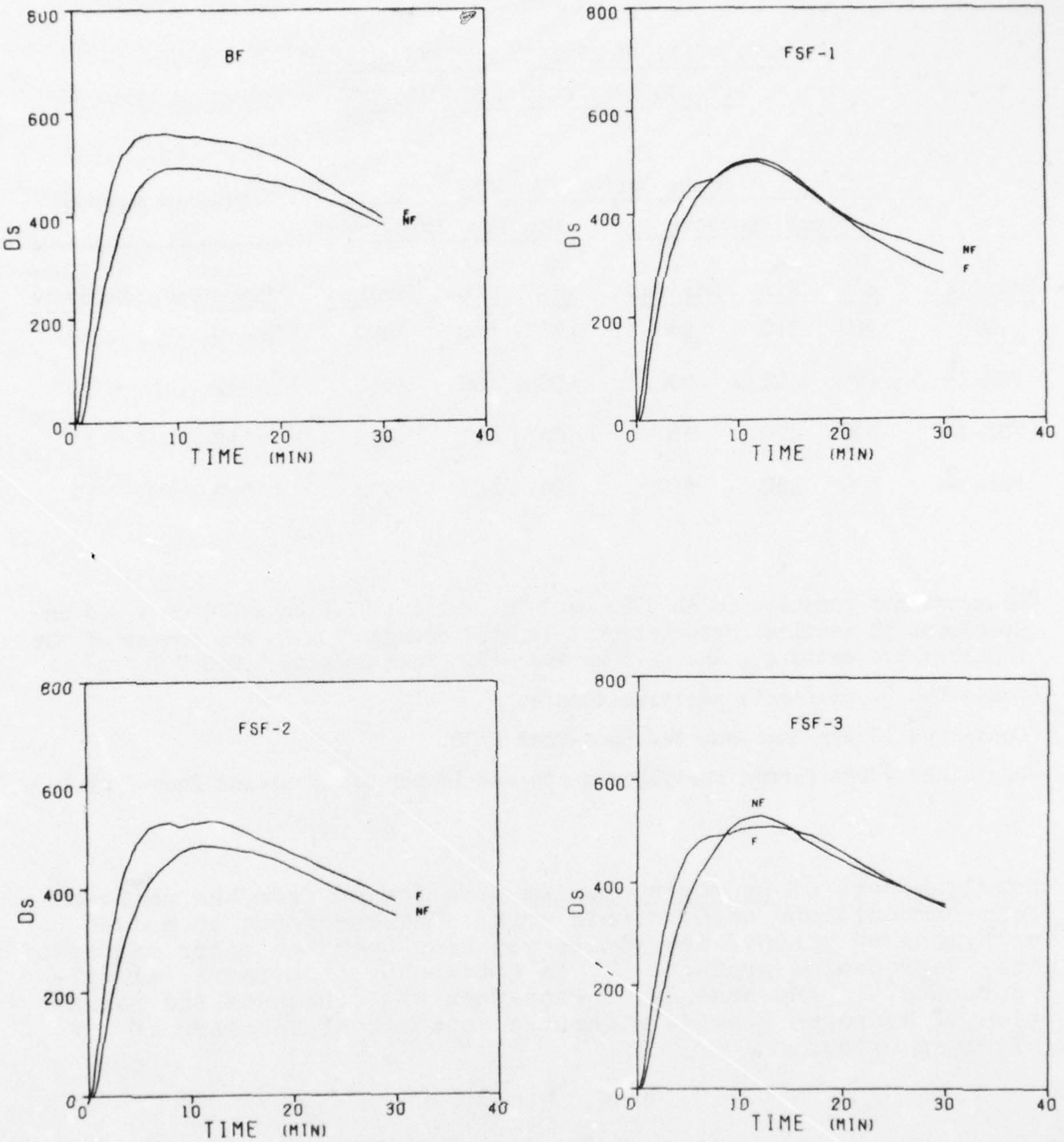


Figure 27. Smoke Optical Densities During the Burning of Experimental Neoprene Foam Compositions

Table VIII

SUMMARY OF CO, CO_2, NO_x, HCl, HCN AND HYDROCARBONS CONCENTRATION DATA DURING TESTS WITH NEOPRENE FOAM COMPOSITIONS

		Concentration[a]						Time to Maximum Concentration (min)	
		Flame Exposure			Nonflame Exposure				
Gaseous Combustion Product	Material	10 min	20 min	Maximum	10 min	20 min	Maximum	Flame Exposure	Nonflame Exposure
CO	BF	1050	2000	2600	490	1400	2100	30	30
CO	FSF-1	1200	2100	2700	900	2000	2900	30	30
CO	FSF-2	900	1800	2300	550	1600	2200	30	30
CO	FSF-3	930	1800	2300	680	1650	2100	30	30
CO_2	BF	0.56	1.15	1.89	0.22	0.58	1.00	30	30
CO_2	FSF-1	0.80	1.65	2.43	0.42	1.02	1.61	30	30
CO_2	FSF-2	0.63	1.34	2.03	0.25	0.69	1.15	30	30
CO_2	FSF-3	0.68	1.44	2.16	0.38	0.94	1.37	30	30
NO_x	BF	12	19	25	1.8	3.6	5.4	30	30
NO_x	FSF-1	11	18	23	2.2	3.7	5.3	30	30
NO_x	FSF-2	14	23	30	3.8	6.4	8.7	27	30
NO_x	FSF-3	14	23	30	3.7	7.7	10.1	30	30
Hydrocarbons	BF	3700	5600	6600	2800	3200	3300	30	30
Hydrocarbons	FSF-1	3300	3800	3900	3400	3700	3800	20	17
Hydrocarbons	FSF-2	2200	2800	2900	2000	2700	2700	27	21
Hydrocarbons	FSF-3	2600	3500	3800	2300	2700	2700	27	21
		5 min	15 min	30 min	5 min	15 min	30 min		
HCl	BF	930	2100	1550	1100	2100	1950		
HCl	FSF-1	1050	2300	1550	1100	2000	1500		
HCl	FSF-2	1500	1600	1550	1150	2300	2300		
HCl	FSF-3	950	2000	1450	800	1650	1600		
HCN[b]	BF	3.3	16.8	31.8					
HCN	FSF-1	1.5	1.7	9.1	1.8	2.3	5.9		
HCN	FSF-2	3.2	8.4	36.8	4.6	16.6	40.2		
HCN	FSF-3	4.6	37.6	61.3	2.2	36.9	53.6		

[a] The concentrations of CO, NO_x, HCl, HCN and hydrocarbons are reported in ppmv. The concentrations of CO_2 are expressed in volume percent.

[b] The hydrogen cyanide was formed from nitrogen-containing components, including the polyisocyanate, in the neoprene rubber compositions.

4. RECOMMENDATIONS

4.1 GENERAL

It is recommended that fire performance objectives, in terms of specific test results, be established for PVC and neoprene compositions used aboard ship. These can be based on past fire accident history, analysis of potentially hazardous situations, large-scale test results, and the availability of fire prevention and extinguishing means. Such objectives will constitute specific goals for materials development programs; they will also serve as guidelines in analyzing the trade-off options available through the selection of ingredients and through special treatments.

4.2 POLYVINYL CHLORIDE COMPOSITIONS

1. For applications in which the polymer cannot be coated with an intumescent paint, the composition containing copper(II) acetylacetonate is recommended on the technical basis. However, it is also suggested that the environmental impact and the cost be analyzed for the two PVC compositions containing the smoke-retardant additives.

   [This recommendation is based on the observed significant reduction of smoke formation with iron(III) and copper(II) acetylacetonates, the copper-containing additive being more effective. Also, less carbon monoxide is generated from the copper-containing PVC composition under nonflame exposure conditions; under flame exposure conditions, the compositions FSP-1 and FSP-2 perform very similarly with regard to CO formation.]

2. For applications in which coated PVC can be used, the alkyd-based intumescent coating (IC-1) is recommended above others tested in this program for interior applications. For exterior applications, the epoxy-based coating (IC-2) is recommended.

3. Additional experimental work is suggested with the two recommended intumescent coatings to determine optimum thicknesses and optimum concentrations of the ammonium phosphate type fire retardants/blowing agents in these compositions. (Flame propagation measurements indicated that the fire-retardant concentrations of the commercially available intumescent coatings are not sufficiently high for the inherently somewhat fire-retardant PVC compositions.)

4. The optimized PVC materials should then be prepared in larger quantities in order to determine their performances in use configurations, in large-scale accident-simulative tests.

4.3 NEOPRENE COMPOSITIONS

1. It is recommended that candidate crosslinking catalysts be evaluated by thermogravimetric analysis. Incorporation of the candidate materials into molded neoprene compositions will expedite the screening process.

2. Candidate fire- and smoke-retardant neoprene foams should be prepared only with those additives that exhibit significant char-enhancing effects in the thermogravimetric screening experiments.

5. REFERENCES

1. Sales Merchandising Bulletin No. 1403, "Intumescent Fire Retardant Paint," C. M. Athey Paint Company, Baltimore, Md.

2. Preliminary Data Sheet, "Ocean No. 330 Intumescent Flat Emulsion Fire-Retardant Coating," Ocean Chemicals, Inc., Savannah, Ga.

3. Product Information Bulletin "Ocean Intumescent Fire Retardant Catalytic Epoxy Paint No. 477," Ocean Chemicals, Inc., Savannah, Ga.

4. J. C. Carl, "Neoprene Latex," E. I. duPont de Nemours and Co., Elastomer Chemicals Department, Wilmington, Del., 1962.

5. "Standard Isocyanate-Modified Neoprene Foam Using Neoprene Latex 357," SD-2311, Second Revised Edition, Du Pont Company, Elastomer Chemicals Department, Wilmington, Del., July 4, 1976.

6. H. Burkheimer, Du Pont Company, Elastomer Chemicals Department, personal communications, August 1976.

7. C. W. Stewart, Sr., R. L. Dawson, and P. R. Johnson, "The Effect of Compounding Variables on the Rates of Heat and Smoke Release from Polychloroprene Foam," *Rubber Chem. Technol.* 48(1), 132 (1975).

8. R. G. Bayless, C. P. Shank, R. A. Botham, and D. W. Werkmeister, "Process for Forming Minute Capsules and Three-Phase Capsule-Forming System Useful in Said Process," U.S. Patent 3,674,704, July 4, 1972.

9. N. P. Setchkin, "A Method and Apparatus for Determining the Ignition Characteristics of Plastics," *J. Res. Natl. Bur. Stand.* 43, 591 (1949).

10. "Standard Method of Test for Ignition Properties of Plastics," ASTM Designation ASTM D 1929-68, Annual Book of ASTM Standards, Part 35, Am. Soc. for Testing and Mat., Philadelphia, 1974, p. 614.

11. L. Parts, R. G. Olt, and G. W. Wooten, "Products Resulting from Polymer Combustion," Polymer Conference Series, Flammability of Materials, University of Utah, Salt Lake City, Utah, July 11, 1974.

12. D. Gross, J. J. Loftus, and A. F. Robertson, "Method for Measuring Smoke from Burning Materials," Symposium on Fire Test Methods - Restraint and Smoke," ASTM STP 422, Am. Soc. for Testing and Mat., Philadelphia, 1966, p. 166.

13. F. D. Snell, C. T. Snell, and C. A. Snell, "Colorimetric Methods of Analysis," D. Van Nostrand Company, Inc., New York, 1959, p. 610.

14. H. Small, L. S. Stevens, and W. C. Baumann, "Novel Ion Exchange Chromatographic Method Using Conductimetric Detection," *Anal. Chem.* 47, 1801 (1975).

15. "Standard Method of Test for Surface Flammability of Materials Using a Radiant Energy Source," ASTM Designation E 162-76, Annual Book of ASTM Standards, Part 18, Am. Soc. for Testing and Mat., Philadelphia, 1976, p. 751.

16. S. L. Madorsky, "Thermal Degradation of Organic Polymers," Interscience Publishers, New York, 1964, p. 160.

17. Unpublished results, Monsanto Research Corporation.

18. H. Amariglio and X. Duval, "A Study of Catalytic Combustion of Graphite," *Carbon* 4, 323 (1966).

19. D. W. McKee, "The Copper-Catalyzed Oxidation of Graphite," *Carbon* 8, 131 (1970).

20. D. W. McKee, "Metal Oxides as Catalysts for the Oxidation of Graphite," *Carbon* 8, 623 (1970).

21. L. Parts and J. T. Miller, Jr., "Smoke-Retardant Styrene Polymer Compositions," U.S. Patent 3,766,157, Oct. 16, 1973.

22. L. Parts and J. T. Miller, Jr., "Smoke-Retardant Styrene Polymer Compositions Containing a Metal Phthalocyanine," U.S. Patent 3,825,520, July 27, 1974.

23. T. C. Mathis and A. W. Morgan, "Smoke-Retardant Halogen-Containing Polymer System," U.S. Patent 3,869,420, March 4, 1975.

24. A. W. Morgan, Monsanto Company, personal communication, 1974.

25. J. A. Ellard, "Performance of Intumescent Fire Barriers," presented at the 165th National Meeting of the American Chemical Society, Dallas, Texas, April 1973.

26. J. T. Miller and L. Parts, "Enhancement of Fire Performance of Fiberglass-Reinforced Plastic Panels by Fire-Retardant Coatings," MRC Report MRC-DA-456, November 1974.

27. R. Slysh, "Flame-Retardant Coatings for Plastics," *J. Paint Technol.* 47, 31 (1975).

APPENDIX

Figures 28 through 61

Tables IX through LIII

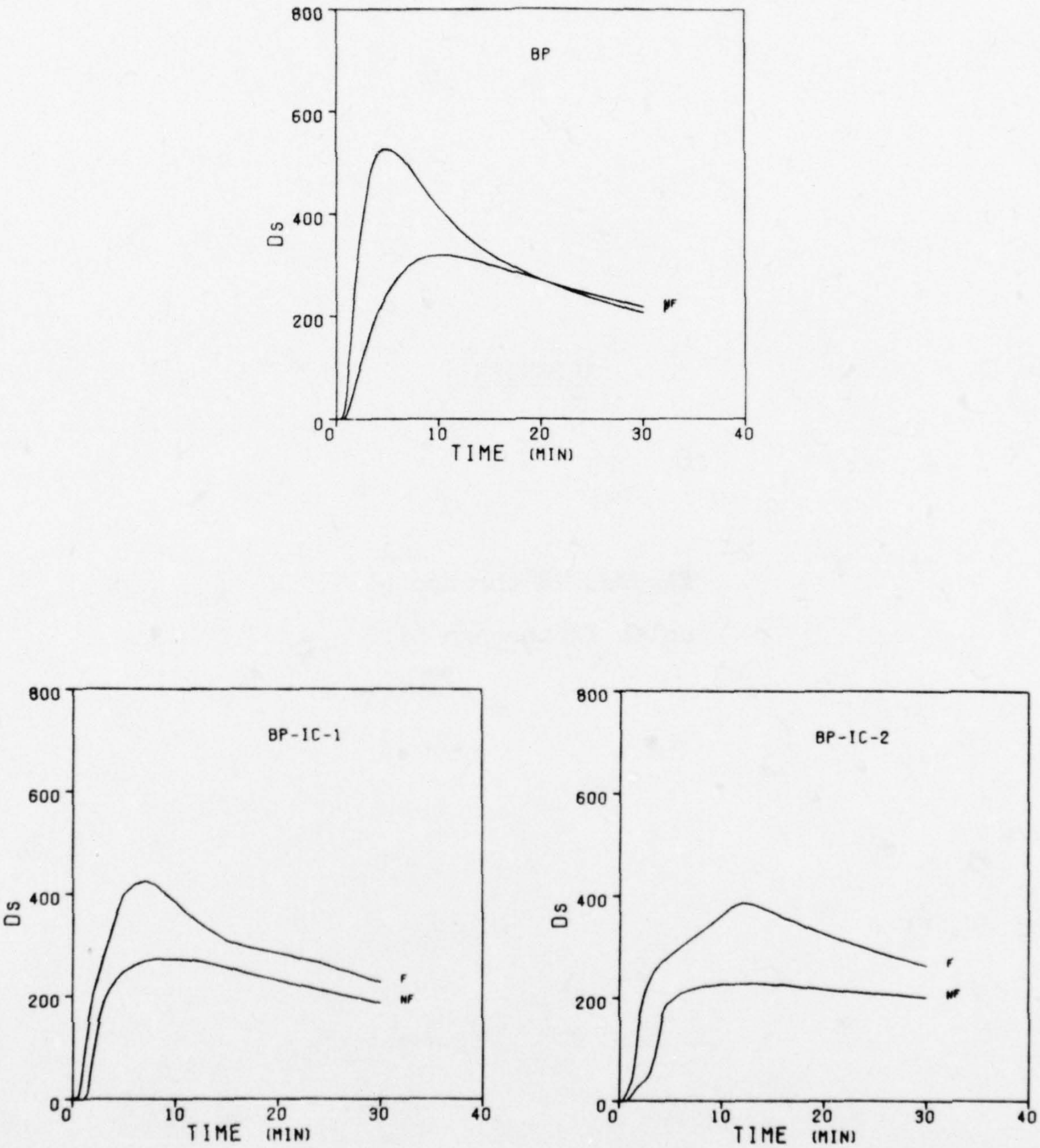


Figure 28. Smoke Optical Densities During the Burning of BP-IC Compositions

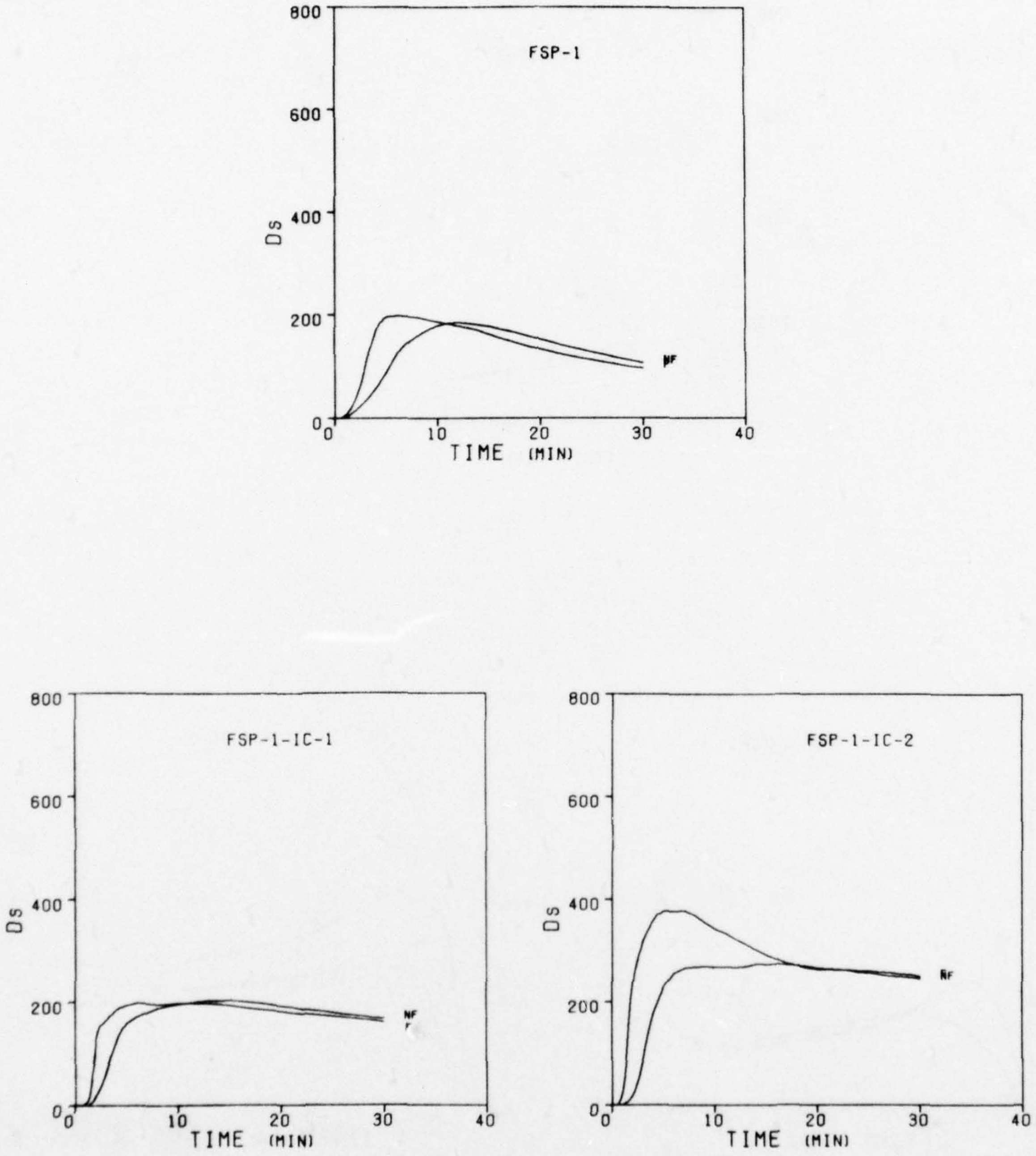


Figure 29. Smoke Optical Densities During the Burning of FSP-1-IC Compositions

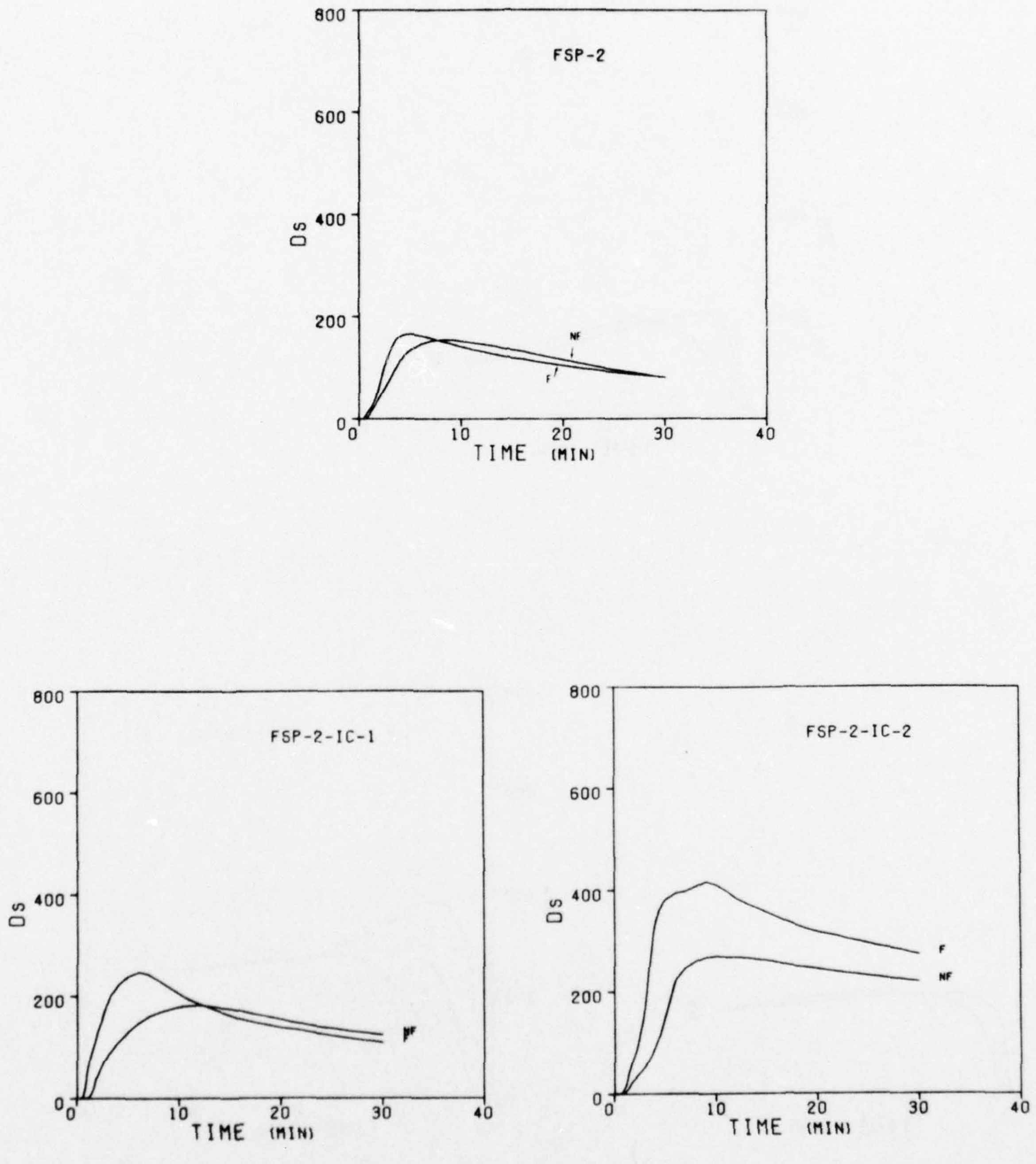
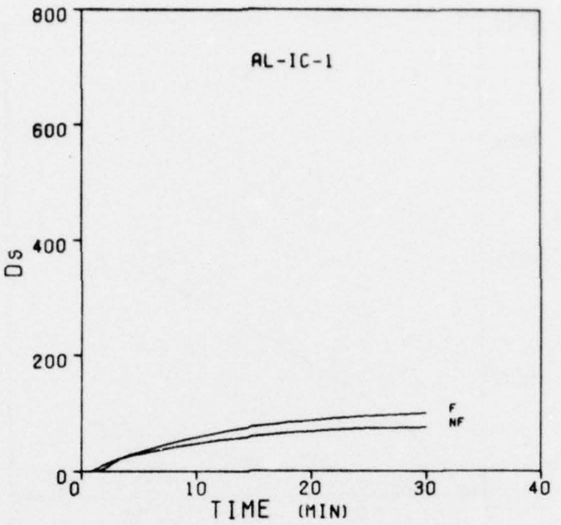


Figure 30. Smoke Optical Densities During the Burning of FSP-2-IC Compositions



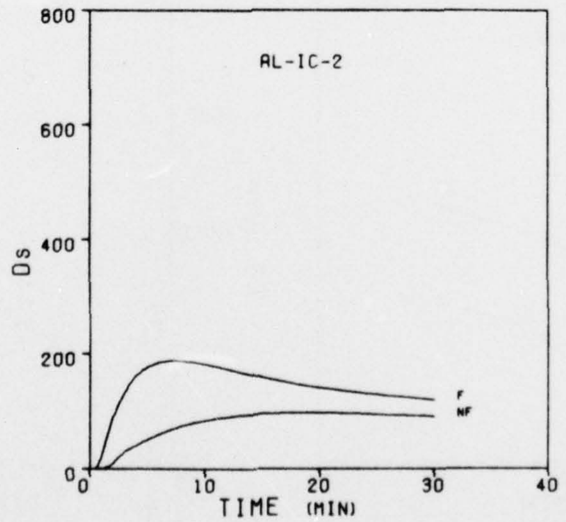


Figure 31. Smoke Optical Densities During the Exposure of Al-IC Compositions

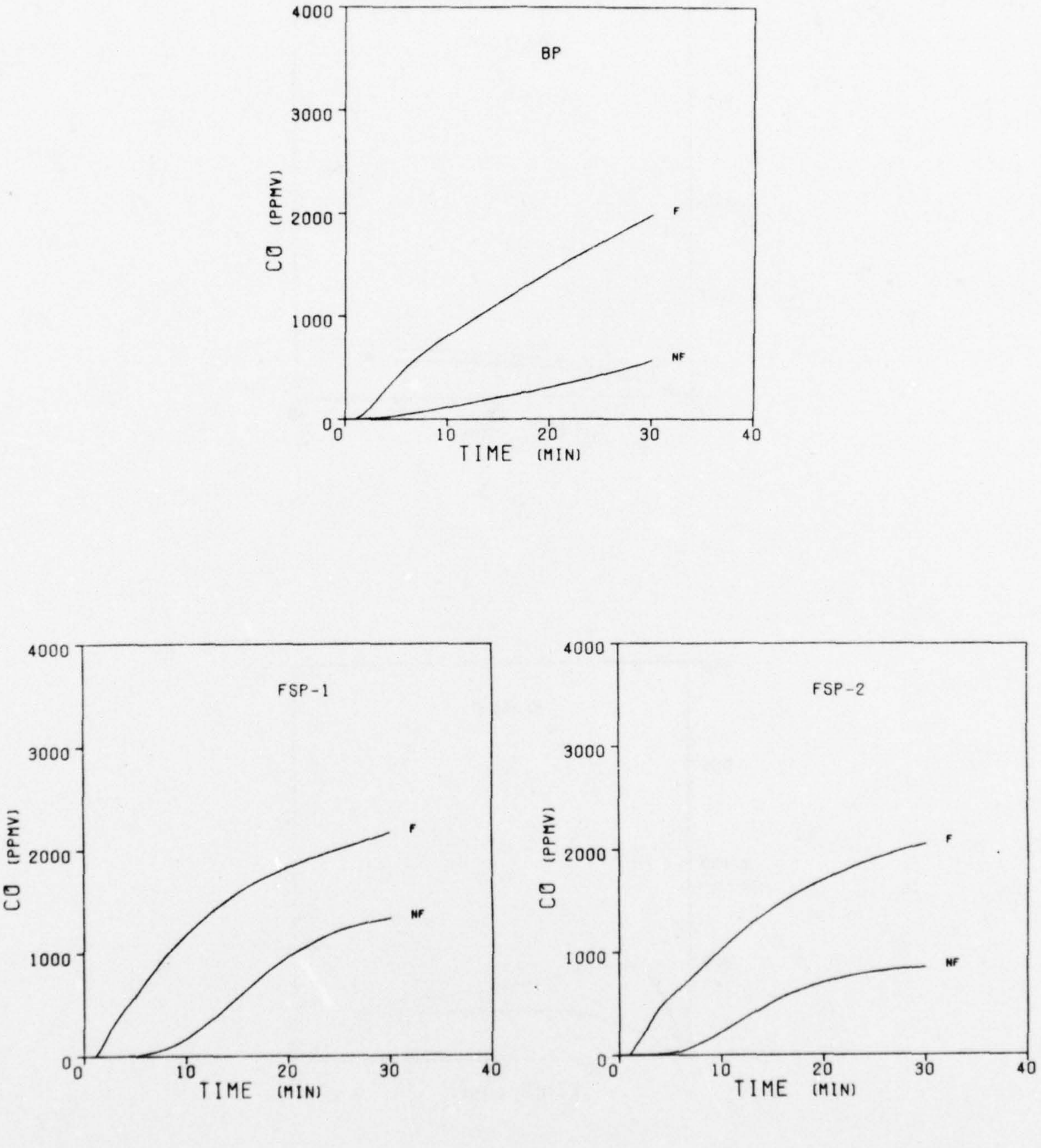


Figure 32. Carbon Monoxide Concentrations During the Burning of PVC Compositions

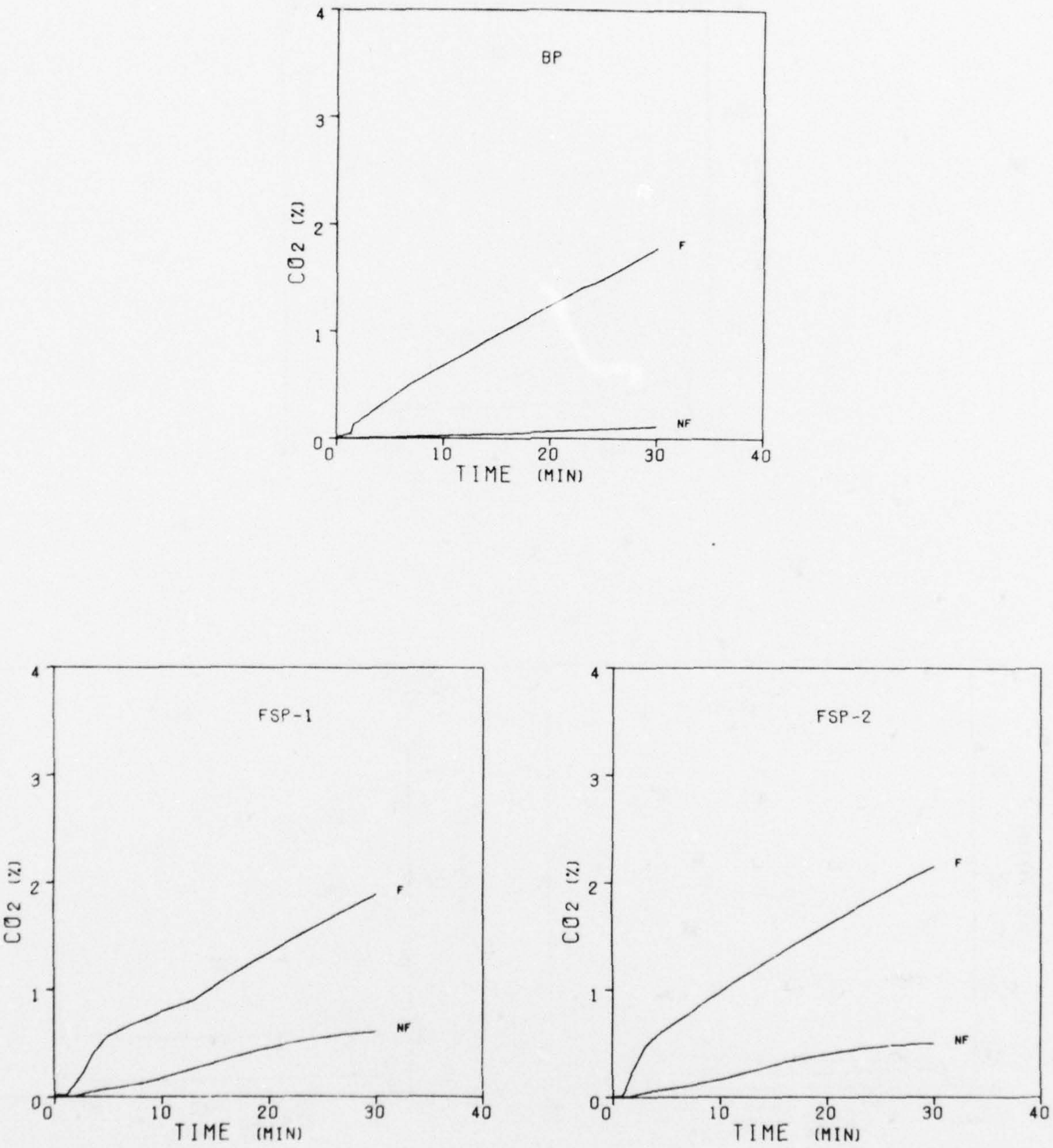


Figure 33. Carbon Dioxide Concentrations During the Burning of PVC Compositions

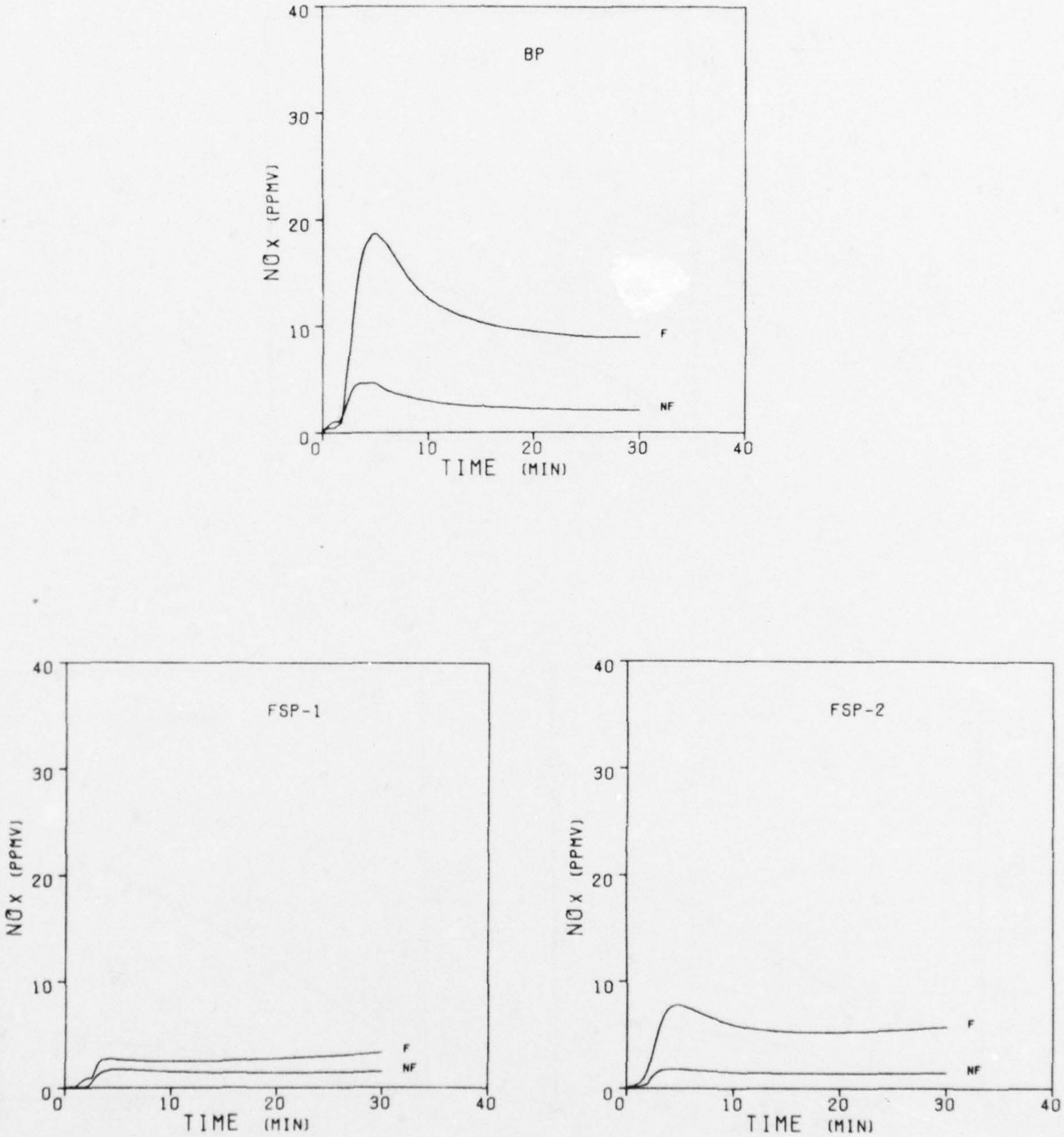


Figure 34. NO_x Concentrations During the Burning of PVC Compositions

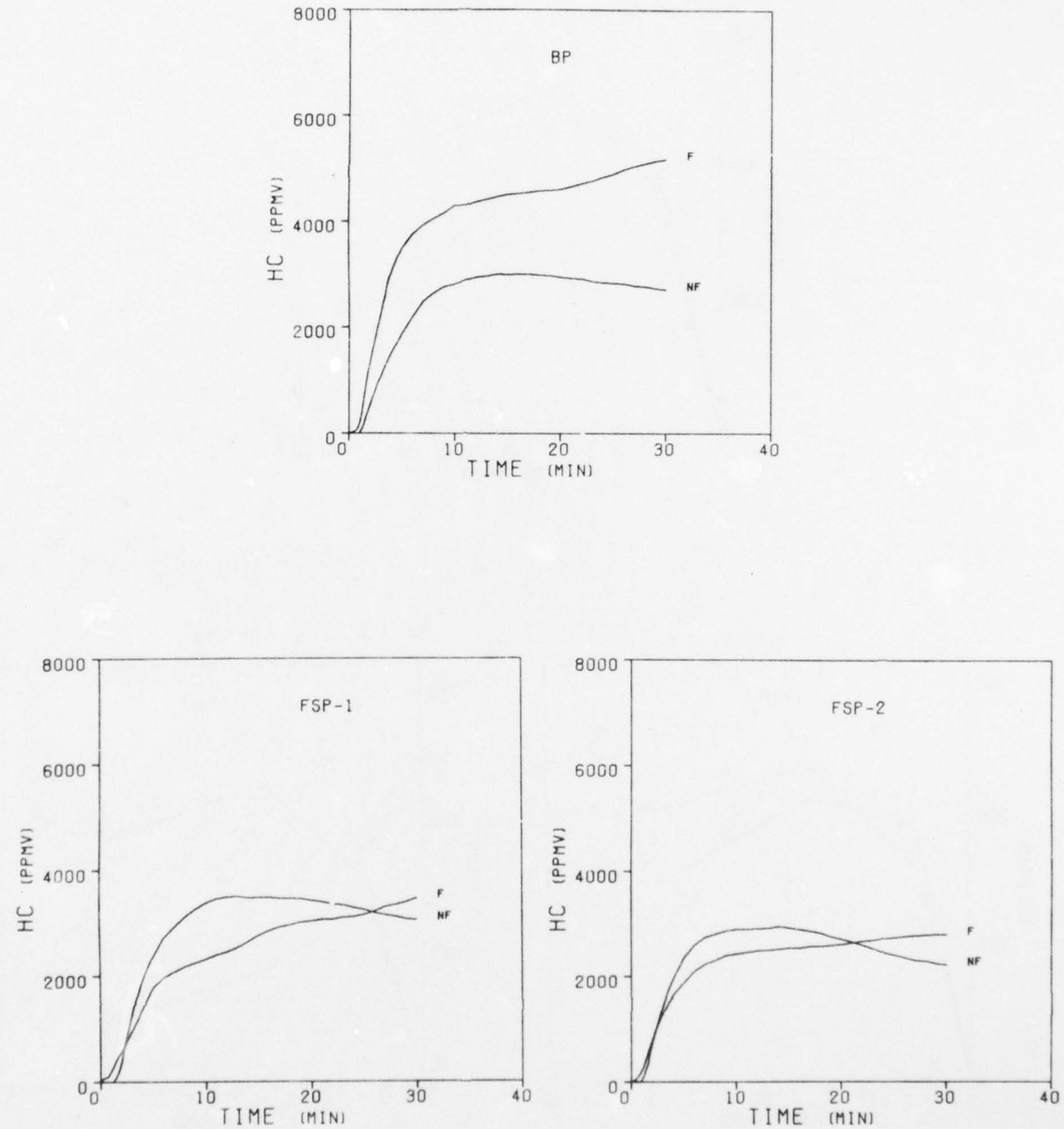


Figure 35. Hydrocarbons Concentrations During the Burning of PVC Compositions

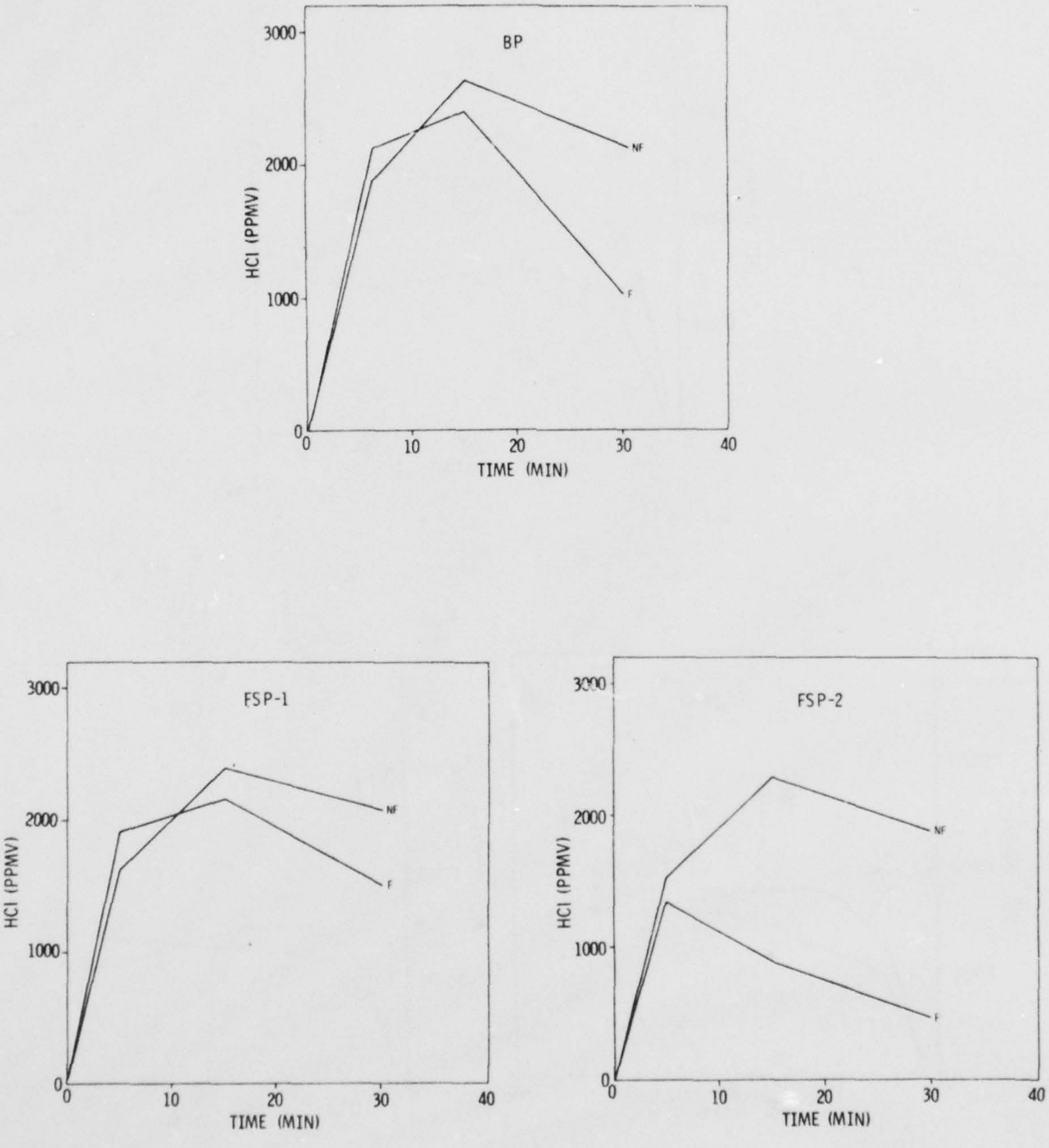


Figure 36. HCl Concentrations During the Burning of PVC Compositions

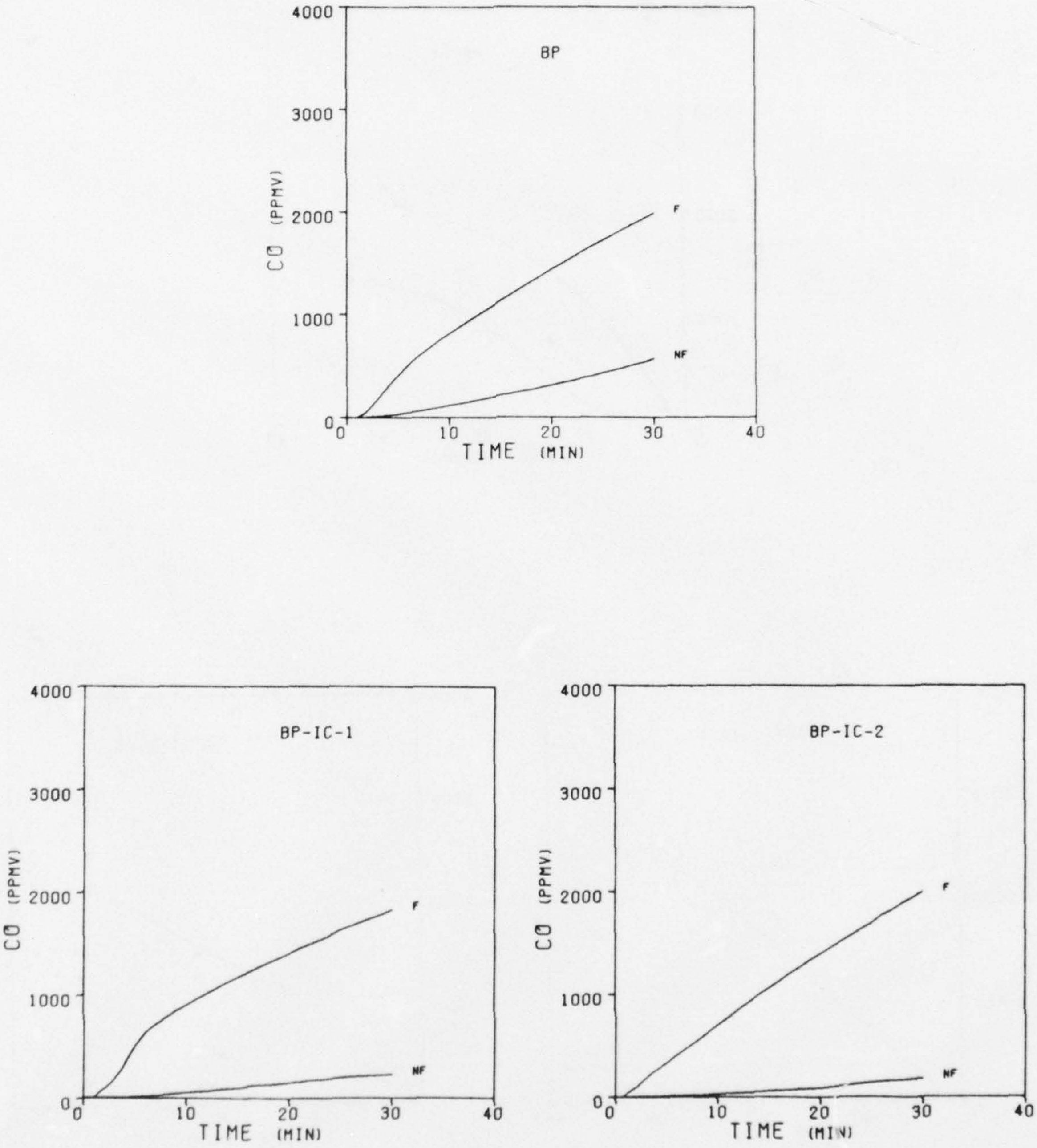


Figure 37. Carbon Monoxide Concentrations During the Burning of BP-IC Compositions

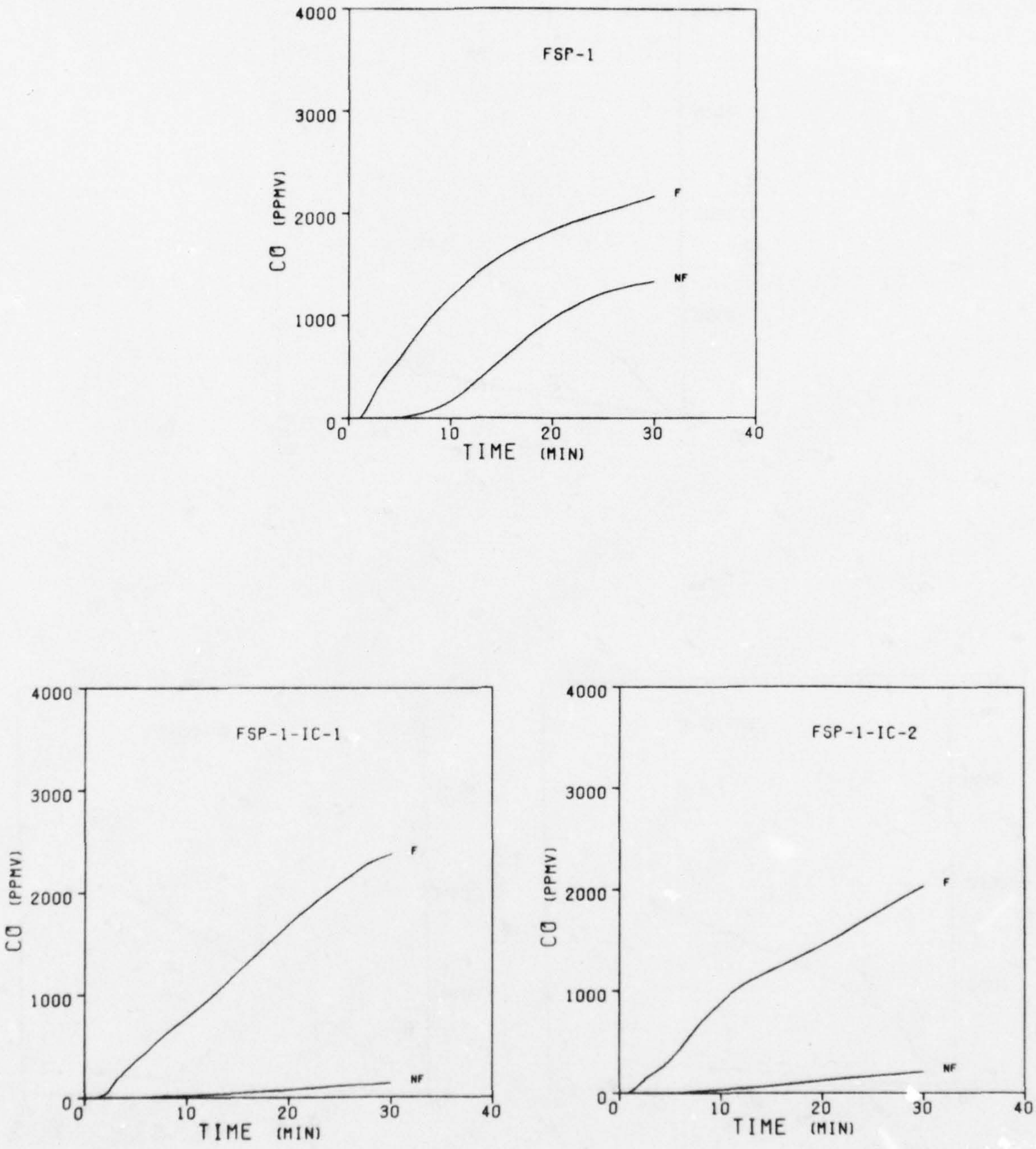


Figure 38. Carbon Monoxide Concentrations During the Burning of FSP-1-IC Compositions

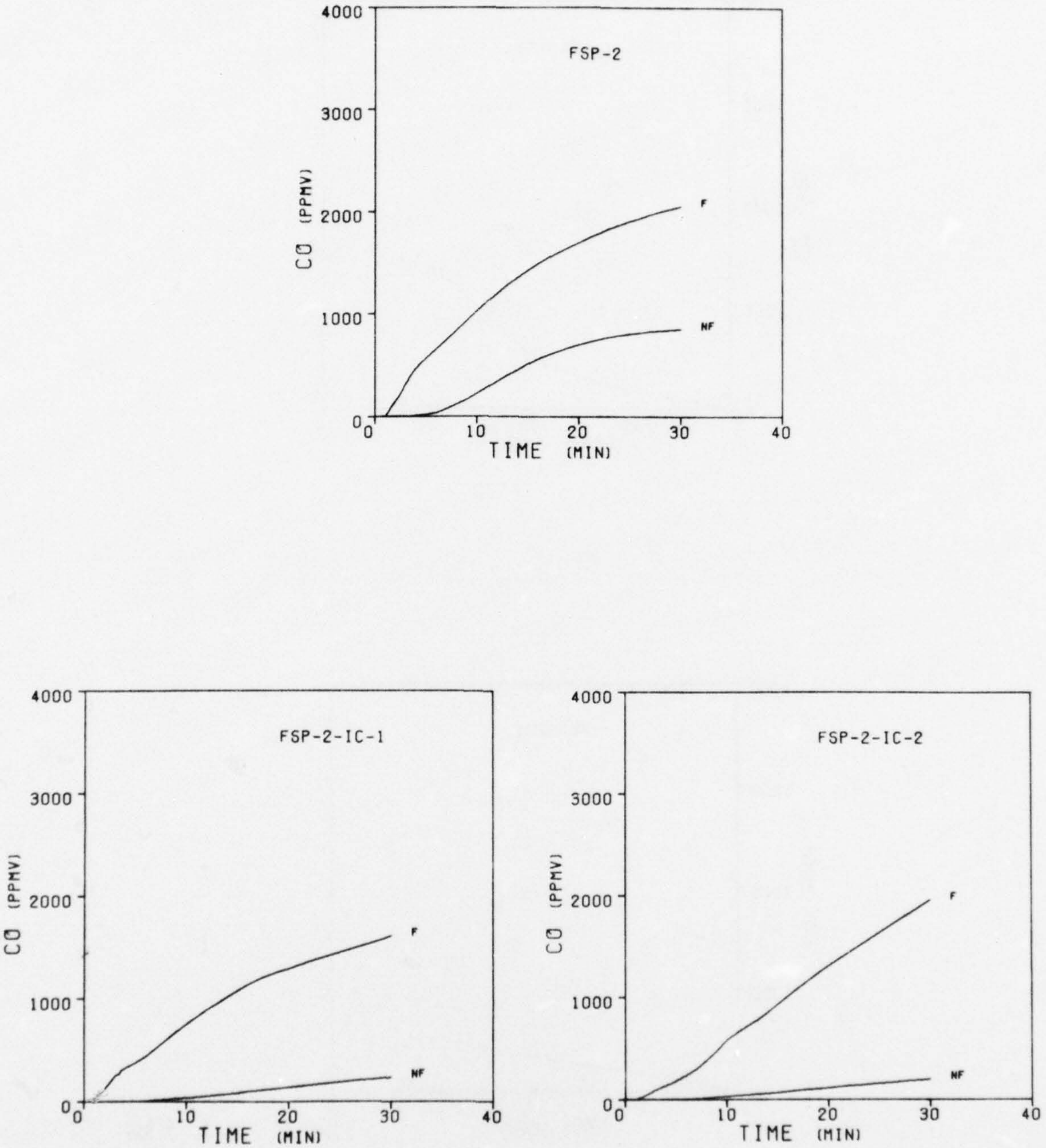


Figure 39. Carbon Monoxide Concentrations During the Burning of FSP-2-IC Compositions

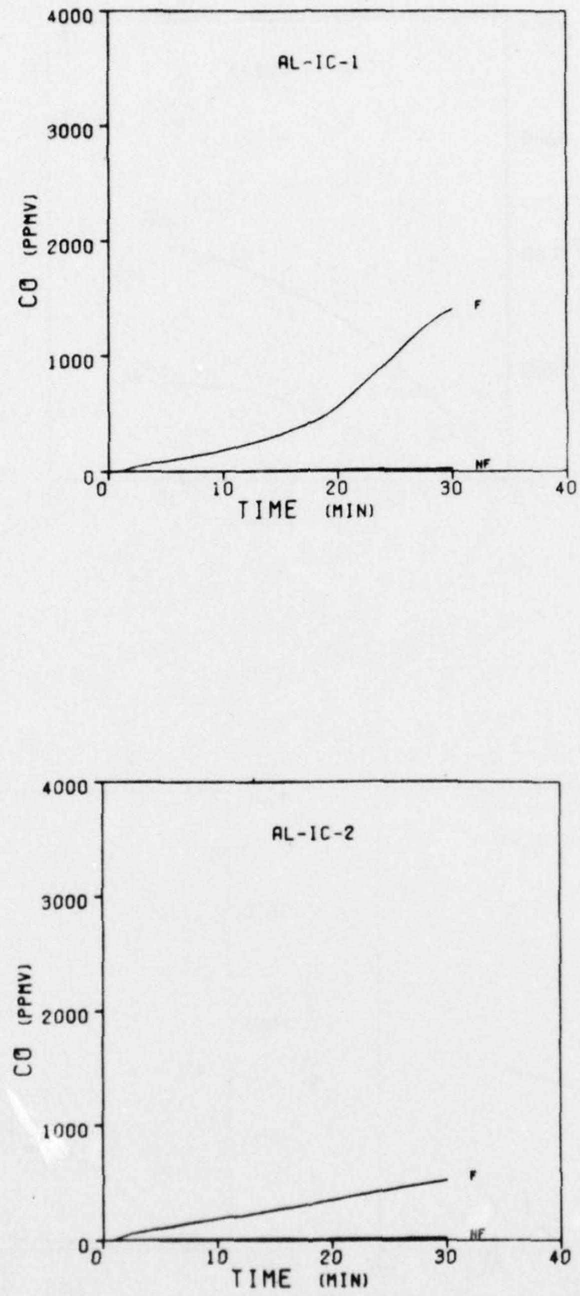


Figure 40. Carbon Monoxide Concentrations During the Exposure of Al-IC Compositions

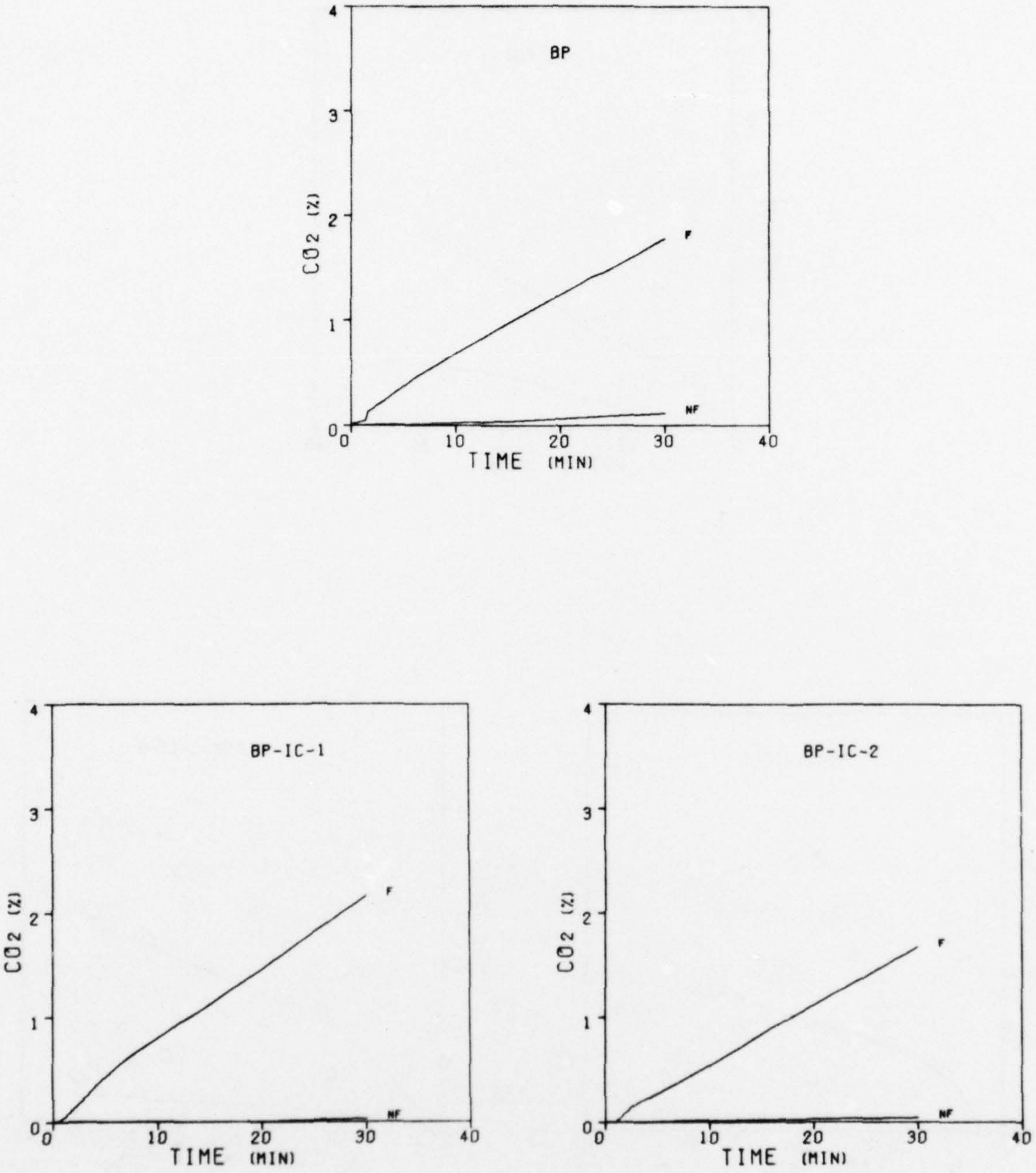


Figure 41. Carbon Dioxide Concentrations During the Burning of BP-IC Compositions

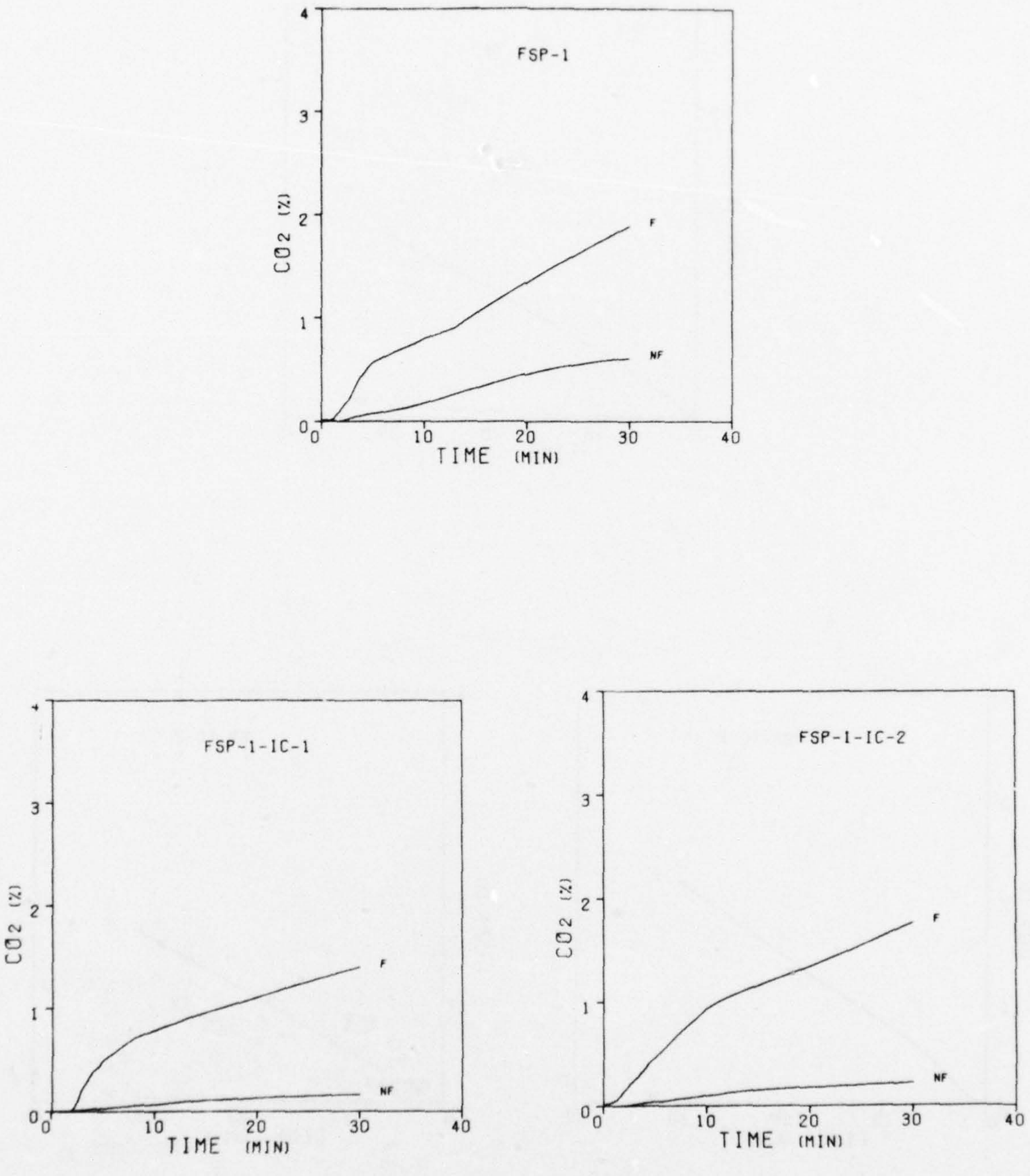


Figure 42. Carbon Dioxide Concentrations During the Burning of FSP-1-IC Compositions

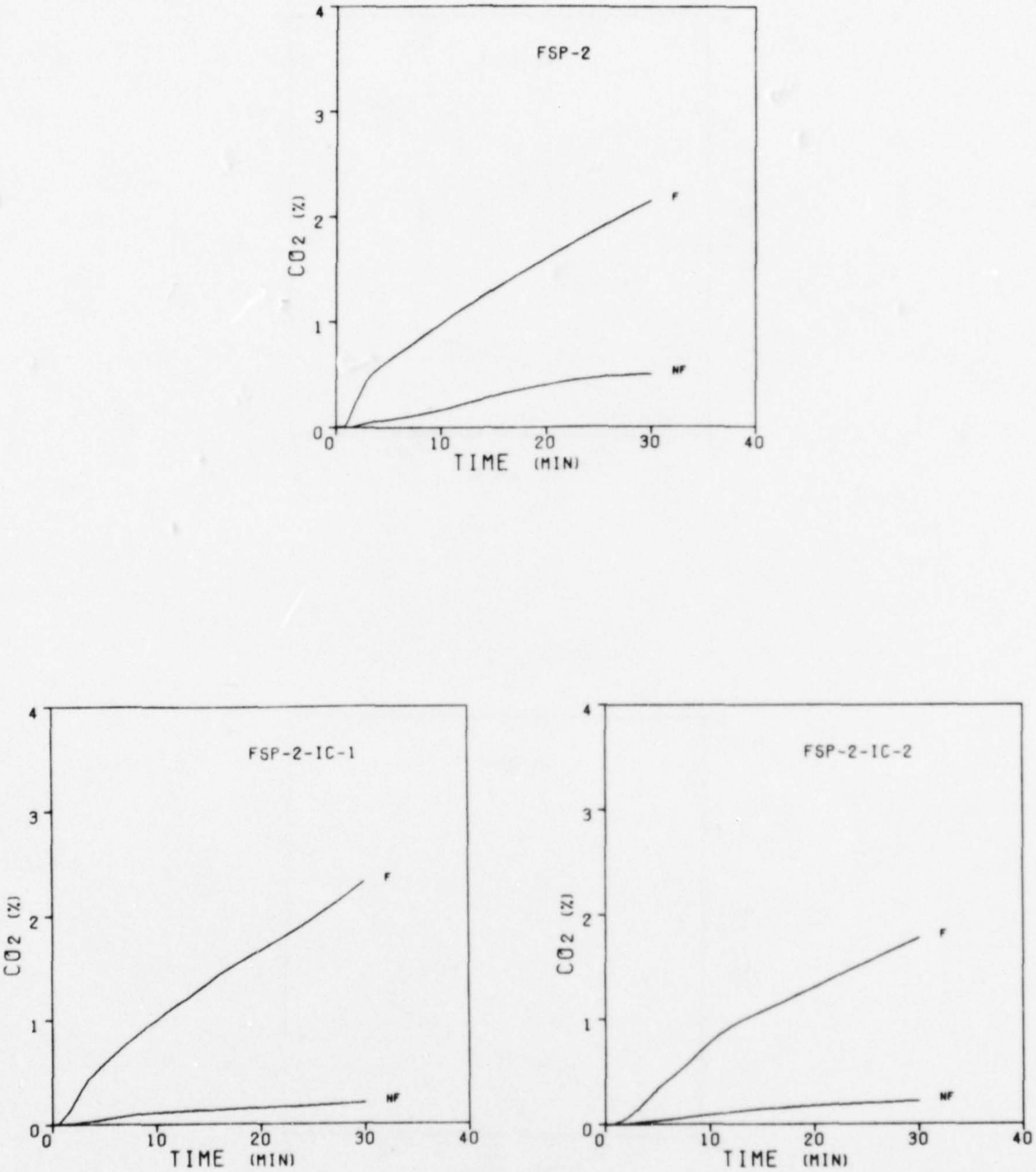
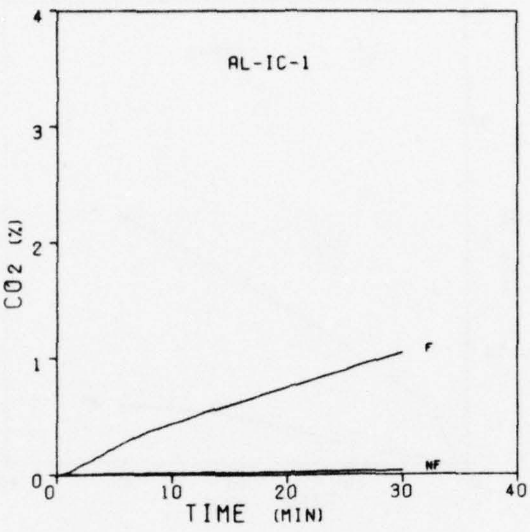


Figure 43. Carbon Dioxide Concentrations During the Burning of FSP-2-IC Compositions



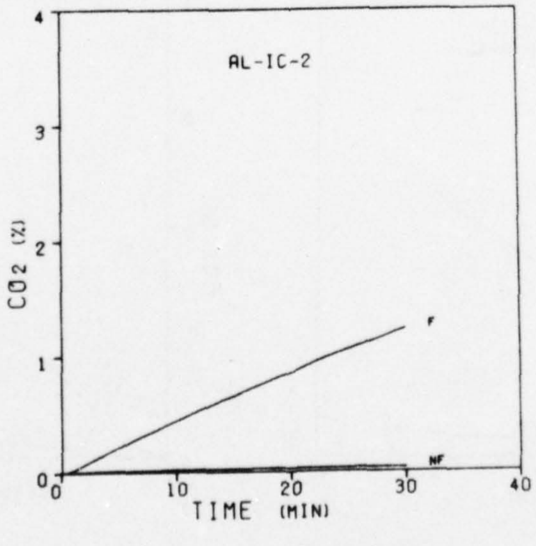


Figure 44. Carbon Dioxide Concentrations During the Exposure of Al-IC Compositions

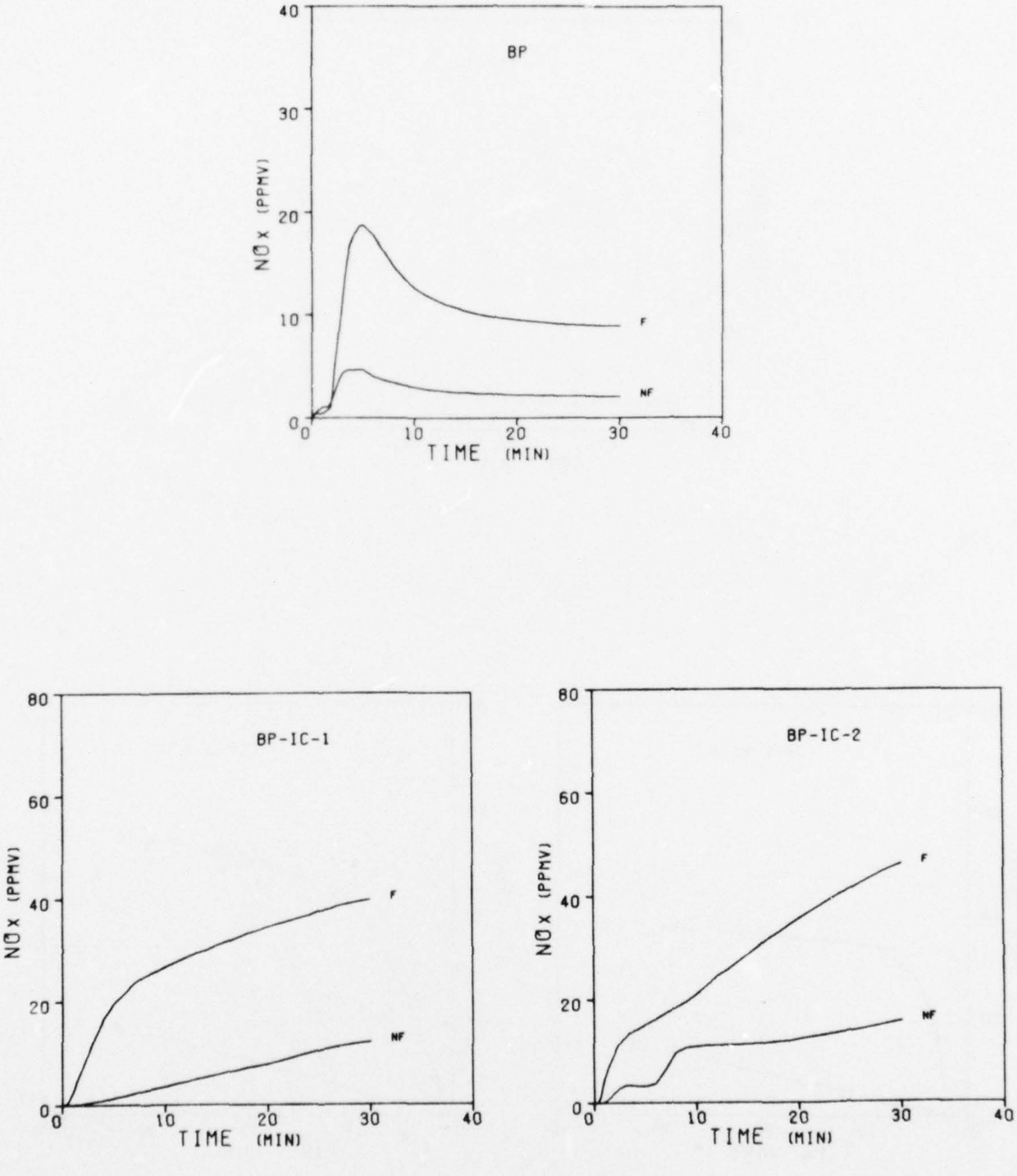


Figure 45. NO_x Concentrations During the Burning of BP-IC Compositions

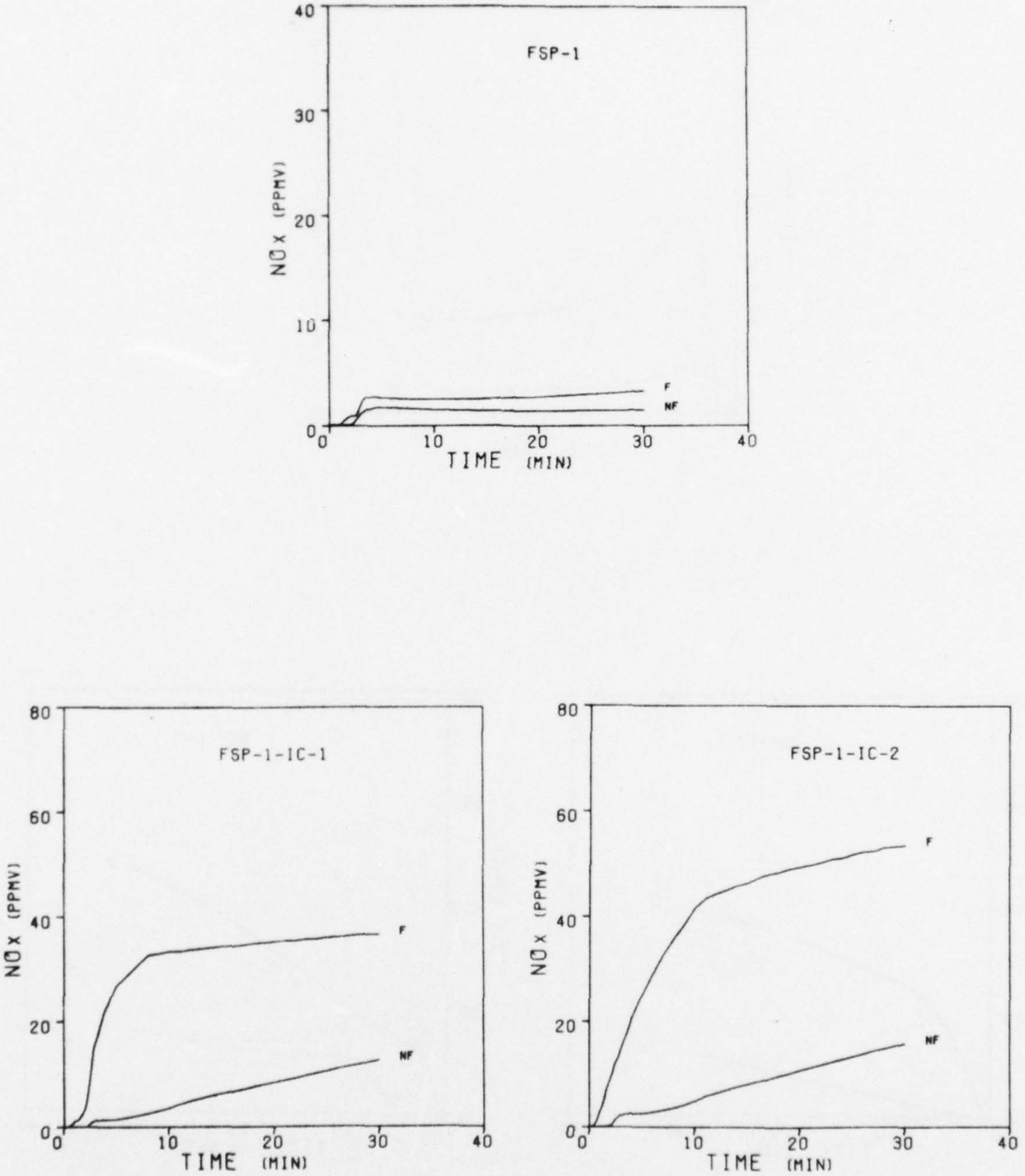


Figure 46. NO_X Concentrations During the Burning of FSP-1-IC Compositions

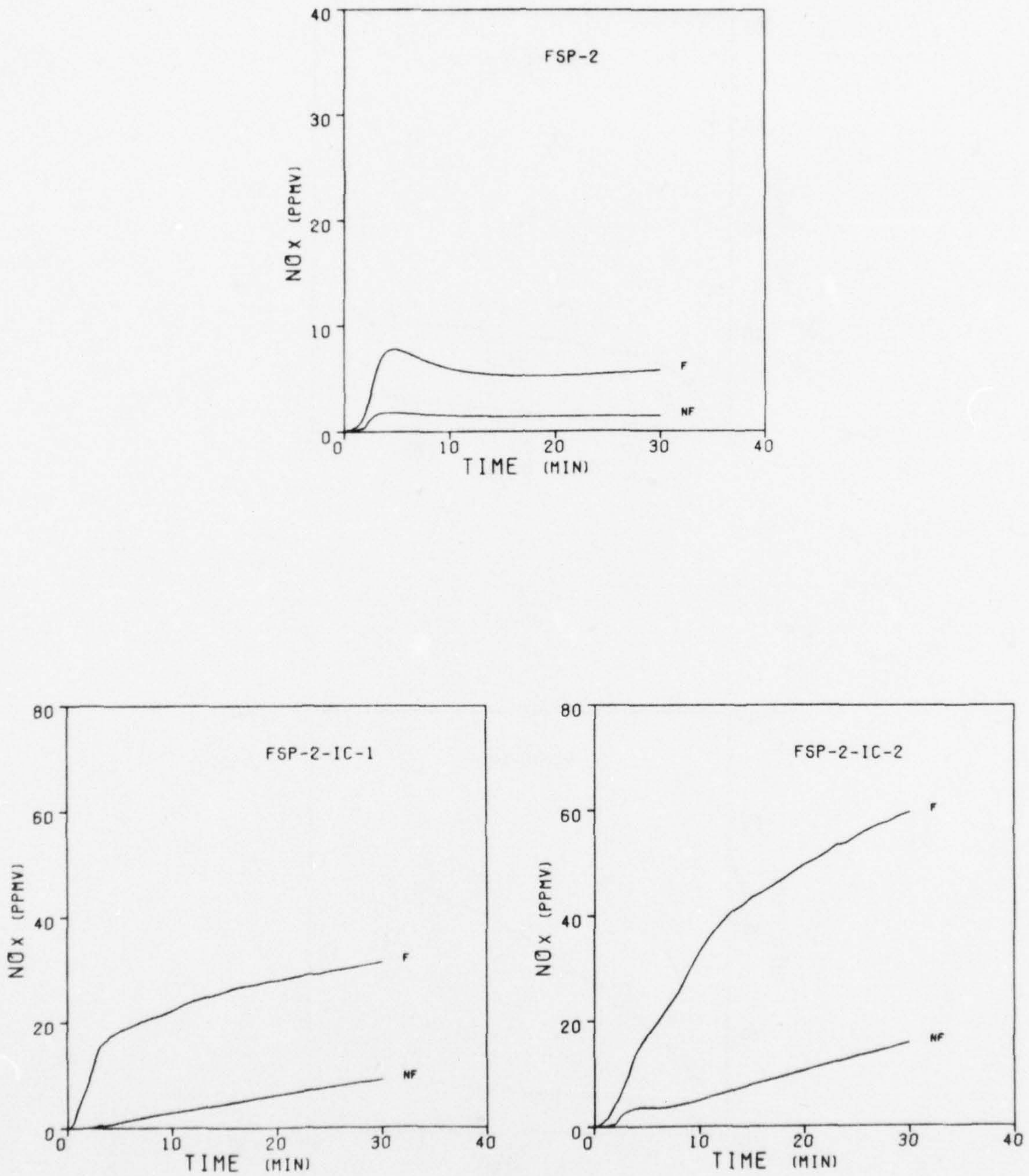


Figure 47. NO_x Concentrations During the Burning of FSP-2-IC Compositions

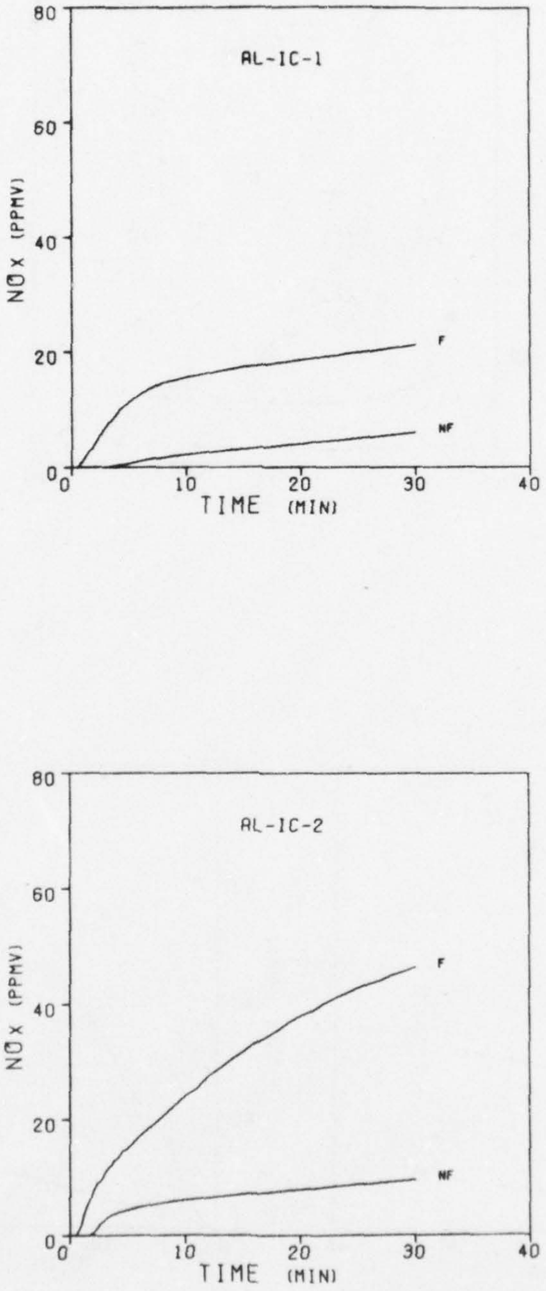


Figure 48. NO_x Concentrations during the Exposure of Al-IC Compositions

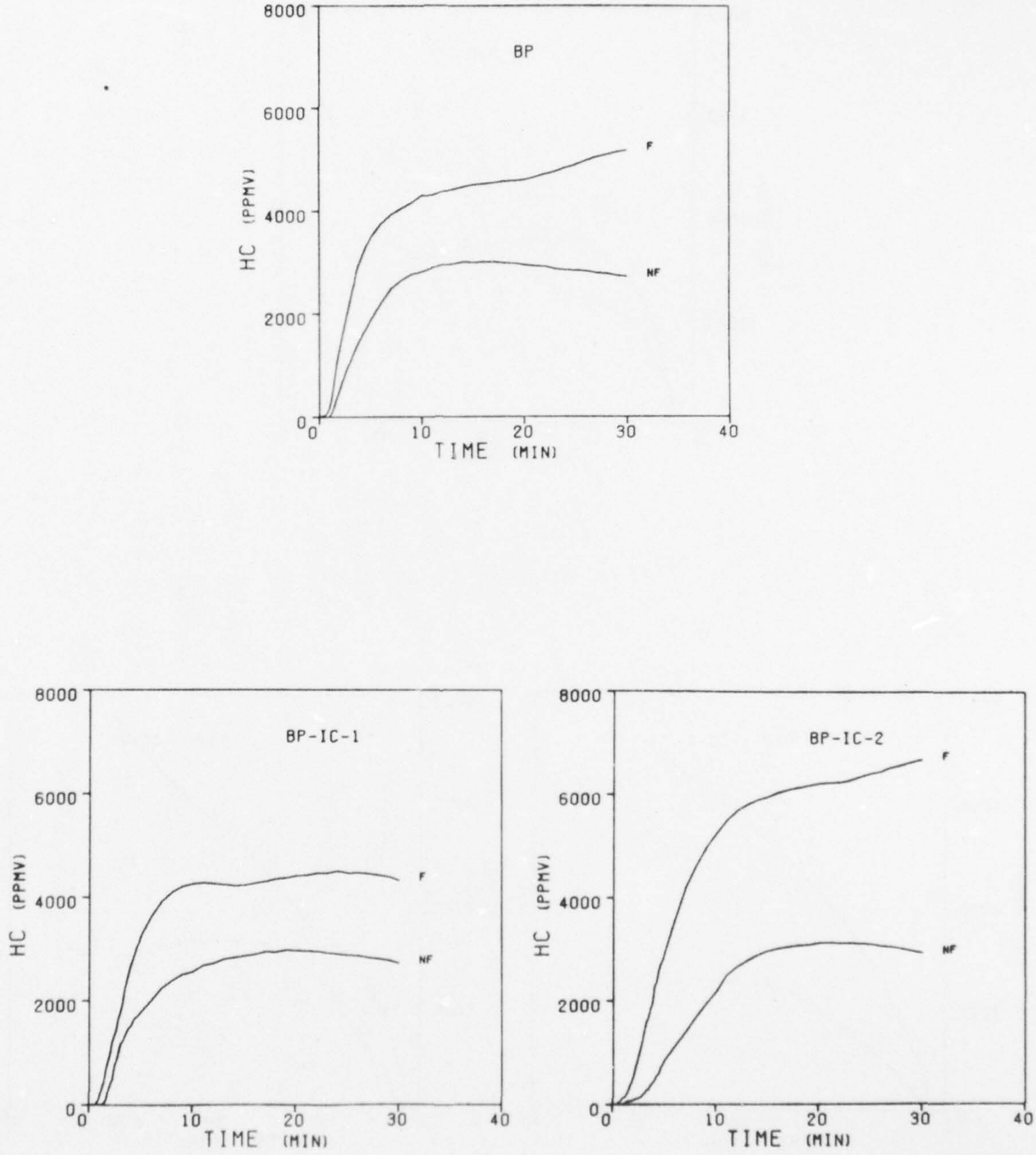


Figure 49. Hydrocarbons Concentrations During the Burning of BP-IC Compositions

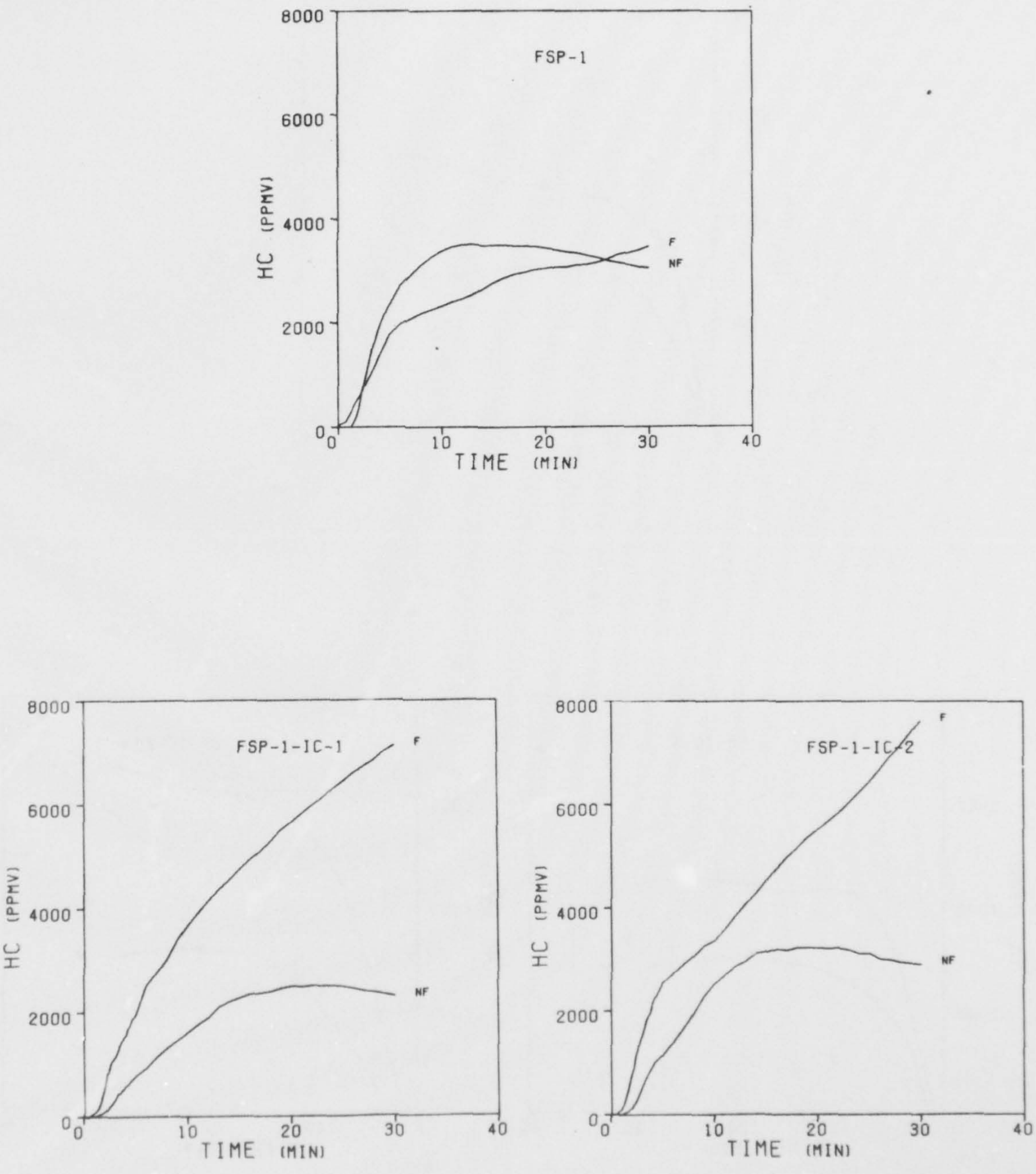


Figure 50. Hydrocarbons Concentrations During the Burning of FSP-1-IC Compositions

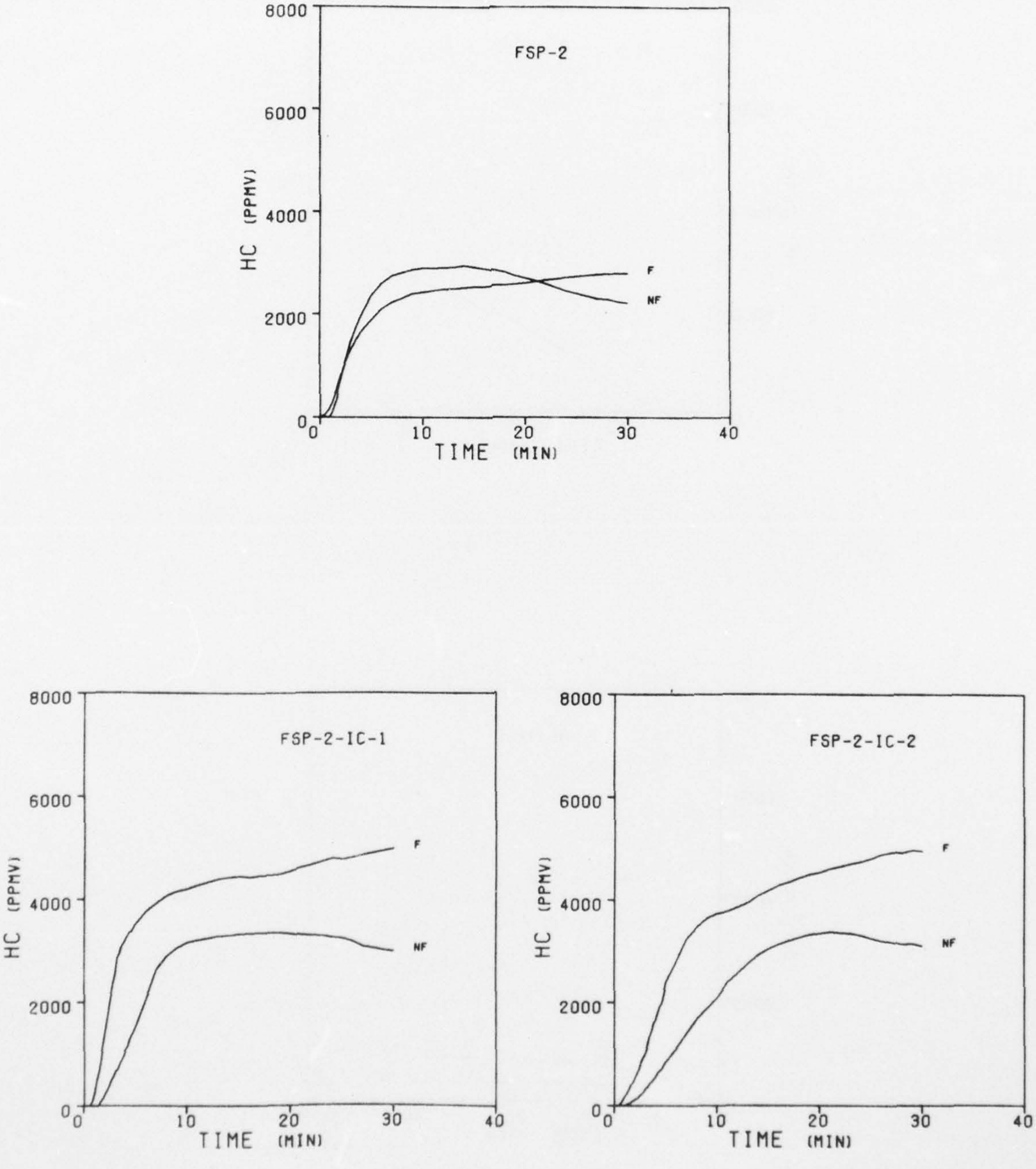
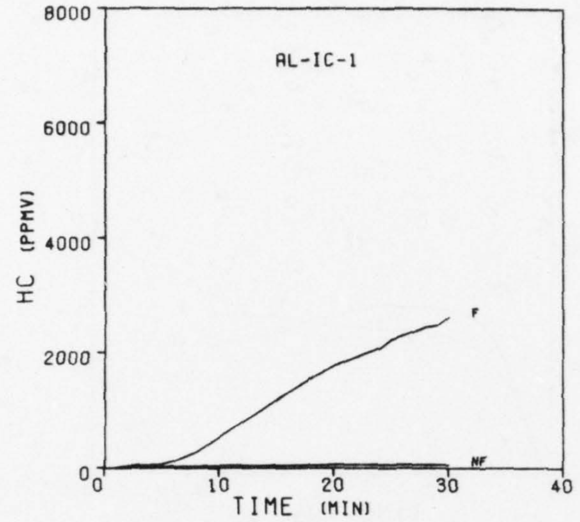


Figure 51. Hydrocarbons Concentrations During the Burning of FSP-2-IC Compositions



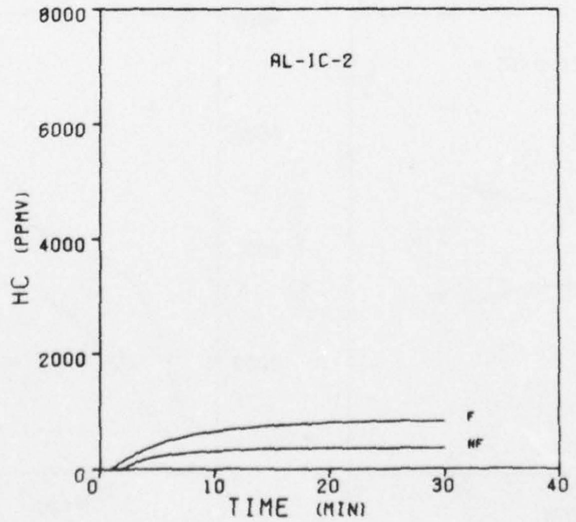


Figure 52. Hydrocarbons Concentrations During the Exposure of Al-IC Compositions

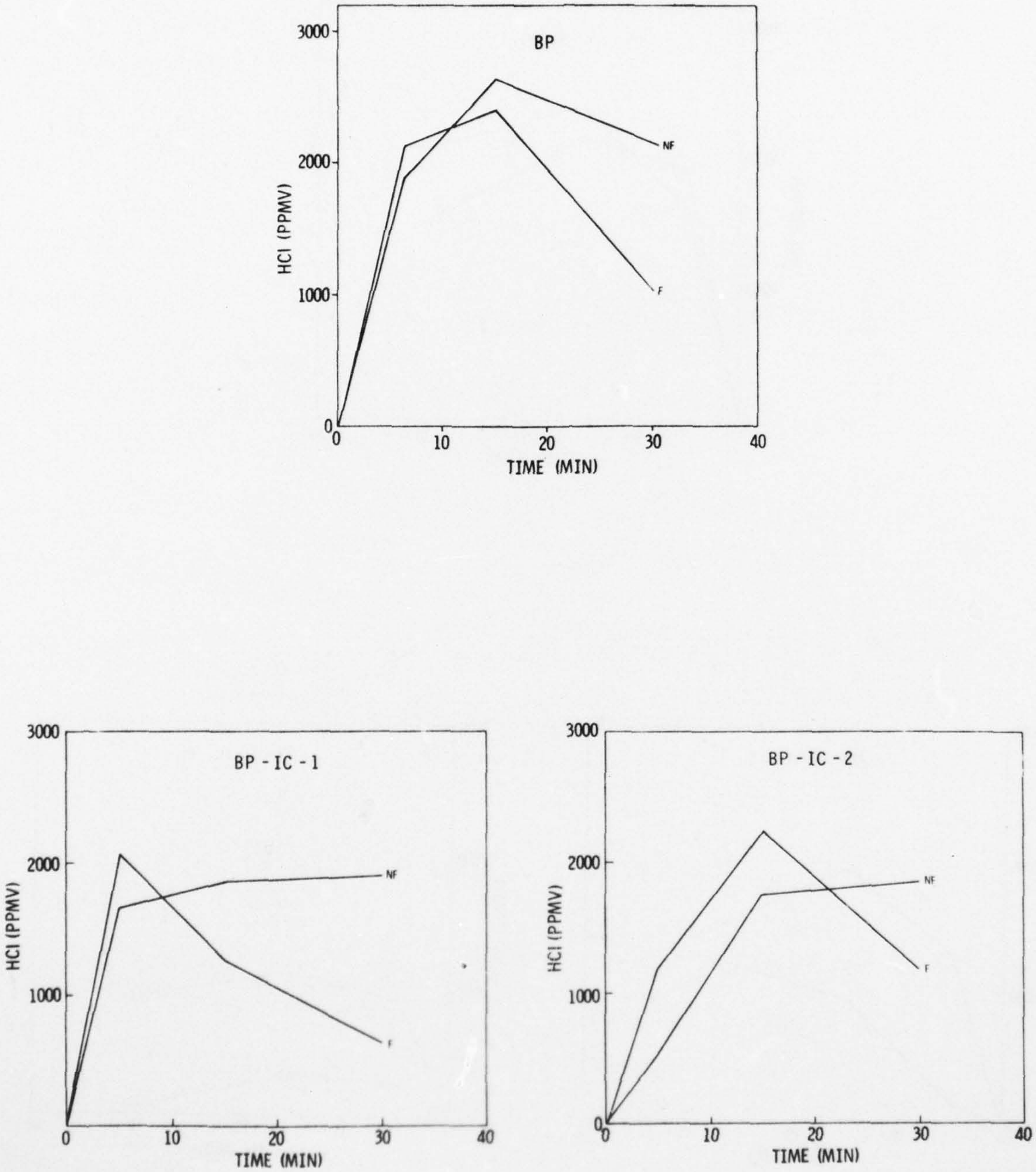


Figure 53. HCl Concentrations During the Burning of BP-IC Compositions

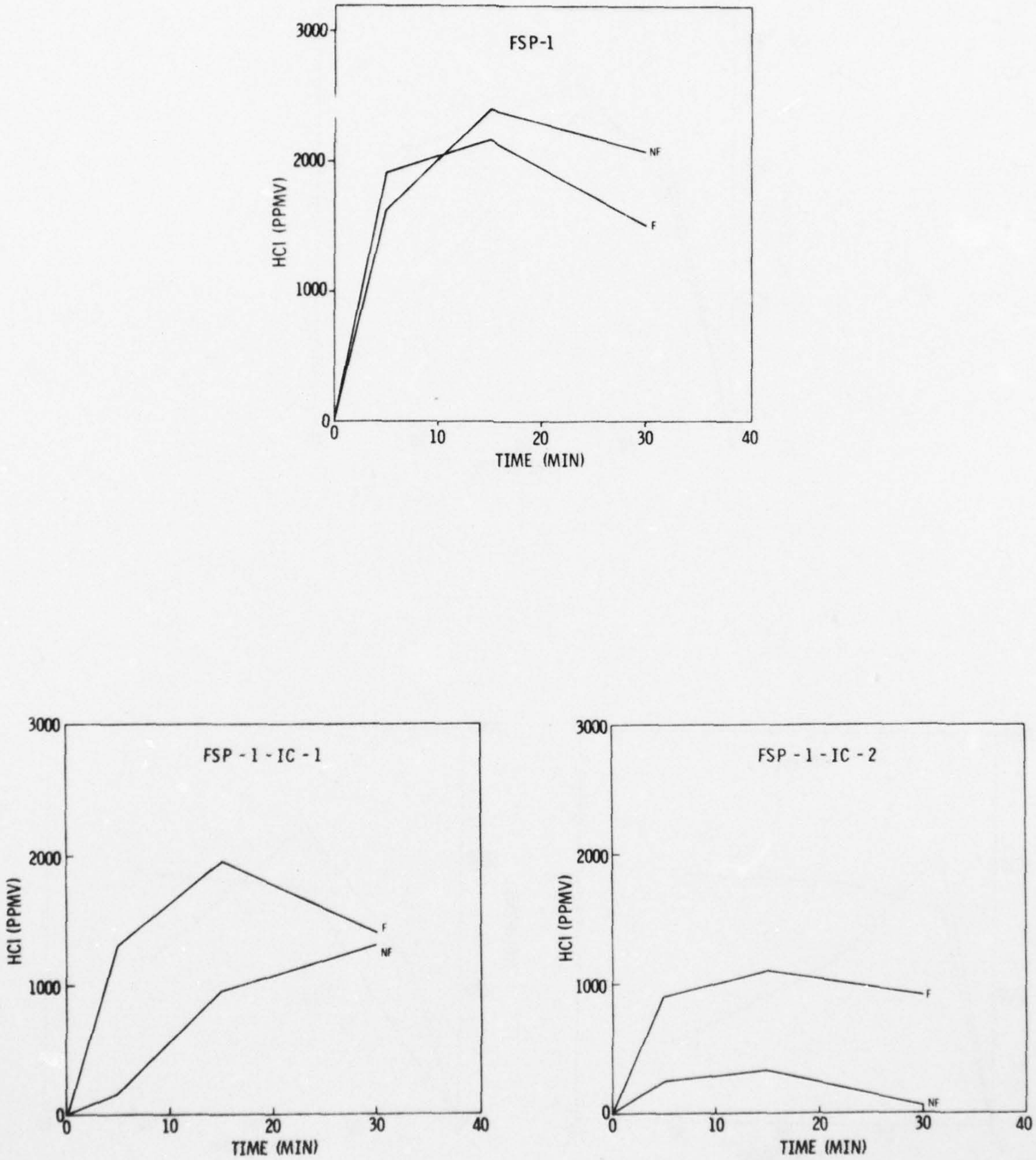


Figure 54. HCl Concentrations During the Burning of FSP-1-IC Compositions

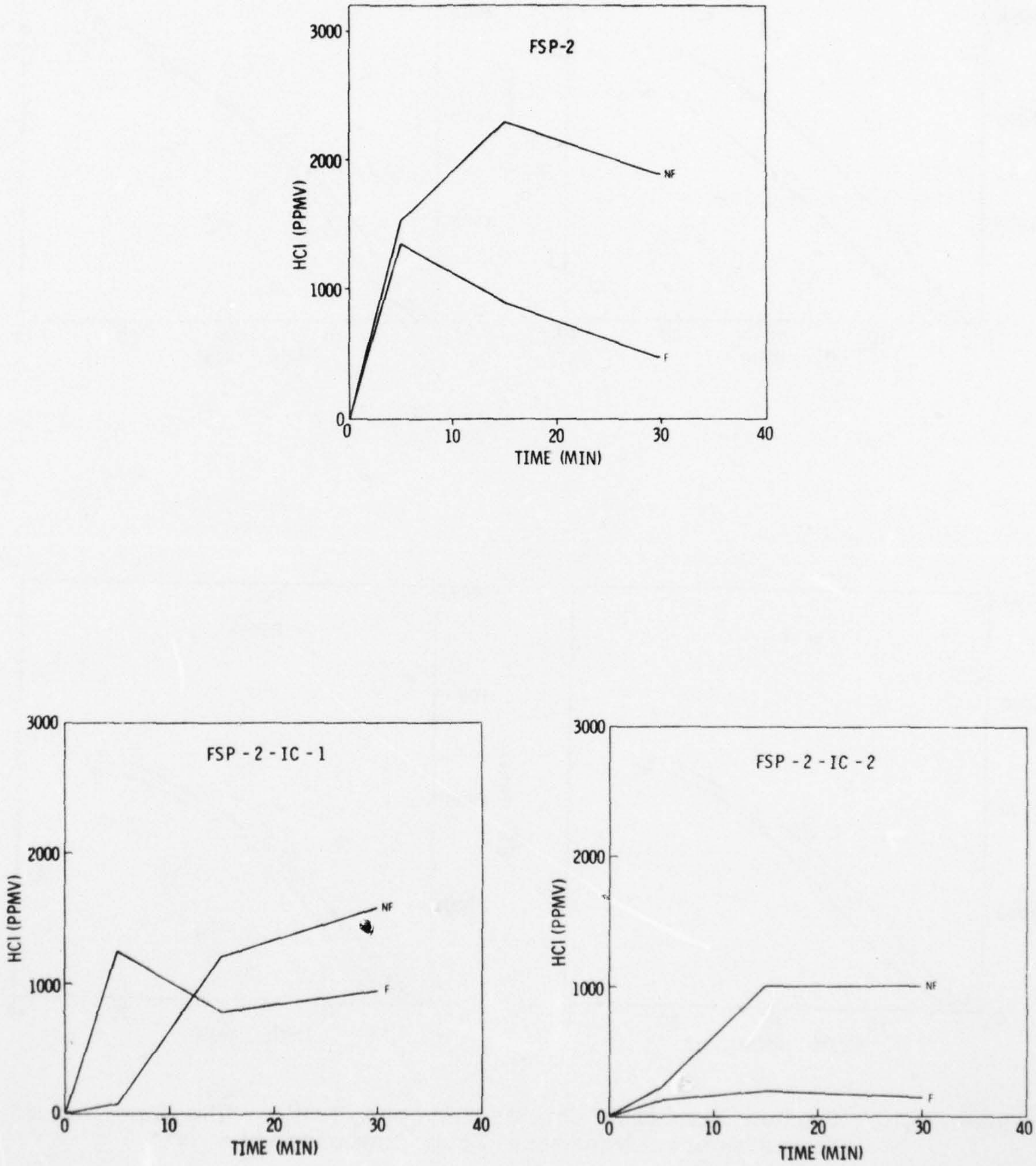


Figure 55. HCl Concentrations During the Burning of FSP-2-IC Compositions

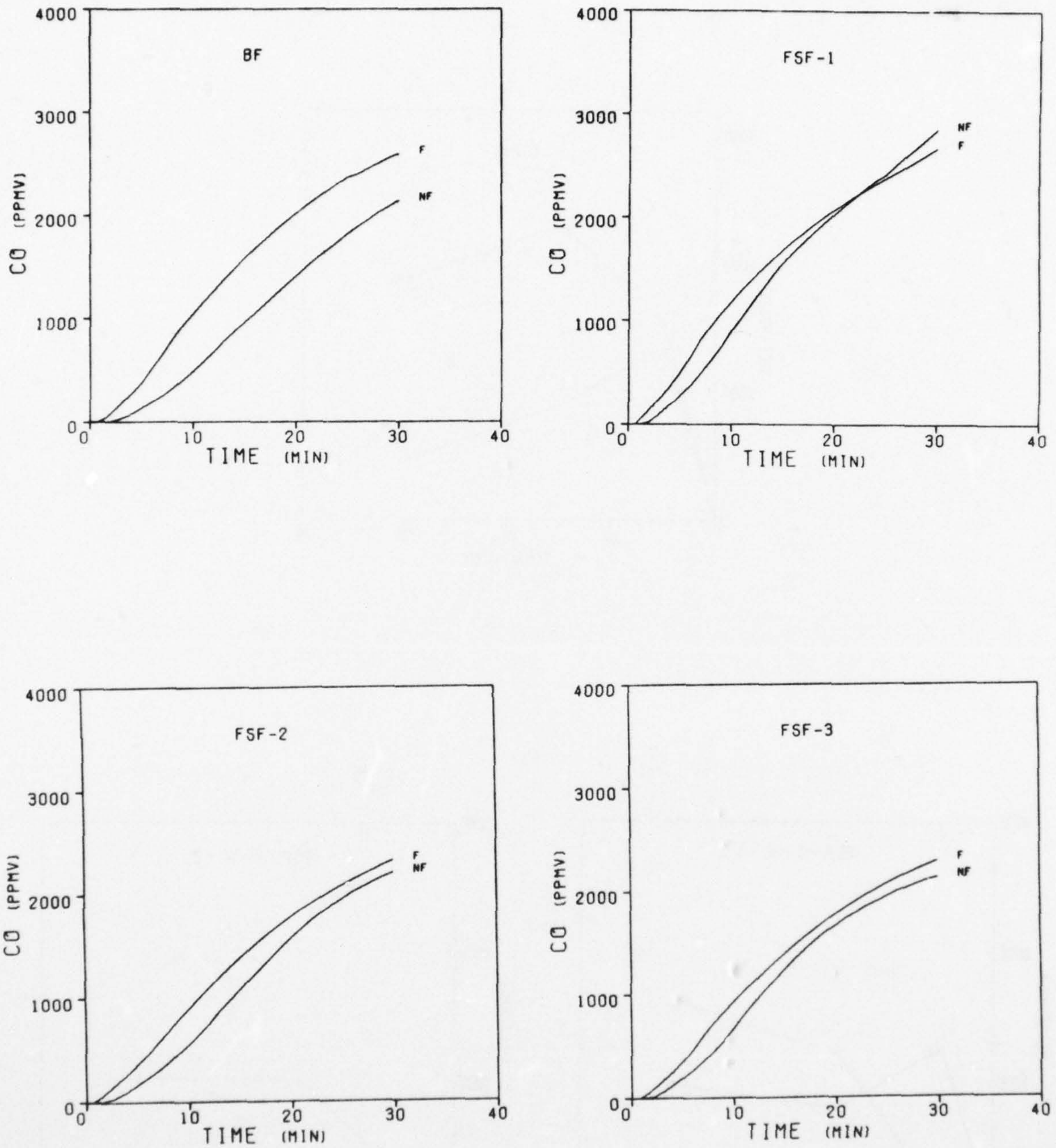


Figure 56. Carbon Monoxide Concentrations During the Burning of Experimental Neoprene Foam Compositions

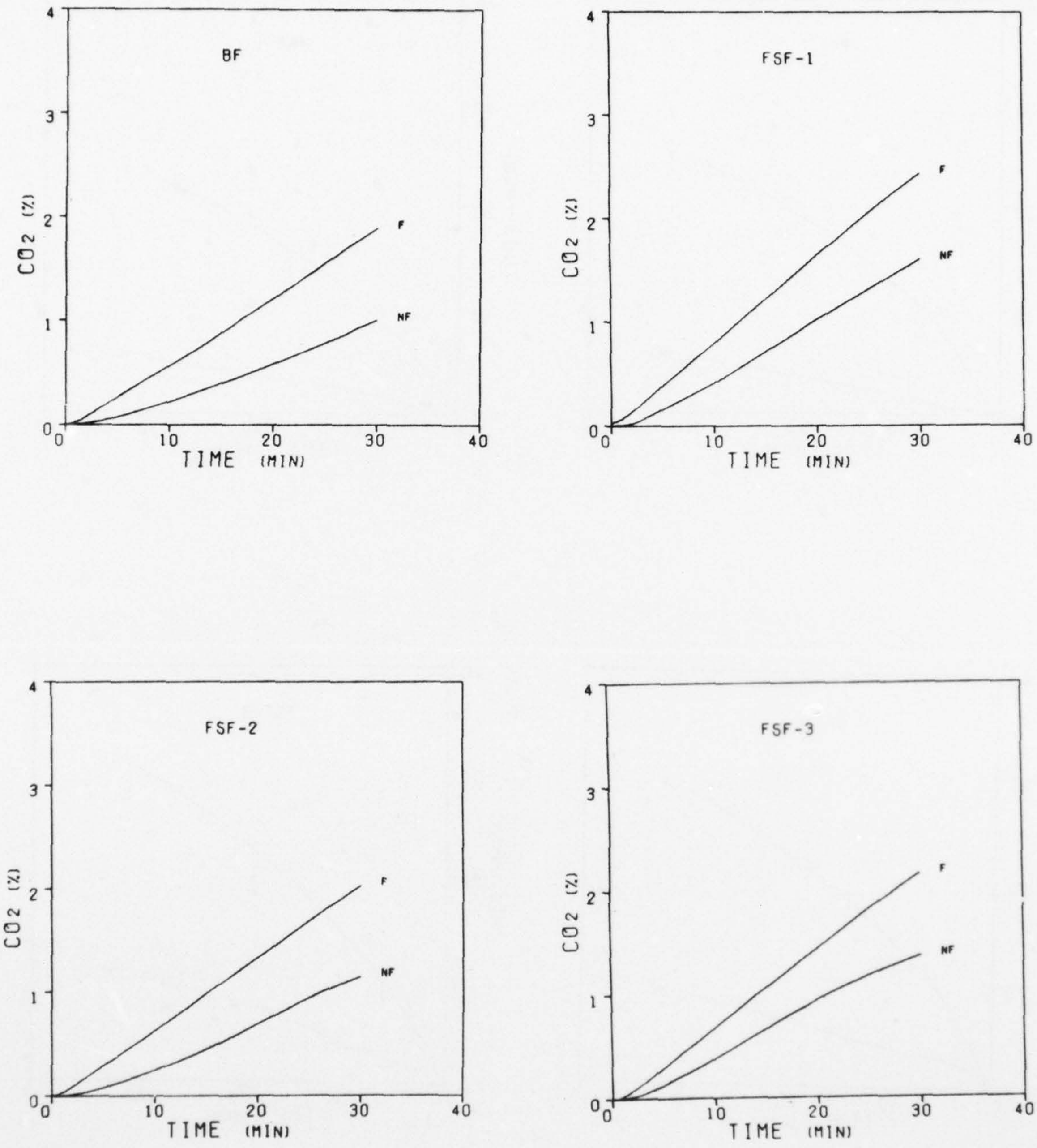


Figure 57. Carbon Dioxide Concentrations During the Burning of Experimental Neoprene Foam Compositions

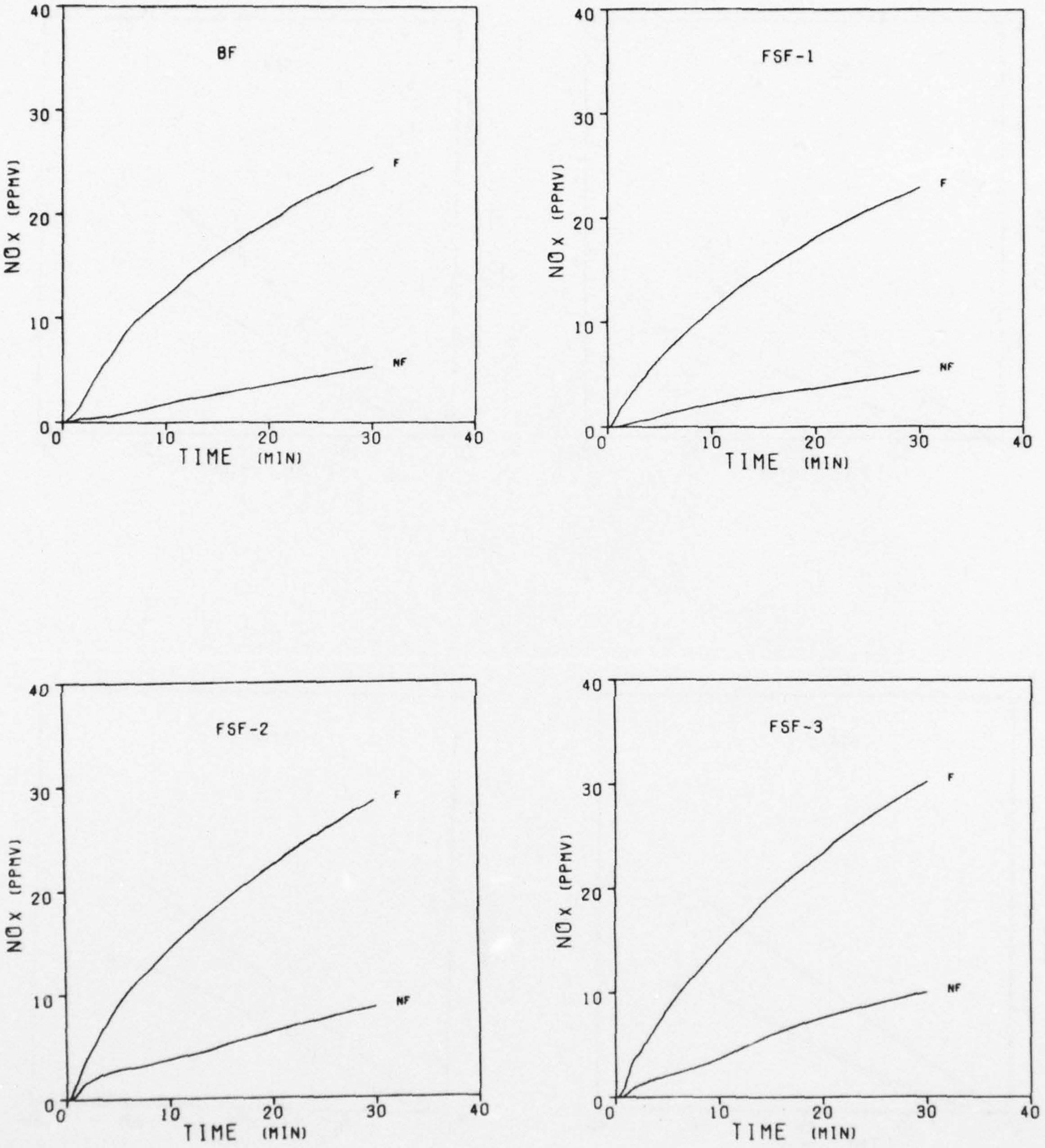


Figure 58. NO_x Concentrations During the Burning of Experimental Neoprene Foam Compositions

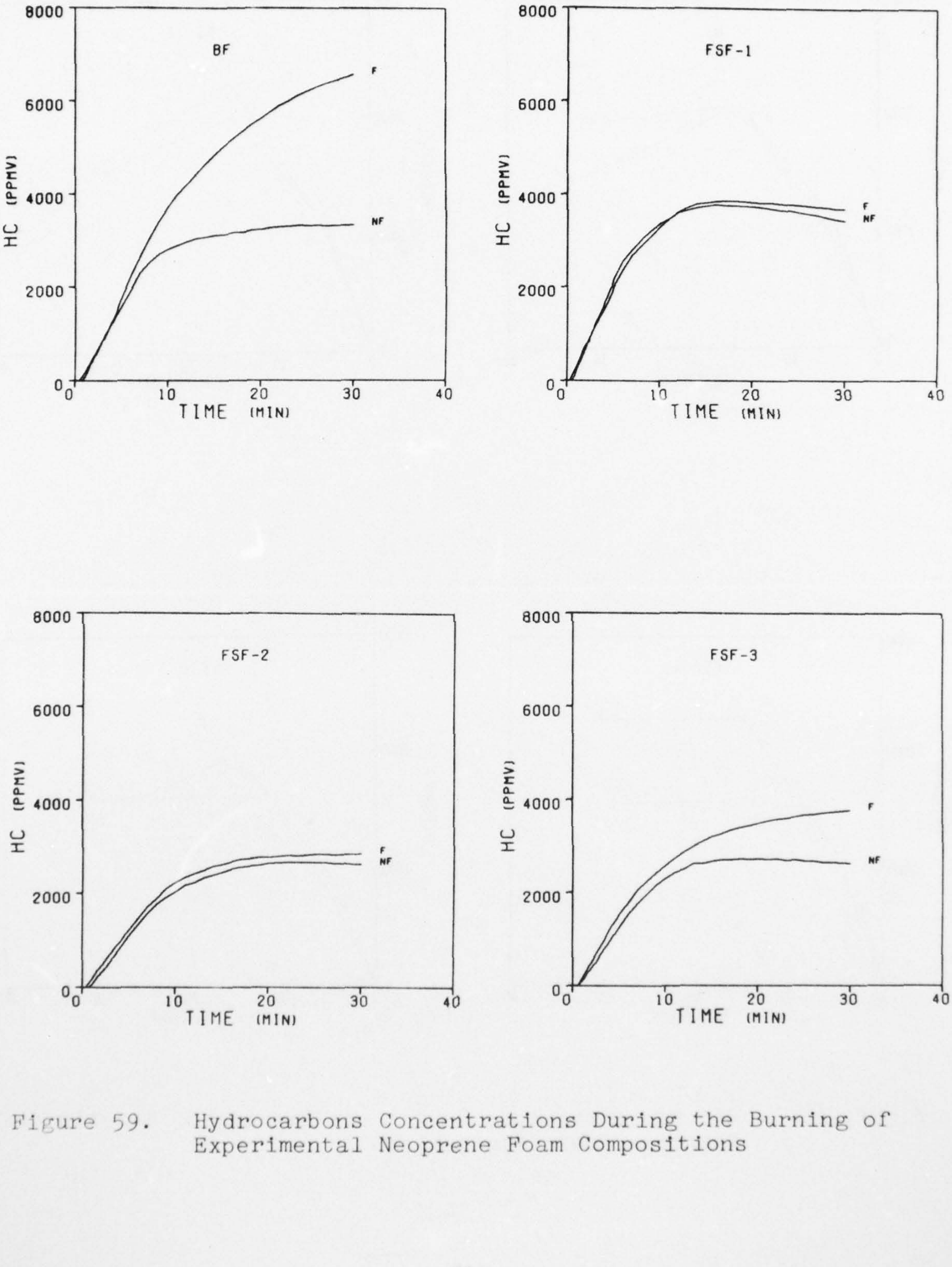


Figure 59. Hydrocarbons Concentrations During the Burning of Experimental Neoprene Foam Compositions

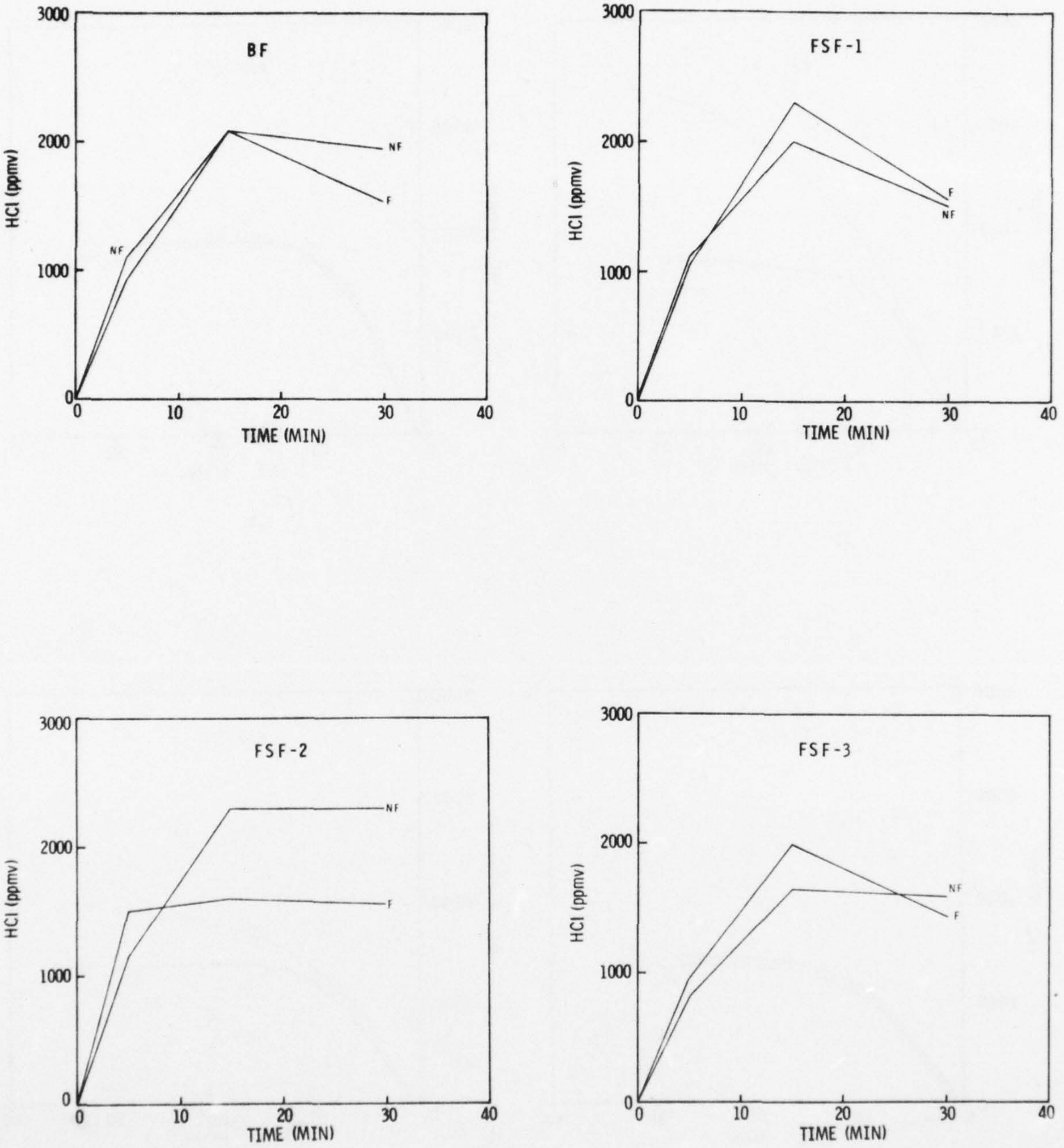


Figure 60. HCl Concentrations During the Burning of Experimental Neoprene Foam Compositions

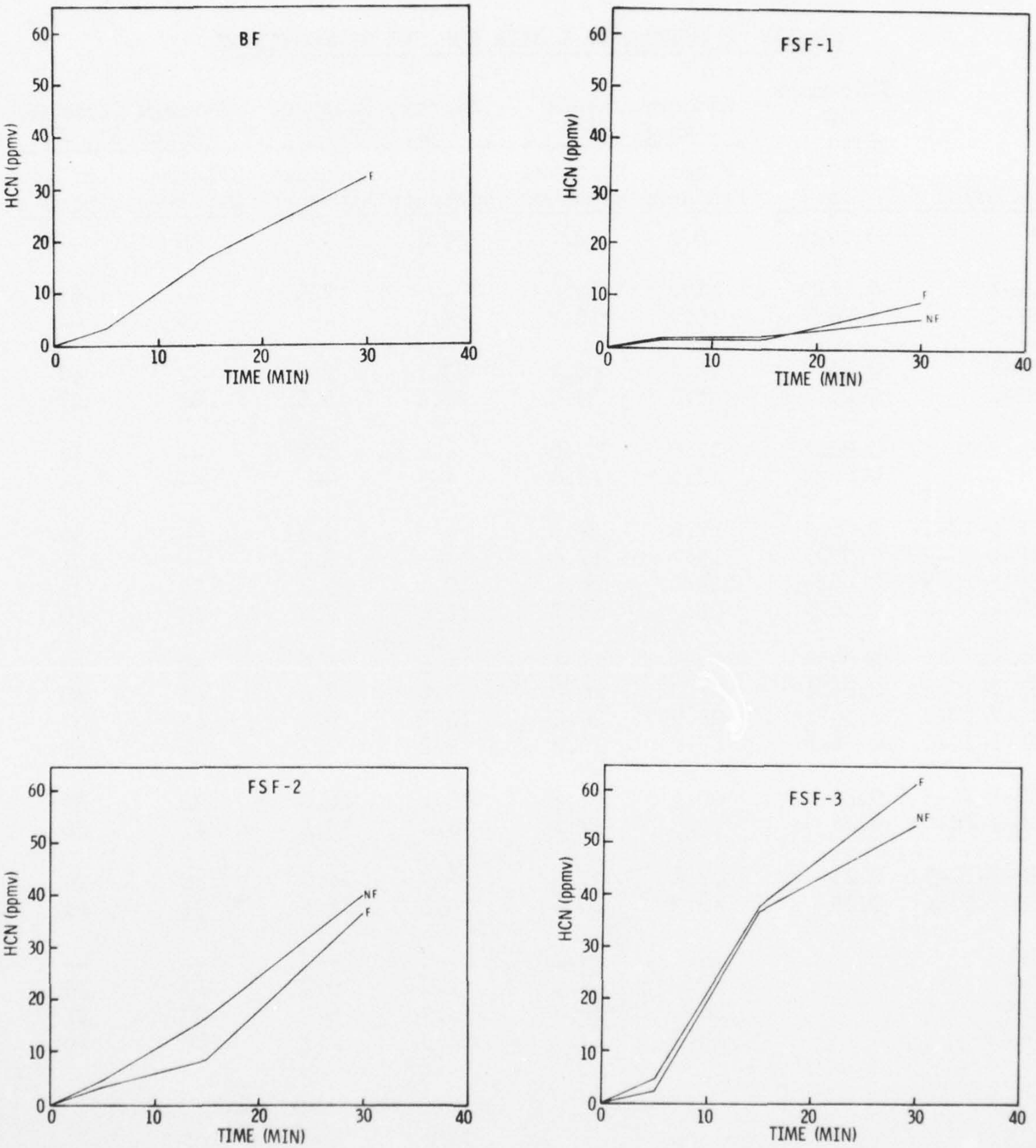


Figure 61. HCN Concentrations During the Burning of Experimental Neoprene Foam Compositions

Table IX

SUMMARY OF SAMPLE MASS DATA FOR PVC COMPOSITIONS

Material	Thickness of Plastic Sample (in.)	Average Sample Mass (g)[a]		Average Consumed Mass (g)[b]		Average Consumed Mass (wt. %)	
		Flame Exposure	Nonflame Exposure	Flame Exposure	Nonflame Exposure	Flame Exposure	Nonflame Exposure
BP	0.0625	10.1	10.0	8.1	--	80	--
FSP-1	0.0625	11.5	12.0	--	7.6	--	63
FSP-2	0.0625	10.9	12.1	8.2	--	75	--
FSP-1	0.25	45.4	46.4	23.5	22.2	52	48
FSP-2	0.25	35.0	33.0	21.4	15.6	61	47
BP-IC-1	0.0625	11.6	12.8	--	7.3	--	57
BP-IC-2	0.0625	12.5	12.8	--	--	--	--
FSP-1-IC-1	0.0625	17.6	17.0	--	5.9	--	35
FSP-1-IC-2	0.0625	15.7	17.6	--	7.1	--	41
FSP-1-IC-3	0.0625	29.6	26.1	13.4	9.2	45	35
FSP-1-IC-4	0.0625	21.3	18.7	10.6	7.4	50	40
FSP-2-IC-1	0.0625	13.2	15.4	6.6	6.0	50	39
FSP-2-IC-2	0.0625	17.0	16.0	7.5	7.4	45	46
FSP-2-IC-3	0.0625	28.9	24.2	12.9	9.0	45	37
FSP-2-IC-4	0.0625	17.6	16.2	9.2	7.2	52	44
FSP-1-IC-3	0.25	60.5	61.2	19.1	16.0	32	26
FSP-1-IC-4	0.25	39.3	47.1	18.4	12.1	47	26
FSP-2-IC-3	0.25	47.8	51.0	23.7	14.3	50	28
FSP-2-IC-4	0.25	42.3	40.6	13.0	10.5	31	26
IC-1		9.1	9.2	--	--	--	--
IC-2		8.5	8.4	1.5	0.9	18	10
IC-3		28.4	31.2	8.4	6.5	30	21
IC-4		13.3	13.3	2.3	2.1	17	16

[a] The measurements were conducted with 3 in. x 3 in. (7.6 cm x 7.6 cm) samples of different thicknesses.

[b] The chars formed from some specimens could not be recovered completely. Therefore, the data in the consumed mass column are incomplete.

Table X

SMOKE OPTICAL DATA SUMMARY FOR PVC COMPOSITIONS

Material	Thickness of Plastic Sample (in.)	Maximum Smoke Optical Density		Time To Maximum Smoke Optical Density (min)	
		Flame Exposure	Nonflame Exposure	Flame Exposure	Nonflame Exposure
BP	0.0625	510	320	4	10
FSP-1	0.0625	200	185	6	12
FSP-2	0.0625	165	155	5	8
FSP-1	0.25	240	260	17	22
FSP-2	0.25	230	195	20	20
BP-IC-1	0.0625	420	270	7	8
BP-IC-2	0.0625	390	230	12	13
FSP-1-IC-1	0.0625	200	200	11	15
FSP-1-IC-2	0.0625	380	270	7	16
FSP-1-IC-3	0.0625	720	490	7	11
FSP-1-IC-4	0.0625	340	260	7	9
FSP-2-IC-1	0.0625	250	180	6	12
FSP-2-IC-2	0.0625	420	270	9	10
FSP-2-IC-3	0.0625	680	500	7	8
FSP-2-IC-4	0.0625	310	240	7	9
FSP-1-IC-3	0.25	460	470	8	14
FSP-1-IC-4	0.25	320	250	15	16
FSP-2-IC-3	0.25	490	450	12	13
FSP-2-IC-4	0.25	330	260	13	20
IC-1		100	76	30	30
IC-2		190	97	7	17
IC-3		490	330	10	16
IC-4		140	93	19	17

AD-A049 923 MONSANTO RESEARCH CORP DAYTON OHIO DAYTON LAB F/G 11/9
FLAME- AND SMOKE-RETARDANT POLYMER SYSTEMS.(U)
FEB 78 L PARTS, R D MYERS, C A THOMPSON N00024-76-C-5336
UNCLASSIFIED MRC-DA-722 NL

2 OF 2
AD
A049923

END
DATE
FILMED
3-78
DDC

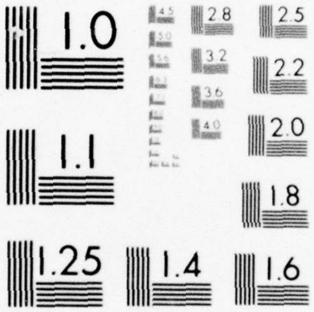

1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

Table XI

SUMMARY OF MAXIMUM CO CONCENTRATION DATA FOR PVC COMPOSITIONS

Material	Thickness of Plastic Sample (in.)	Maximum CO Concentration (ppm)		Time To Maximum CO Concentration (min)	
		Flame Exposure	Nonflame Exposure	Flame Exposure	Nonflame Exposure
BP	0.0625	1900	570	30	30
FSP-1	0.0625	2200	1350	30	30
FSP-2	0.0625	2100	850	30	30
FSP-1	0.25	4800	1900	30	30
FSP-2	0.25	3300	2000	30	30
BP-IC-1	0.0625	1850	230	30	30
BP-IC-2	0.0625	2000	180	30	30
FSP-1-IC-1	0.0625	2350	135	30	30
FSP-1-IC-2	0.0625	2050	210	30	30
FSP-1-IC-3	0.0625	1400	210	30	30
FSP-1-IC-4	0.0625	2000	180	30	30
FSP-2-IC-1	0.0625	1600	235	30	30
FSP-2-IC-2	0.0625	1950	200	30	30
FSP-2-IC-3	0.0625	2000	195	30	30
FSP-2-IC-4	0.0625	1800	190	30	30
FSP-1-IC-3	0.25	1800	1150	30	30
FSP-1-IC-4	0.25	3100	580	30	30
FSP-2-IC-3	0.25	1250	290	30	30
FSP-2-IC-4	0.25	1000	240	30	30
IC-1		1400	25	30	30
IC-2		520	20	30	30
IC-3		1300	125	30	30
IC-4		610	50	30	30

Table XII

SUMMARY OF MAXIMUM CO_2 CONCENTRATION DATA FOR PVC COMPOSITIONS

Material	Thickness of Plastic Sample (in.)	Maximum CO_2 Concentration (%)		Time To Maximum CO_2 Concentration (min)	
		Flame Exposure	Nonflame Exposure	Flame Exposure	Nonflame Exposure
BP	0.0625	1.78	0.12	30	30
FSP-1	0.0625	1.89	0.60	30	29
FSP-2	0.0625	2.16	0.50	30	29
FSP-1	0.25	2.70	0.89	30	30
FSP-2	0.25	2.36	0.72	30	30
BP-IC-1	0.0625	2.16	0.03	30	30
BP-IC-2	0.0625	1.68	0.04	30	30
FSP-1-IC-1	0.0625	1.40	0.16	30	30
FSP-1-IC-2	0.0625	1.77	0.22	30	30
FSP-1-IC-3	0.0625	2.26	0.24	30	30
FSP-1-IC-4	0.0625	1.59	0.16	30	30
FSP-2-IC-1	0.0625	2.32	0.20	30	30
FSP-2-IC-2	0.0625	1.78	0.22	30	30
FSP-2-IC-3	0.0625	2.01	0.24	30	30
FSP-2-IC-4	0.0625	1.78	0.15	30	30
FSP-1-IC-3	0.25	1.97	0.55	30	30
FSP-1-IC-4	0.25	1.58	0.35	30	30
FSP-2-IC-3	0.25	2.06	0.32	30	30
FSP-2-IC-4	0.25	1.80	0.24	30	30
IC-1		1.05	0.03	30	30
IC-2		1.24	0.04	30	30
IC-3		1.86	0.24	30	30
IC-4		1.14	0.06	30	30

Table XIII

SUMMARY OF MAXIMUM NO_x CONCENTRATION DATA FOR PVC COMPOSITIONS

Material	Thickness of Plastic Sample (in.)	Maximum NO_x Concentration (ppm)		Time To Maximum NO_x Concentration (min)	
		Flame Exposure	Nonflame Exposure	Flame Exposure	Nonflame Exposure
BP	0.0625	19	4.6	5	4
FSP-1	0.0625	3.3	1.8	30	5
FSP-2	0.0625	7.7	1.6	5	4
FSP-1	0.25	5.4	2.6	30	30
FSP-2	0.25	7.8	2.4	30	30
BP-IC-1	0.0625	40	12	30	30
BP-IC-2	0.0625	46	16	30	30
FSP-1-IC-1	0.0625	37	13	30	30
FSP-1-IC-2	0.0625	54	16	30	30
FSP-1-IC-3	0.0625	92	27	30	30
FSP-1-IC-4	0.0625	56	20	30	30
FSP-2-IC-1	0.0625	31	9.1	30	30
FSP-2-IC-2	0.0625	60	16	30	30
FSP-2-IC-3	0.0625	88	27	30	30
FSP-2-IC-4	0.0625	56	18	30	30
FSP-1-IC-3	0.25	88	30	30	30
FSP-1-IC-4	0.25	37	18	30	30
FSP-2-IC-3	0.25	96	34	30	30
FSP-2-IC-4	0.25	61	21	30	30
IC-1		21	6.0	30	30
IC-2		46	9.5	30	30
IC-3		82	44	30	30
IC-4		53	32	30	30

Table XIV

SUMMARY OF MAXIMUM HCl CONCENTRATION DATA FOR PVC COMPOSITIONS

Material	Thickness of Plastic Sample (in.)	Maximum HCl Concentration (ppm)		Time To Maximum HCl Concentration (min)	
		Flame Exposure	Nonflame Exposure	Flame Exposure	Nonflame Exposure
BP	0.0625	2400	2600	15	15
FSP-1	0.0625	2200	2400	15	15
FSP-2	0.0625	1350	2300	5	15
FSP-1	0.25	7500	7800	30	30
FSP-2	0.25	7300	3600	30	30
BP-IC-1	0.0625	2100	1900	5	30
BP-IC-2	0.0625	2200	1850	15	30
FSP-1-IC-1	0.0625	1950	1300	15	30
FSP-1-IC-2	0.0625	1100	330	15	15
FSP-1-IC-3	0.0625	1200	1600	15	15
FSP-1-IC-4	0.0625	1400	2800	15	30
FSP-2-IC-1	0.0625	1250	1600	5	30
FSP-2-IC-2	0.0625	190	1000	15	15
FSP-2-IC-3	0.0625	1100	1800	15	15
FSP-2-IC-4	0.0625	2900	3200	15	15
FSP-1-IC-3	0.25	1900	2000	15	30
FSP-1-IC-4	0.25	4000	2900	30	30
FSP-2-IC-3	0.25	3700	3300	30	30
FSP-2-IC-4	0.25	3700	2400	30	30
IC-1		--	--	--	--
IC-2		<63	<63	--	--
IC-3		580	530	30	15
IC-4		145	96	30	30

Table XV

SUMMARY OF MAXIMUM HYDROCARBONS CONCENTRATION DATA FOR PVC COMPOSITIONS

Material	Thickness of Plastic Sample (in.)	Maximum Hydrocarbons Concentration (ppm)		Time To Maximum Hydrocarbons Concentration (min)	
		Flame Exposure	Nonflame Exposure	Flame Exposure	Nonflame Exposure
BP	0.0625	5200	3000	30	17
FSP-1	0.0625	3500	3500	30	13
FSP-2	0.0625	2800	2900	30	14
FSP-1	0.25	9600	7300	30	30
FSP-2	0.25	9100	6800	30	30
BP-IC-1	0.0625	4500	3000	24	19
BP-IC-2	0.0625	6700	3100	30	20
FSP-1-IC-1	0.0625	7100	2500	30	22
FSP-1-IC-2	0.0625	7600	3200	30	18
FSP-1-IC-3	0.0625	4300	3000	17	24
FSP-1-IC-4	0.0625	4900	2700	30	12
FSP-2-IC-1	0.0625	5000	3300	30	19
FSP-2-IC-2	0.0625	5000	3400	29	21
FSP-2-IC-3	0.0625	4600	3200	20	22
FSP-2-IC-4	0.0625	4000	2700	30	22
FSP-1-IC-3	0.25	5600	5300	30	30
FSP-1-IC-4	0.25	8800	3900	30	30
FSP-2-IC-3	0.25	7400	5500	27	30
FSP-2-IC-4	0.25	8800	3900	30	30
IC-1		2600	62	30	29
IC-2		830	360	25	20
IC-3		3100	2400	25	30
IC-4		2000	470	30	26

Table XVI

EXPERIMENTAL FLAME PROPAGATION DATA FOR PVC COMPOSITIONS

Material	t_3[a] (sec)	t_6[a] (sec)	t_9[a] (sec)	t_{12}[a] (sec)	t_{15}[a] (sec)	ΔT[b] (°C)
BP	38	861				18
	32	866				8
FSP-2	34	21	28	153	664	18
FSP-1-IC-1	54	45	58	741		8
	53	18	101	720		8
FSP-1-IC-2	36	20	172	247		13
	25	20	39	816		14
	23	21	304	552		7
FSP-1-IC-3	83	1.5	45	770		14
	41	4.1	81	344	429	22
	42	27	257	574		6
FSP-1-IC-4	60	21	78	738		8
	43	25	61	771		9
FSP-2-IC-1	62	42	197			50
	98	17	786			28
	46	54	43	757		10
FSP-2-IC-2	28	13	857			18
	26	32	841			20
FSP-2-IC-3	80	7.5	813			20
	67	9.8	823			23
FSP-2-IC-4	72	29	68	730		16
	83	115	87	614		13

[a] t_3....t_{15} represent times in seconds from initial sample exposure until the arrival of the flame front at the positions 3....15 in., respectively, along the length of the specimen.

[b] ΔT is the maximum temperature rise of the exhaust gases, in °C, with reference to the exhaust temperature measured with an asbestos-cement sample.

Table XVII

COMBUSTION PRODUCTS FORMED FROM BP UNDER FLAME EXPOSURE CONDITIONS

MATERIAL PVC-BP
SAMPLE MASS 10.67
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

CONCENTRATIONS

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	28.	6.	0.06	163.	0.3	20.56
2.	167.	39.	0.23	1054.	0.7	20.44
3.	288.	89.	0.28	1947.	8.0	20.41
4.	370.	154.	0.35	2777.	19.0	20.45
5.	425.	234.	0.42	3366.	23.4	20.31
6.	463.	355.	0.51	3778.	23.1	20.21
7.	464.	462.	0.59	4082.	21.2	20.24
8.	448.	559.	0.64	4313.	19.1	20.17
9.	429.	655.	0.70	4567.	17.4	20.20
10.	407.	746.	0.76	4852.	16.1	20.17
11.	387.	831.	0.82	4897.	15.2	20.08
12.	369.	917.	0.87	5048.	14.4	20.10
13.	353.	1009.	0.94	5184.	13.8	20.07
14.	338.	1093.	1.00	5290.	13.4	20.47
15.	325.	1175.	1.06	5388.	12.9	20.40
16.	312.	1259.	1.11	5448.	12.5	20.36
17.	302.	1346.	1.17	5501.	12.1	20.35
18.	291.	1424.	1.23	5569.	11.9	20.27
19.	280.	1513.	1.29	5622.	11.7	20.27
20.	272.	1594.	1.35	5690.	11.5	20.16
21.	264.	1670.	1.41	5796.	11.3	20.16
22.	257.	1744.	1.47	5924.	11.1	20.16
23.	248.	1815.	1.55	6045.	10.9	20.12
24.	241.	1886.	1.56	6188.	10.7	20.06
25.	234.	1955.	1.62	6332.	10.5	20.15
26.	227.	2024.	1.68	6505.	10.4	20.06
27.	221.	2094.	1.75	6649.	10.4	20.00
28.	214.	2163.	1.81	6770.	10.3	20.00
29.	208.	2231.	1.88	6875.	10.2	19.95
30.	202.	2300.	1.94	6966.	10.1	19.88

Table XVIII

COMBUSTION PRODUCTS FORMED FROM BP UNDER FLAME EXPOSURE CONDITIONS

MATERIAL PVC-FP
SAMPLE MASS 9.51
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

CONCENTRATIONS

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	64.	5.	0.02	222.	0.7	21.00
2.	415.	101.	0.08	1634.	4.5	20.97
3.	594.	274.	0.17	2555.	15.8	20.78
4.	660.	442.	0.25	3287.	16.2	20.59
5.	445.	576.	0.33	3597.	14.0	20.58
6.	567.	665.	0.38	3718.	12.3	20.52
7.	524.	731.	0.44	3771.	11.1	20.29
8.	482.	784.	0.49	3786.	10.1	20.26
9.	446.	833.	0.55	3763.	9.5	20.22
10.	417.	872.	0.60	3740.	9.0	20.16
11.	395.	917.	0.65	3710.	8.6	20.09
12.	370.	961.	0.71	3695.	8.4	20.05
13.	352.	998.	0.76	3665.	8.1	19.87
14.	335.	1039.	0.82	3650.	7.9	19.88
15.	321.	1081.	0.87	3627.	7.7	19.75
16.	307.	1119.	0.92	3612.	7.6	19.62
17.	298.	1163.	0.98	3589.	7.5	19.58
18.	287.	1202.	1.03	3582.	7.5	19.54
19.	278.	1240.	1.08	3552.	7.5	19.45
20.	269.	1281.	1.13	3536.	7.4	19.34
21.	261.	1323.	1.17	3521.	7.4	19.26
22.	255.	1364.	1.22	3506.	7.4	19.26
23.	248.	1404.	1.27	3491.	7.4	19.16
24.	242.	1444.	1.32	3484.	7.4	19.09
25.	235.	1484.	1.37	3469.	7.5	19.06
26.	231.	1524.	1.42	3453.	7.5	18.94
27.	225.	1564.	1.47	3446.	7.5	18.91
28.	219.	1603.	1.52	3438.	7.5	18.87
29.	215.	1643.	1.57	3416.	7.6	18.82
30.	209.	1682.	1.62	3393.	7.6	18.72

Table XIX

COMBUSTION PRODUCTS FORMED FROM BP UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL PVC-BP
SAMPLE MASS 10.46
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

CONCENTRATIONS

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	5.	0.	0.00	16.	2.0	21.00
2.	77.	0.	0.01	571.	2.0	21.00
3.	152.	7.	0.01	1077.	4.0	21.00
4.	223.	17.	0.01	1584.	4.1	21.00
5.	268.	29.	0.01	1968.	4.2	21.00
6.	303.	43.	0.01	2336.	3.1	21.00
7.	327.	58.	0.02	2601.	2.6	20.95
8.	342.	76.	0.02	2759.	2.3	20.95
9.	350.	95.	0.02	2878.	2.1	20.92
10.	352.	114.	0.02	2931.	1.9	20.93
11.	353.	134.	0.03	2999.	1.7	20.84
12.	347.	153.	0.03	3082.	1.7	20.84
13.	344.	173.	0.03	3099.	1.6	20.78
14.	338.	192.	0.04	3148.	1.5	20.79
15.	332.	211.	0.04	3141.	1.5	20.74
16.	325.	231.	0.04	3135.	1.4	20.89
17.	318.	246.	0.05	3159.	1.4	20.95
18.	311.	269.	0.05	3136.	1.4	21.00
19.	304.	292.	0.06	3133.	1.4	20.96
20.	298.	316.	0.06	3115.	1.4	20.92
21.	291.	341.	0.07	3094.	1.3	21.00
22.	285.	367.	0.07	3073.	1.3	21.00
23.	278.	393.	0.08	3026.	1.3	21.00
24.	273.	421.	0.09	3002.	1.3	21.00
25.	268.	450.	0.09	2995.	1.3	21.00
26.	263.	478.	0.10	2985.	1.3	20.63
27.	257.	510.	0.10	2957.	1.3	20.90
28.	252.	541.	0.11	2940.	1.3	20.88
29.	247.	574.	0.11	2912.	1.3	20.86
30.	241.	605.	0.12	2892.	1.3	20.81

Table XX

COMBUSTION PRODUCTS FORMED FROM BP UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL PVC-BP
SAMPLE MASS 9.52
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

CONCENTRATIONS

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	13.	0.	0.00	16.	0.1	21.00
2.	80.	10.	0.01	521.	1.8	21.00
3.	139.	19.	0.01	1050.	4.7	21.00
4.	189.	28.	0.01	1431.	5.1	21.00
5.	221.	38.	0.01	1783.	5.0	21.00
6.	247.	53.	0.02	2063.	4.9	21.00
7.	266.	67.	0.01	2373.	4.6	21.00
8.	278.	83.	0.02	2538.	4.4	21.00
9.	284.	104.	0.02	2657.	4.2	21.00
10.	286.	122.	0.03	2715.	4.0	20.86
11.	286.	141.	0.03	2785.	3.8	20.88
12.	283.	160.	0.03	2822.	3.7	20.90
13.	279.	179.	0.04	2841.	3.6	20.92
14.	275.	200.	0.04	2872.	3.4	20.88
15.	269.	218.	0.04	2865.	3.4	20.85
16.	264.	234.	0.05	2878.	3.3	20.72
17.	259.	252.	0.05	2855.	3.2	20.60
18.	253.	266.	0.06	2834.	3.2	20.59
19.	248.	286.	0.06	2828.	3.1	20.60
20.	242.	305.	0.06	2782.	3.1	21.00
21.	237.	327.	0.07	2766.	3.0	21.00
22.	230.	348.	0.08	2770.	3.0	21.00
23.	226.	370.	0.08	2719.	2.9	21.00
24.	221.	377.	0.09	2705.	2.9	20.94
25.	216.	413.	0.09	2689.	2.9	20.90
26.	211.	430.	0.10	2666.	2.9	20.97
27.	206.	454.	0.10	2616.	2.8	20.92
28.	202.	481.	0.11	2618.	2.8	21.00
29.	197.	495.	0.11	2567.	2.8	21.00
30.	192.	537.	0.12	2556.	2.8	20.93

Table XXI

COMBUSTION PRODUCTS FORMED FROM FSP-1 UNDER FLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-1
SAMPLE MASS 11.93
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

CONCENTRATIONS

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	0.	2.	0.01	127.	0.2	21.00
2.	0.	165.	0.01	119.	0.1	21.00
3.	70.	396.	0.15	417.	2.3	21.00
4.	163.	584.	0.41	855.	3.8	20.67
5.	211.	661.	0.56	1308.	3.6	20.49
6.	213.	776.	0.58	1370.	3.5	20.48
7.	216.	873.	0.60	1421.	3.4	20.49
8.	218.	975.	0.61	1489.	3.4	20.52
9.	218.	1077.	0.63	1555.	3.3	20.39
10.	219.	1180.	0.64	1595.	3.3	20.39
11.	219.	1273.	0.66	1644.	3.3	20.38
12.	219.	1372.	0.68	1682.	3.3	20.31
13.	217.	1465.	0.70	1709.	3.2	20.28
14.	212.	1544.	0.79	1838.	3.2	20.27
15.	206.	1627.	0.88	1977.	3.2	20.17
16.	198.	1708.	0.98	2099.	3.2	20.04
17.	190.	1764.	1.06	2165.	3.3	19.90
18.	184.	1822.	1.13	2179.	3.3	19.76
19.	178.	1880.	1.21	2197.	3.4	19.62
20.	172.	1942.	1.29	2217.	3.4	19.38
21.	167.	1997.	1.37	2220.	3.4	19.35
22.	162.	2046.	1.45	2215.	3.5	19.23
23.	157.	2091.	1.52	2217.	3.5	19.16
24.	152.	2132.	1.61	2199.	3.6	19.03
25.	148.	2173.	1.68	2179.	3.6	18.91
26.	144.	2214.	1.76	2179.	3.7	18.80
27.	139.	2256.	1.83	2209.	3.8	18.68
28.	135.	2299.	1.90	2190.	3.8	18.68
29.	132.	2343.	1.97	2179.	3.9	18.50
30.	129.	2386.	2.04	2208.	4.0	18.47

Table XXII

COMBUSTION PRODUCTS FORMED FROM FSP-1 UNDER FLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-1
SAMPLE MASS 11.02
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

CONCENTRATIONS

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	11.	2.	0.03	265.	0.1	20.96
2.	73.	113.	0.25	1024.	1.6	20.69
3.	142.	251.	0.41	1504.	1.8	20.40
4.	171.	348.	0.49	1876.	1.7	20.33
5.	181.	501.	0.57	2262.	1.7	20.43
6.	183.	673.	0.65	2561.	1.7	20.28
7.	179.	831.	0.73	2733.	1.7	20.22
8.	171.	981.	0.81	2875.	1.7	20.06
9.	162.	1095.	0.87	2937.	1.7	19.98
10.	153.	1194.	0.94	3047.	1.7	19.98
11.	145.	1278.	1.00	3157.	1.8	19.79
12.	137.	1352.	1.05	3231.	1.8	19.76
13.	131.	1425.	1.10	3375.	1.8	19.79
14.	125.	1490.	1.15	3470.	1.9	19.53
15.	118.	1543.	1.19	3563.	1.9	19.46
16.	112.	1581.	1.23	3625.	1.9	19.40
17.	107.	1631.	1.27	3690.	2.0	19.44
18.	102.	1668.	1.31	3758.	2.0	19.42
19.	97.	1698.	1.35	3837.	2.1	19.25
20.	93.	1727.	1.39	3867.	2.1	19.10
21.	89.	1756.	1.43	3917.	2.2	19.00
22.	85.	1783.	1.47	3923.	2.2	18.86
23.	82.	1802.	1.50	4001.	2.3	18.80
24.	78.	1825.	1.54	4042.	2.3	18.73
25.	76.	1851.	1.57	4137.	2.4	18.59
26.	73.	1868.	1.61	4265.	2.4	18.58
27.	70.	1887.	1.64	4412.	2.5	18.54
28.	67.	1913.	1.68	4513.	2.5	18.59
29.	65.	1930.	1.71	4618.	2.6	18.40
30.	63.	1954.	1.75	4724.	2.6	18.36

Table XXIII

COMBUSTION PRODUCTS FORMED FROM FSP-1 UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-1
SAMPLE MASS 13.04
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

CONCENTRATIONS

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	0.	1.	0.01	0.	0.1	21.00
2.	13.	1.	0.02	287.	0.2	21.00
3.	33.	5.	0.04	1246.	1.3	21.00
4.	58.	12.	0.06	1946.	2.1	21.00
5.	86.	22.	0.08	2406.	2.2	21.00
6.	127.	39.	0.09	2739.	2.1	21.00
7.	151.	62.	0.11	2959.	2.1	21.00
8.	169.	97.	0.13	3163.	2.0	21.00
9.	184.	153.	0.17	3359.	2.0	20.99
10.	195.	228.	0.20	3504.	1.9	20.90
11.	200.	315.	0.23	3608.	1.9	20.86
12.	199.	414.	0.27	3653.	1.9	20.78
13.	195.	511.	0.30	3668.	1.9	20.72
14.	188.	609.	0.33	3631.	1.9	20.61
15.	183.	702.	0.35	3620.	1.9	20.57
16.	178.	780.	0.38	3576.	1.9	20.74
17.	172.	856.	0.41	3526.	1.9	20.68
18.	166.	927.	0.43	3507.	1.9	20.68
19.	160.	986.	0.45	3474.	1.9	20.71
20.	154.	1039.	0.47	3419.	1.9	20.60
21.	149.	1088.	0.49	3386.	1.9	20.59
22.	143.	1128.	0.50	3348.	1.9	20.54
23.	138.	1166.	0.52	3320.	1.9	20.56
24.	133.	1199.	0.53	3277.	1.9	20.67
25.	129.	1227.	0.54	3265.	1.9	20.50
26.	124.	1246.	0.55	3219.	1.9	20.48
27.	120.	1255.	0.56	3178.	2.0	20.41
28.	116.	1276.	0.57	3160.	2.0	20.45
29.	112.	1280.	0.58	3105.	2.0	20.45
30.	108.	1298.	0.58	3066.	2.0	20.41

Table XXIV

COMBUSTION PRODUCTS FORMED FROM FSP-1 UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-1
SAMPLE MASS 11.57
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

CONCENTRATIONS

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	3.	0.	0.00	2.	0.0	20.73
2.	17.	0.	0.01	468.	0.1	20.57
3.	34.	0.	0.03	1310.	1.0	20.33
4.	56.	0.	0.06	1900.	1.3	20.23
5.	90.	0.	0.07	2320.	1.3	20.21
6.	120.	9.	0.09	2694.	1.3	20.31
7.	138.	29.	0.10	2886.	1.2	20.31
8.	147.	49.	0.12	3053.	1.1	20.23
9.	155.	76.	0.13	3160.	1.1	20.32
10.	163.	117.	0.16	3258.	1.1	20.31
11.	168.	166.	0.18	3316.	1.0	20.21
12.	171.	224.	0.21	3357.	1.0	20.19
13.	171.	283.	0.24	3349.	1.0	20.51
14.	171.	359.	0.26	3337.	0.9	20.53
15.	170.	442.	0.29	3366.	0.9	20.43
16.	167.	535.	0.32	3399.	0.9	20.96
17.	164.	629.	0.36	3414.	0.9	20.96
18.	159.	721.	0.39	3433.	0.9	20.95
19.	154.	808.	0.41	3440.	0.9	20.97
20.	149.	887.	0.44	3432.	0.9	21.00
21.	144.	968.	0.47	3406.	0.9	20.95
22.	138.	1032.	0.50	3378.	0.9	20.75
23.	134.	1103.	0.52	3350.	0.9	20.71
24.	131.	1159.	0.54	3301.	1.0	20.51
25.	126.	1213.	0.56	3227.	0.9	20.55
26.	121.	1257.	0.58	3165.	0.9	20.55
27.	116.	1295.	0.59	3118.	1.0	20.37
28.	111.	1328.	0.61	3088.	1.0	20.52
29.	107.	1353.	0.62	3040.	1.0	20.49
30.	103.	1371.	0.63	3044.	1.0	20.43

Table XXV

COMBUSTION PRODUCTS FORMED FROM FSP-2 UNDER FLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-2
SAMPLE MASS 11.00
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

CONCENTRATIONS

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	15.	3.	0.02	185.	0.4	21.00
2.	36.	128.	0.25	655.	1.3	20.78
3.	86.	242.	0.42	1155.	6.4	20.61
4.	115.	364.	0.51	1525.	9.2	20.45
5.	125.	449.	0.57	1780.	9.4	20.33
6.	127.	520.	0.63	1990.	9.0	20.28
7.	126.	599.	0.70	2210.	8.5	20.20
8.	124.	688.	0.76	2355.	7.9	20.08
9.	122.	780.	0.82	2505.	7.5	19.94
10.	119.	867.	0.88	2610.	7.0	19.86
11.	115.	952.	0.95	2690.	6.7	19.78
12.	112.	1036.	1.01	2755.	6.5	19.65
13.	109.	1123.	1.07	2800.	6.3	19.54
14.	105.	1196.	1.12	2860.	6.1	19.47
15.	102.	1271.	1.17	2880.	6.0	19.35
16.	99.	1343.	1.23	2885.	5.9	19.32
17.	97.	1406.	1.28	2915.	5.8	19.25
18.	94.	1466.	1.33	2935.	5.7	19.11
19.	91.	1527.	1.39	2945.	5.7	19.06
20.	89.	1580.	1.44	2990.	5.7	18.96
21.	86.	1631.	1.49	3056.	5.6	18.88
22.	84.	1679.	1.54	3132.	5.6	18.89
23.	82.	1727.	1.59	3212.	5.6	18.83
24.	80.	1769.	1.64	3290.	5.6	18.73
25.	78.	1807.	1.69	3360.	5.7	18.67
26.	76.	1849.	1.74	3417.	5.7	18.58
27.	74.	1883.	1.79	3463.	5.7	18.50
28.	73.	1918.	1.84	3500.	5.8	18.45
29.	71.	1948.	1.88	3531.	5.8	18.36
30.	69.	1978.	1.92	3560.	5.9	18.28

Table XXVI

COMBUSTION PRODUCTS FORMED FROM FSP-2 UNDER FLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-2
SAMPLE MASS 10.90
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

CONCENTRATIONS

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	19.	10.	0.05	235.	0.3	20.82
2.	99.	167.	0.26	925.	2.3	20.71
3.	178.	385.	0.49	1415.	4.7	20.39
4.	208.	561.	0.61	1765.	5.9	20.09
5.	206.	682.	0.70	1980.	6.0	20.02
6.	198.	791.	0.77	2210.	5.8	19.80
7.	188.	889.	0.85	2255.	5.5	19.76
8.	178.	993.	0.93	2270.	5.2	19.83
9.	170.	1092.	1.01	2290.	5.0	19.85
10.	162.	1189.	1.08	2260.	4.8	19.72
11.	156.	1283.	1.16	2240.	4.7	19.53
12.	150.	1372.	1.23	2235.	4.6	19.47
13.	144.	1458.	1.30	2195.	4.6	19.42
14.	139.	1527.	1.37	2190.	4.6	19.21
15.	135.	1589.	1.44	2210.	4.6	19.14
16.	132.	1650.	1.51	2190.	4.6	19.06
17.	128.	1702.	1.58	2225.	4.7	18.98
18.	123.	1752.	1.64	2205.	4.7	18.82
19.	120.	1796.	1.71	2240.	4.8	18.67
20.	116.	1835.	1.77	2240.	4.8	18.39
21.	113.	1877.	1.83	2221.	4.9	18.31
22.	110.	1912.	1.90	2198.	5.0	18.21
23.	107.	1948.	1.97	2173.	5.1	18.19
24.	104.	1981.	2.03	2148.	5.1	18.08
25.	102.	2012.	2.09	2125.	5.2	17.94
26.	99.	2036.	2.15	2105.	5.3	17.89
27.	97.	2066.	2.21	2089.	5.4	17.79
28.	94.	2089.	2.27	2075.	5.5	17.64
29.	93.	2112.	2.33	2062.	5.6	17.56
30.	90.	2136.	2.39	2050.	5.7	17.52

Table XXVII

COMBUSTION PRODUCTS FORMED FROM FSP-2 UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-2
SAMPLE MASS 12.50
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

CONCENTRATIONS

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	6.	4.	0.00	29.	0.2	20.92
2.	51.	4.	0.02	753.	0.5	20.86
3.	93.	8.	0.04	1609.	1.4	20.82
4.	121.	19.	0.06	2150.	1.6	20.65
5.	138.	35.	0.08	2638.	1.6	20.61
6.	150.	61.	0.09	2886.	1.5	20.72
7.	158.	121.	0.12	3086.	1.5	20.68
8.	161.	196.	0.14	3184.	1.5	20.61
9.	161.	266.	0.17	3301.	1.4	20.49
10.	157.	348.	0.20	3352.	1.4	20.43
11.	153.	429.	0.23	3385.	1.4	20.43
12.	149.	502.	0.26	3415.	1.4	20.34
13.	145.	570.	0.29	3421.	1.4	20.38
14.	139.	627.	0.32	3433.	1.4	20.38
15.	135.	679.	0.34	3390.	1.4	20.26
16.	131.	717.	0.36	3341.	1.4	20.37
17.	125.	741.	0.37	3296.	1.4	20.30
18.	120.	750.	0.38	3270.	1.4	20.31
19.	115.	766.	0.39	3204.	1.4	20.35
20.	110.	774.	0.39	3159.	1.5	20.23
21.	106.	781.	0.40	3139.	1.5	20.16
22.	102.	787.	0.40	3082.	1.5	20.22
23.	98.	793.	0.40	3024.	1.5	20.28
24.	94.	800.	0.41	2990.	1.5	20.15
25.	91.	808.	0.41	2949.	1.5	20.24
26.	88.	812.	0.42	2908.	1.5	20.27
27.	85.	821.	0.41	2880.	1.5	20.24
28.	83.	826.	0.42	2858.	1.5	20.20
29.	80.	832.	0.42	2822.	1.5	20.19
30.	78.	837.	0.42	2786.	1.6	20.26

Table XXVIII

COMBUSTION PRODUCTS FORMED FROM FSP-2 UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-2
SAMPLE MASS 11.61
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

CONCENTRATIONS

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	11.	2.	0.01	37.	0.1	20.82
2.	35.	2.	0.02	701.	0.5	20.70
3.	63.	2.	0.05	1282.	1.8	20.61
4.	106.	2.	0.06	1766.	2.1	20.71
5.	131.	2.	0.08	2079.	2.1	20.47
6.	142.	8.	0.09	2311.	1.9	20.61
7.	146.	24.	0.10	2408.	1.8	20.56
8.	147.	42.	0.10	2444.	1.7	20.62
9.	146.	64.	0.12	2449.	1.7	20.55
10.	144.	98.	0.13	2441.	1.6	20.35
11.	143.	139.	0.15	2415.	1.5	20.44
12.	141.	187.	0.18	2409.	1.5	20.46
13.	139.	237.	0.20	2424.	1.5	20.31
14.	135.	285.	0.23	2464.	1.5	20.20
15.	134.	348.	0.26	2450.	1.4	20.25
16.	131.	409.	0.29	2432.	1.4	20.21
17.	127.	468.	0.32	2421.	1.4	20.35
18.	124.	525.	0.35	2379.	1.4	20.33
19.	120.	579.	0.38	2304.	1.4	20.33
20.	117.	631.	0.41	2242.	1.4	20.39
21.	114.	678.	0.44	2153.	1.3	20.17
22.	110.	720.	0.47	2101.	1.3	20.17
23.	107.	755.	0.50	2015.	1.3	20.21
24.	103.	783.	0.52	1901.	1.3	20.07
25.	99.	805.	0.53	1846.	1.3	20.18
26.	95.	822.	0.55	1795.	1.3	20.16
27.	92.	837.	0.56	1725.	1.3	20.14
28.	89.	847.	0.57	1721.	1.3	20.10
29.	85.	858.	0.57	1659.	1.3	20.05
30.	82.	862.	0.58	1647.	1.4	19.99

Table XXIX

COMBUSTION PRODUCTS FORMED FROM BP-IC-1 UNDER FLAME EXPOSURE CONDITIONS

MATERIAL PVC-BP-IC-1
SAMPLE MASS AVG 11.5759
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	66.	11.	0.04	149.	2.3	21.00
2.	204.	97.	0.13	968.	7.2	20.92
3.	277.	189.	0.23	1768.	12.3	20.71
4.	343.	266.	0.33	2668.	16.8	20.67
5.	399.	514.	0.43	3258.	19.7	20.44
6.	418.	646.	0.52	3631.	21.6	20.36
7.	424.	727.	0.60	3916.	23.7	20.22
8.	417.	786.	0.67	4105.	25.0	19.99
9.	399.	849.	0.74	4210.	25.8	19.94
10.	383.	907.	0.80	4263.	26.8	19.86
11.	363.	967.	0.87	4278.	27.7	19.75
12.	346.	1021.	0.94	4256.	28.6	19.64
13.	332.	1075.	1.00	4241.	29.5	19.52
14.	320.	1130.	1.06	4218.	30.1	19.35
15.	307.	1180.	1.12	4233.	31.0	19.31
16.	301.	1227.	1.19	4271.	31.7	19.26
17.	295.	1274.	1.26	4301.	32.5	19.14
18.	291.	1320.	1.32	4346.	33.3	19.00
19.	287.	1365.	1.39	4369.	33.9	18.88
20.	283.	1411.	1.46	4407.	34.6	18.72
21.	279.	1458.	1.54	4422.	35.2	18.62
22.	273.	1499.	1.60	4459.	35.7	18.52
23.	269.	1542.	1.67	4459.	36.3	18.40
24.	265.	1586.	1.74	4497.	36.8	18.29
25.	258.	1640.	1.82	4459.	37.6	18.20
26.	251.	1676.	1.88	4475.	38.0	18.05
27.	246.	1717.	1.95	4452.	38.7	17.93
28.	239.	1753.	2.02	4422.	39.1	17.78
29.	232.	1789.	2.09	4392.	39.5	17.71
30.	226.	1837.	2.16	4324.	39.8	17.59

Table XXX

COMBUSTION PRODUCTS FORMED FROM BP-IC-1
UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL PVC-BP-IC-1
SAMPLE MASS AVG 12.8166
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	1.	4.	0.00	12.	0.1	20.87
2.	98.	4.	0.00	411.	0.3	20.70
3.	189.	4.	0.00	1181.	0.7	20.80
4.	225.	6.	0.00	1509.	1.0	20.66
5.	248.	13.	0.00	1794.	1.4	20.79
6.	260.	19.	0.00	2006.	1.8	20.68
7.	268.	27.	0.00	2245.	2.3	20.66
8.	272.	36.	0.00	2393.	2.8	20.62
9.	271.	45.	0.00	2511.	3.2	20.60
10.	271.	53.	0.00	2562.	3.6	20.55
11.	270.	65.	0.00	2679.	4.1	20.55
12.	268.	72.	0.00	2724.	4.5	20.44
13.	264.	87.	0.00	2801.	5.0	20.39
14.	259.	96.	0.00	2825.	5.4	20.32
15.	254.	102.	0.00	2864.	5.8	20.21
16.	249.	119.	0.00	2885.	6.3	20.29
17.	243.	128.	0.00	2940.	6.7	20.11
18.	238.	137.	0.00	2934.	7.2	20.17
19.	234.	144.	0.00	2965.	7.5	20.20
20.	229.	156.	0.00	2961.	7.9	20.20
21.	224.	161.	0.01	2947.	8.4	20.20
22.	220.	174.	0.01	2944.	8.9	20.19
23.	216.	182.	0.01	2911.	9.5	20.17
24.	211.	191.	0.01	2894.	10.0	20.16
25.	207.	199.	0.02	2872.	10.5	20.15
26.	202.	208.	0.02	2858.	10.9	20.14
27.	198.	215.	0.02	2816.	11.3	20.14
28.	194.	222.	0.03	2801.	11.6	20.13
29.	189.	224.	0.03	2768.	11.9	20.13
30.	185.	232.	0.03	2715.	12.1	20.13

Table XXXI

COMBUSTION PRODUCTS FORMED FROM BP-IC-2 UNDER FLAME EXPOSURE CONDITIONS

MATERIAL PVC-BP-IC-2
SAMPLE MASS AVG 12.5466
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	29.	24.	0.00	136.	4.6	21.00
2.	167.	97.	0.10	567.	9.4	20.84
3.	236.	187.	0.18	1399.	12.6	20.70
4.	268.	266.	0.23	2283.	14.1	20.59
5.	284.	337.	0.27	2954.	15.2	20.51
6.	300.	411.	0.32	3589.	16.2	20.51
7.	316.	481.	0.38	4187.	17.4	20.45
8.	331.	548.	0.43	4611.	18.5	20.24
9.	346.	624.	0.48	4966.	19.6	20.21
10.	363.	699.	0.54	5245.	21.0	20.04
11.	379.	772.	0.60	5502.	22.7	20.00
12.	386.	845.	0.66	5690.	24.5	19.96
13.	383.	916.	0.71	5811.	25.7	19.79
14.	375.	988.	0.78	5902.	27.2	19.79
15.	367.	1054.	0.84	5962.	28.7	19.69
16.	356.	1126.	0.90	6038.	30.2	19.57
17.	350.	1198.	0.96	6098.	31.7	19.43
18.	340.	1261.	1.01	6136.	32.9	19.47
19.	333.	1332.	1.07	6181.	34.3	19.42
20.	325.	1390.	1.12	6219.	35.6	19.34
21.	318.	1453.	1.18	6226.	36.8	19.29
22.	311.	1515.	1.23	6241.	38.0	19.27
23.	304.	1575.	1.29	6279.	39.2	19.21
24.	298.	1634.	1.34	6355.	40.4	19.12
25.	291.	1689.	1.40	6407.	41.3	19.01
26.	285.	1770.	1.45	6453.	42.4	18.87
27.	279.	1819.	1.51	6528.	43.5	18.75
28.	274.	1887.	1.57	6581.	44.5	18.63
29.	268.	1942.	1.62	6641.	45.4	18.53
30.	263.	1993.	1.68	6694.	46.2	18.38

Table XXXII

COMBUSTION PRODUCTS FORMED FROM BP-IC-2 UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL PVC-BP-IC-2
SAMPLE MASS AVG 12.8162
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	6.	2.	0.00	10.	0.2	20.82
2.	32.	2.	0.00	90.	2.1	20.79
3.	58.	5.	0.00	220.	3.4	20.81
4.	150.	7.	0.00	472.	3.3	20.79
5.	193.	9.	0.00	858.	3.2	20.70
6.	209.	10.	0.00	1129.	3.8	20.68
7.	216.	14.	0.01	1392.	6.6	20.70
8.	222.	15.	0.01	1680.	9.8	20.77
9.	224.	19.	0.01	1942.	10.7	20.75
10.	227.	23.	0.01	2180.	10.9	20.79
11.	227.	35.	0.01	2495.	11.1	20.70
12.	227.	38.	0.02	2662.	11.1	20.85
13.	228.	45.	0.02	2782.	11.2	20.81
14.	227.	52.	0.02	2888.	11.2	20.89
15.	225.	60.	0.02	2971.	11.3	20.75
16.	226.	66.	0.02	3024.	11.4	20.74
17.	223.	72.	0.02	3046.	11.6	20.74
18.	220.	82.	0.03	3077.	11.8	20.68
19.	219.	87.	0.03	3092.	11.9	20.71
20.	216.	92.	0.03	3129.	12.3	20.73
21.	214.	100.	0.03	3129.	12.6	20.70
22.	212.	110.	0.03	3122.	12.9	20.65
23.	211.	121.	0.03	3122.	13.2	20.58
24.	209.	131.	0.03	3107.	13.5	20.50
25.	208.	142.	0.03	3099.	13.8	20.44
26.	207.	151.	0.04	3062.	14.1	20.40
27.	206.	159.	0.04	3046.	14.5	20.37
28.	204.	166.	0.04	3009.	14.9	20.36
29.	202.	173.	0.04	2971.	15.3	20.36
30.	201.	180.	0.04	2926.	15.7	20.36

Table XXXIII

COMBUSTION PRODUCTS FORMED FROM FSP-1-IC-1 UNDER FLAME EXPOSURE CONDITIONS

MATERIAL FSP-1-IC-1
SAMPLE MASS AVG 17.5614
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	5.	6.	0.00	79.	1.1	20.80
2.	127.	42.	0.02	592.	3.4	20.64
3.	165.	162.	0.23	1147.	16.0	20.54
4.	185.	265.	0.39	1556.	22.6	20.33
5.	194.	362.	0.50	1969.	26.9	20.18
6.	199.	441.	0.57	2515.	28.8	20.03
7.	197.	538.	0.64	2775.	30.8	19.92
8.	195.	627.	0.71	3045.	32.7	19.80
9.	196.	705.	0.75	3406.	33.0	19.75
10.	198.	778.	0.79	3679.	33.4	19.60
11.	198.	860.	0.82	3919.	33.4	19.56
12.	197.	946.	0.86	4150.	33.7	19.49
13.	197.	1035.	0.90	4369.	33.9	19.47
14.	195.	1128.	0.93	4551.	34.1	19.43
15.	193.	1223.	0.96	4748.	34.3	19.27
16.	190.	1319.	0.99	4944.	34.4	19.29
17.	187.	1409.	1.02	5095.	34.6	19.19
18.	185.	1505.	1.05	5276.	34.9	19.14
19.	183.	1597.	1.08	5502.	35.0	19.08
20.	181.	1688.	1.11	5646.	35.2	19.13
21.	178.	1778.	1.14	5812.	35.4	19.06
22.	176.	1857.	1.17	5970.	35.4	18.97
23.	175.	1941.	1.20	6114.	35.7	18.88
24.	173.	2014.	1.23	6295.	35.7	18.96
25.	171.	2091.	1.26	6431.	36.0	18.86
26.	169.	2162.	1.29	6589.	36.1	18.84
27.	167.	2236.	1.32	6718.	36.3	18.84
28.	165.	2206.	1.35	6838.	36.5	18.69
29.	163.	2286.	1.38	7012.	36.6	18.66
30.	160.	2373.	1.40	7133.	36.6	18.62

Table XXXIV

COMBUSTION PRODUCTS FORMED FROM FSP-1-IC-1 UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-1-IC-1
SAMPLE MASS AVG 16.9847
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	1.	0.	0.00	10.	0.0	20.85
2.	20.	0.	0.01	111.	0.0	20.85
3.	68.	0.	0.01	354.	1.2	20.81
4.	125.	0.	0.02	589.	1.4	20.82
5.	159.	2.	0.03	794.	1.5	20.78
6.	172.	6.	0.04	937.	1.8	20.78
7.	180.	10.	0.05	1140.	2.2	20.89
8.	188.	13.	0.05	1308.	2.6	20.89
9.	193.	17.	0.06	1464.	3.1	20.84
10.	196.	21.	0.07	1616.	3.6	20.81
11.	198.	25.	0.08	1767.	4.3	20.81
12.	201.	30.	0.09	1896.	4.9	20.84
13.	202.	35.	0.09	2105.	5.4	20.85
14.	202.	40.	0.10	2201.	5.9	20.76
15.	203.	46.	0.11	2271.	6.3	20.85
16.	201.	55.	0.11	2345.	6.7	20.71
17.	199.	59.	0.12	2364.	7.1	20.81
18.	197.	66.	0.12	2389.	7.6	20.63
19.	194.	70.	0.13	2446.	8.0	20.61
20.	191.	76.	0.13	2485.	8.4	20.67
21.	189.	83.	0.13	2482.	8.8	20.73
22.	185.	89.	0.14	2499.	9.2	20.65
23.	183.	96.	0.14	2494.	9.7	20.70
24.	181.	105.	0.15	2499.	10.1	20.69
25.	178.	109.	0.15	2482.	10.5	20.66
26.	175.	115.	0.15	2435.	11.0	20.67
27.	173.	122.	0.16	2392.	11.4	20.70
28.	171.	120.	0.16	2367.	11.7	20.69
29.	168.	128.	0.16	2325.	12.2	20.73
30.	167.	134.	0.16	2286.	12.6	20.70

Table XXXV

COMBUSTION PRODUCTS FORMED FROM FSP-1-IC-2 UNDER FLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-1-IC-2
SAMPLE MASS AVG 15.6842
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	23.	13.	0.05	105.	3.0	21.00
2.	234.	85.	0.14	783.	9.2	21.00
3.	319.	173.	0.25	1537.	14.8	20.96
4.	359.	239.	0.36	2149.	20.6	20.75
5.	377.	324.	0.47	2551.	25.2	20.63
6.	377.	437.	0.57	2732.	29.1	20.39
7.	378.	565.	0.67	2915.	32.8	20.27
8.	369.	691.	0.76	3069.	35.8	20.13
9.	355.	788.	0.84	3271.	38.5	19.98
10.	342.	884.	0.94	3372.	41.6	19.80
11.	334.	979.	1.00	3594.	43.4	19.67
12.	322.	1048.	1.05	3840.	44.3	19.58
13.	312.	1109.	1.09	4072.	45.0	19.51
14.	301.	1160.	1.12	4284.	45.8	19.44
15.	291.	1209.	1.16	4533.	46.3	19.46
16.	283.	1256.	1.20	4759.	47.2	19.33
17.	275.	1305.	1.23	4978.	48.0	19.20
18.	270.	1355.	1.27	5159.	48.4	19.13
19.	266.	1406.	1.31	5363.	49.0	19.16
20.	263.	1456.	1.34	5514.	49.4	19.07
21.	263.	1511.	1.38	5673.	49.8	19.02
22.	262.	1567.	1.42	5831.	50.3	18.88
23.	262.	1629.	1.47	6027.	50.9	18.87
24.	260.	1688.	1.50	6231.	51.1	18.77
25.	260.	1750.	1.55	6435.	51.8	18.78
26.	258.	1809.	1.59	6661.	52.3	18.47
27.	257.	1869.	1.63	6910.	52.4	18.37
28.	254.	1928.	1.68	7129.	53.1	18.21
29.	253.	1983.	1.72	7378.	53.2	18.25
30.	249.	2040.	1.77	7612.	53.6	18.12

Table XXXVI

COMBUSTION PRODUCTS FORMED FROM FSP-1-IC-2
UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-1-IC-2
SAMPLE MASS AVG 17.5677
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	1.	0.	0.00	11.	0.1	20.69
2.	20.	0.	0.00	131.	0.4	20.74
3.	89.	0.	0.02	544.	2.3	20.70
4.	177.	0.	0.03	932.	2.5	20.77
5.	230.	2.	0.04	1143.	2.6	20.65
6.	256.	7.	0.05	1393.	2.9	20.55
7.	266.	13.	0.06	1658.	3.3	20.66
8.	268.	21.	0.07	1951.	3.7	20.76
9.	269.	28.	0.09	2283.	4.3	20.72
10.	268.	35.	0.10	2519.	5.0	20.67
11.	268.	43.	0.11	2702.	5.9	20.62
12.	267.	50.	0.13	2865.	6.5	20.58
13.	269.	57.	0.14	2974.	7.1	20.55
14.	274.	66.	0.15	3120.	7.7	20.44
15.	273.	75.	0.15	3153.	8.2	20.39
16.	274.	86.	0.16	3202.	8.7	20.42
17.	272.	96.	0.16	3179.	9.2	20.42
18.	271.	106.	0.17	3233.	9.8	20.47
19.	269.	116.	0.17	3227.	10.3	20.50
20.	265.	126.	0.18	3224.	10.9	20.50
21.	264.	135.	0.18	3208.	11.4	20.47
22.	263.	144.	0.19	3220.	11.9	20.46
23.	261.	153.	0.19	3178.	12.4	20.43
24.	257.	161.	0.20	3114.	12.9	20.53
25.	256.	170.	0.20	3105.	13.4	20.54
26.	253.	179.	0.20	3003.	13.9	20.53
27.	250.	187.	0.21	2980.	14.5	20.46
28.	249.	195.	0.21	2929.	14.9	20.53
29.	247.	203.	0.22	2913.	15.4	20.53
30.	245.	210.	0.22	2898.	15.9	20.58

Table XXXVII

COMBUSTION PRODUCTS FORMED FROM FSP-2-IC-1 UNDER FLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-2-IC-1
SAMPLE MASS AVG 13.2391
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	53.	36.	0.05	244.	3.7	20.99
2.	130.	126.	0.19	1377.	8.6	20.81
3.	187.	249.	0.36	2539.	14.8	20.67
4.	221.	328.	0.49	3206.	17.1	20.52
5.	239.	379.	0.58	3518.	18.4	20.40
6.	247.	438.	0.68	3755.	19.2	20.26
7.	242.	522.	0.77	3921.	20.1	20.08
8.	230.	601.	0.84	4069.	20.8	20.00
9.	217.	678.	0.93	4149.	21.4	19.85
10.	204.	754.	1.00	4198.	22.2	19.70
11.	192.	825.	1.07	4266.	23.3	19.59
12.	184.	893.	1.14	4333.	24.1	19.41
13.	176.	955.	1.20	4386.	24.7	19.41
14.	168.	1019.	1.28	4416.	25.2	19.25
15.	161.	1081.	1.35	4439.	25.8	19.11
16.	154.	1141.	1.43	4416.	26.5	19.00
17.	149.	1190.	1.49	4447.	26.9	19.03
18.	145.	1228.	1.55	4462.	27.2	18.82
19.	141.	1264.	1.61	4484.	27.7	18.67
20.	137.	1297.	1.67	4537.	27.9	18.63
21.	135.	1331.	1.73	4605.	28.3	18.60
22.	132.	1363.	1.78	4658.	28.7	18.47
23.	128.	1395.	1.84	4718.	29.1	18.41
24.	125.	1425.	1.90	4779.	29.2	18.34
25.	122.	1455.	1.97	4764.	29.7	18.16
26.	119.	1483.	2.03	4804.	30.0	18.08
27.	116.	1513.	2.10	4845.	30.3	17.97
28.	113.	1544.	2.17	4886.	30.7	17.87
29.	111.	1575.	2.24	4928.	31.0	17.76
30.	108.	1608.	2.32	4970.	31.4	17.65

Table XXXVIII

COMBUSTION PRODUCTS FORMED FROM FSP-2-IC-1
UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-2-IC-1
SAMPLE MASS AVG 15.4281
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	1.	0.	0.01	0.	0.0	20.84
2.	44.	0.	0.01	210.	0.1	20.82
3.	84.	0.	0.02	662.	0.4	20.84
4.	109.	0.	0.04	1077.	0.6	20.73
5.	131.	2.	0.05	1528.	1.1	20.63
6.	147.	7.	0.06	2059.	1.5	20.67
7.	160.	13.	0.08	2633.	1.9	20.70
8.	168.	20.	0.09	2888.	2.3	20.71
9.	174.	28.	0.10	3053.	2.6	20.63
10.	179.	36.	0.11	3155.	2.9	20.51
11.	181.	45.	0.12	3204.	3.2	20.35
12.	182.	55.	0.12	3237.	3.5	20.37
13.	179.	64.	0.12	3279.	3.9	20.52
14.	176.	76.	0.13	3290.	4.2	20.58
15.	174.	87.	0.13	3315.	4.5	20.52
16.	170.	98.	0.14	3335.	4.9	20.54
17.	165.	109.	0.14	3342.	5.2	20.51
18.	161.	120.	0.15	3339.	5.6	20.47
19.	157.	131.	0.15	3344.	5.9	20.52
20.	153.	141.	0.16	3320.	6.2	20.52
21.	148.	152.	0.16	3305.	6.5	20.55
22.	145.	162.	0.16	3285.	6.8	20.51
23.	141.	172.	0.17	3282.	7.1	20.52
24.	138.	182.	0.17	3249.	7.4	20.50
25.	136.	192.	0.18	3226.	7.7	20.40
26.	133.	202.	0.18	3172.	8.0	20.43
27.	130.	212.	0.19	3072.	8.3	20.29
28.	128.	214.	0.19	3038.	8.6	20.33
29.	125.	225.	0.20	2997.	8.8	20.25
30.	123.	236.	0.20	2982.	9.1	20.29

Table XXXIX

COMBUSTION PRODUCTS FORMED FROM FSP-2-IC-2 UNDER FLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-2-IC-2
SAMPLE MASS AVG 16.9573
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	11.	6.	0.02	189.	1.3	21.00
2.	77.	43.	0.06	543.	4.4	20.95
3.	169.	97.	0.14	1006.	8.7	20.92
4.	335.	139.	0.24	1663.	13.8	20.86
5.	381.	185.	0.34	2393.	17.1	20.77
6.	394.	240.	0.42	2800.	19.8	20.59
7.	398.	302.	0.50	3238.	22.7	20.58
8.	407.	384.	0.59	3472.	25.5	20.40
9.	416.	482.	0.69	3653.	29.6	20.09
10.	410.	586.	0.78	3736.	33.2	20.08
11.	398.	657.	0.86	3781.	36.2	19.86
12.	383.	720.	0.93	3857.	38.7	19.81
13.	373.	780.	0.99	3947.	40.8	19.70
14.	365.	856.	1.03	4091.	42.0	19.51
15.	356.	934.	1.08	4189.	43.6	19.41
16.	347.	1016.	1.12	4287.	44.6	19.44
17.	338.	1096.	1.17	4347.	45.8	19.21
18.	330.	1172.	1.21	4430.	47.1	19.18
19.	323.	1243.	1.26	4498.	48.5	19.17
20.	317.	1315.	1.31	4544.	49.8	19.05
21.	313.	1381.	1.35	4611.	50.7	19.05
22.	309.	1444.	1.40	4657.	51.9	19.02
23.	303.	1510.	1.45	4710.	53.4	18.88
24.	299.	1576.	1.50	4747.	53.9	18.83
25.	294.	1640.	1.55	4808.	55.2	18.86
26.	289.	1704.	1.60	4891.	56.3	18.73
27.	286.	1768.	1.64	4928.	57.3	18.65
28.	282.	1832.	1.68	4921.	57.9	18.57
29.	277.	1893.	1.73	4966.	59.0	18.34
30.	273.	1958.	1.78	4951.	59.7	18.29

Table XL

COMBUSTION PRODUCTS FORMED FROM FSP-2-IC-2 UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL PVC-FSP-2-IC-2
SAMPLE MASS AVG 16.0654
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 0.0625 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	4.	0.	0.00	12.	0.1	20.78
2.	30.	0.	0.01	131.	0.7	20.82
3.	54.	0.	0.02	329.	2.8	20.94
4.	94.	0.	0.02	567.	3.5	20.88
5.	153.	0.	0.04	863.	3.6	20.75
6.	223.	2.	0.05	1108.	3.5	20.81
7.	247.	9.	0.06	1399.	3.7	20.89
8.	260.	17.	0.07	1678.	4.1	20.83
9.	267.	25.	0.08	1887.	4.5	20.85
10.	269.	32.	0.09	2103.	5.0	20.86
11.	267.	38.	0.10	2390.	5.7	20.83
12.	267.	46.	0.11	2569.	6.2	20.92
13.	266.	53.	0.12	2759.	6.8	20.82
14.	263.	62.	0.14	2927.	7.4	20.88
15.	261.	71.	0.15	3049.	8.0	20.70
16.	257.	79.	0.15	3144.	8.5	20.68
17.	252.	88.	0.16	3206.	9.0	20.70
18.	249.	98.	0.16	3271.	9.5	20.72
19.	247.	107.	0.17	3328.	10.1	20.64
20.	244.	115.	0.18	3350.	10.6	20.63
21.	241.	125.	0.18	3378.	11.2	20.63
22.	238.	133.	0.19	3363.	11.7	20.62
23.	235.	142.	0.19	3354.	12.2	20.59
24.	233.	150.	0.20	3315.	12.7	20.57
25.	230.	159.	0.20	3251.	13.3	20.55
26.	228.	167.	0.20	3205.	13.7	20.53
27.	225.	176.	0.21	3179.	14.2	20.52
28.	224.	184.	0.21	3135.	14.7	20.52
29.	221.	191.	0.21	3147.	15.3	20.52
30.	219.	199.	0.22	3097.	15.8	20.52

Table XLI

COMBUSTION PRODUCTS FORMED FROM Al-IC-1 UNDER FLAME EXPOSURE CONDITIONS

MATERIAL AL-IC-1
SAMPLE MASS AVG 9.1019
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	2.	5.	0.03	10.	1.2	20.99
2.	12.	34.	0.08	35.	4.1	20.95
3.	20.	55.	0.12	48.	7.1	20.82
4.	27.	73.	0.18	55.	9.4	20.73
5.	33.	91.	0.23	66.	11.3	20.70
6.	39.	111.	0.29	124.	12.7	20.59
7.	45.	126.	0.33	197.	13.8	20.49
8.	50.	145.	0.38	284.	14.7	20.55
9.	55.	162.	0.41	413.	15.1	20.44
10.	59.	183.	0.44	536.	15.6	20.37
11.	63.	208.	0.47	667.	15.9	20.38
12.	67.	233.	0.50	804.	16.3	20.23
13.	71.	262.	0.54	923.	16.7	20.33
14.	74.	292.	0.57	1049.	17.0	20.22
15.	77.	321.	0.60	1181.	17.4	20.08
16.	79.	358.	0.63	1308.	17.5	20.17
17.	81.	393.	0.66	1433.	17.8	20.08
18.	84.	433.	0.69	1565.	18.1	20.06
19.	85.	489.	0.72	1663.	18.3	19.95
20.	87.	554.	0.75	1766.	18.6	19.87
21.	89.	638.	0.78	1849.	18.8	19.88
22.	91.	730.	0.81	1931.	19.2	19.88
23.	92.	819.	0.84	2007.	19.3	19.78
24.	94.	908.	0.87	2079.	19.7	19.70
25.	95.	1004.	0.90	2234.	19.9	19.56
26.	96.	1105.	0.94	2302.	20.1	19.54
27.	97.	1200.	0.96	2368.	20.4	19.51
28.	98.	1278.	0.99	2446.	20.7	19.37
29.	99.	1356.	1.02	2477.	20.9	19.51
30.	100.	1405.	1.05	2634.	21.2	19.44

Table XLII

COMBUSTION PRODUCTS FORMED FROM A1-IC-1 UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL AL-IC-1
SAMPLE MASS AVG 9.1910
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	0.	0.	0.00	0.	0.0	21.00
2.	6.	0.	0.00	0.	0.0	20.87
3.	18.	0.	0.01	9.	0.1	20.92
4.	26.	0.	0.01	18.	0.4	20.94
5.	30.	0.	0.01	22.	0.7	20.82
6.	34.	0.	0.01	26.	1.1	20.80
7.	38.	0.	0.01	30.	1.5	20.85
8.	42.	0.	0.01	34.	1.7	20.85
9.	45.	0.	0.01	36.	2.0	20.86
10.	48.	1.	0.02	39.	2.2	20.92
11.	51.	2.	0.02	40.	2.4	20.94
12.	54.	3.	0.02	42.	2.6	20.93
13.	56.	4.	0.02	43.	2.8	20.92
14.	58.	5.	0.02	41.	3.0	20.98
15.	60.	6.	0.02	46.	3.1	20.93
16.	62.	7.	0.02	49.	3.3	20.80
17.	64.	9.	0.02	51.	3.5	20.86
18.	66.	10.	0.02	53.	3.7	20.94
19.	67.	11.	0.02	54.	3.9	20.87
20.	68.	12.	0.02	55.	4.0	20.98
21.	70.	14.	0.03	56.	4.3	21.00
22.	71.	15.	0.03	56.	4.5	21.00
23.	72.	16.	0.03	57.	4.6	21.00
24.	73.	18.	0.03	59.	4.8	20.93
25.	74.	19.	0.03	60.	5.0	20.86
26.	74.	20.	0.03	60.	5.2	20.81
27.	74.	22.	0.03	61.	5.4	20.80
28.	75.	22.	0.03	62.	5.6	20.80
29.	75.	24.	0.03	62.	5.8	20.82
30.	76.	25.	0.03	62.	6.0	20.84

Table XLIII

COMBUSTION PRODUCTS FORMED FROM A1-IC-2 UNDER FLAME EXPOSURE CONDITIONS

MATERIAL AL-IC-2
SAMPLE MASS AVG 8.4956
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	21.	6.	0.03	31.	1.8	20.80
2.	91.	46.	0.08	154.	7.6	20.77
3.	132.	69.	0.12	261.	10.7	20.62
4.	162.	86.	0.18	355.	13.1	20.47
5.	177.	103.	0.22	429.	15.0	20.51
6.	185.	121.	0.27	496.	17.1	20.55
7.	188.	138.	0.31	551.	18.8	20.40
8.	187.	155.	0.36	595.	20.5	20.31
9.	185.	172.	0.40	631.	22.3	20.38
10.	181.	187.	0.45	661.	24.1	20.23
11.	177.	203.	0.49	681.	25.4	20.31
12.	172.	212.	0.53	705.	27.6	20.27
13.	167.	229.	0.58	723.	28.9	20.09
14.	163.	247.	0.62	740.	30.4	20.04
15.	158.	263.	0.66	761.	31.7	20.00
16.	154.	280.	0.70	768.	33.2	19.90
17.	150.	297.	0.74	779.	34.3	19.81
18.	146.	315.	0.78	786.	35.5	19.65
19.	143.	333.	0.82	795.	36.9	19.54
20.	140.	351.	0.86	805.	38.0	19.62
21.	138.	370.	0.90	814.	38.8	19.71
22.	135.	389.	0.95	819.	40.1	19.65
23.	133.	407.	0.98	825.	41.1	19.71
24.	130.	425.	1.02	827.	41.9	19.67
25.	129.	441.	1.06	828.	42.8	19.56
26.	126.	458.	1.09	827.	43.6	19.40
27.	125.	473.	1.13	826.	44.2	19.35
28.	123.	488.	1.16	822.	45.1	19.25
29.	121.	503.	1.20	820.	45.7	19.18
30.	119.	518.	1.24	817.	46.4	19.11

Table XLIV

COMBUSTION PRODUCTS FORMED FROM Al-IC-2 UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL AL-IC-2
SAMPLE MASS AVG 8.4462
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	0.	0.	0.00	0.	0.0	20.78
2.	10.	0.	0.00	16.	0.4	20.69
3.	30.	0.	0.01	113.	2.6	20.75
4.	41.	1.	0.01	176.	3.8	20.73
5.	51.	3.	0.01	218.	4.4	20.60
6.	60.	3.	0.01	251.	4.9	20.62
7.	68.	4.	0.01	272.	5.3	20.69
8.	75.	5.	0.02	288.	5.6	20.65
9.	80.	5.	0.02	302.	5.9	20.67
10.	84.	6.	0.02	313.	6.1	20.56
11.	88.	7.	0.02	325.	6.3	20.33
12.	90.	8.	0.02	330.	6.5	20.45
13.	93.	9.	0.03	339.	6.7	20.40
14.	94.	10.	0.03	346.	6.9	20.43
15.	96.	10.	0.03	351.	7.1	20.40
16.	96.	10.	0.03	355.	7.3	20.45
17.	97.	11.	0.03	359.	7.4	20.47
18.	97.	11.	0.03	360.	7.6	20.33
19.	97.	12.	0.03	361.	7.8	20.37
20.	97.	13.	0.03	363.	7.9	20.32
21.	97.	14.	0.03	363.	8.1	20.32
22.	96.	15.	0.03	362.	8.3	20.17
23.	96.	15.	0.03	361.	8.5	20.02
24.	95.	15.	0.03	364.	8.6	20.16
25.	94.	16.	0.03	359.	8.8	20.20
26.	93.	17.	0.03	360.	8.9	20.16
27.	93.	18.	0.03	357.	9.1	20.03
28.	92.	18.	0.03	355.	9.2	20.24
29.	92.	19.	0.03	351.	9.4	20.29
30.	90.	20.	0.04	348.	9.5	20.29

Table XLV

SAMPLE MASS DATA FOR NEOPRENE COMPOSITIONS

Material	Sample Mass (g)[a]		Consumed Mass (g)[b]	
	Flame Exposure	Nonflame Exposure	Flame Exposure	Nonflame Exposure
BF	17.67	18.14	12.73	11.22
	17.77	18.15	13.22	13.19
FSF-1	14.89	15.82		
	15.94	14.83		
FSF-2	15.47	14.92	11.61	9.99
	15.60	16.74	12.07	10.41
FSF-3	16.08	14.77	10.66	10.31
	14.12	14.71	9.79	9.72

[a] The dimensions of foam specimens were 3 in. x 3 in. x 1 in. (7.6 cm x 7.6 cm x 2.5 cm).

[b] The chars formed from some specimens could not be recovered completely. Therefore, the data in the consumed mass column are incomplete.

Table XLVI

COMBUSTION PRODUCTS FORMED FROM BF UNDER FLAME EXPOSURE CONDITIONS

MATERIAL BF
SAMPLE MASS AVG 17.7082
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X ½ IN.

AVERAGE

TIME (MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	115.	19.	0.03	150.	0.7	20.56
2.	274.	91.	0.08	515.	2.3	20.54
3.	399.	187.	0.14	874.	4.0	20.42
4.	478.	280.	0.21	1279.	5.6	20.37
5.	522.	386.	0.27	1773.	7.0	20.33
6.	548.	523.	0.33	2229.	8.5	20.21
7.	559.	653.	0.39	2646.	9.7	20.17
8.	560.	800.	0.45	3053.	10.6	20.08
9.	561.	939.	0.51	3413.	11.4	20.04
10.	556.	1052.	0.56	3712.	12.2	19.87
11.	553.	1163.	0.62	3985.	13.0	19.80
12.	554.	1268.	0.68	4201.	14.0	19.66
13.	550.	1378.	0.75	4412.	14.8	19.51
14.	546.	1481.	0.81	4627.	15.6	19.52
15.	544.	1585.	0.88	4828.	16.3	19.50
16.	540.	1683.	0.95	5017.	16.9	19.47
17.	533.	1772.	1.02	5183.	17.6	19.34
18.	527.	1860.	1.08	5341.	18.2	19.18
19.	520.	1942.	1.15	5489.	18.8	19.12
20.	512.	2021.	1.21	5625.	19.4	18.90
21.	502.	2097.	1.28	5764.	20.0	18.87
22.	492.	2167.	1.35	5904.	20.8	18.85
23.	480.	2237.	1.42	6002.	21.3	18.76
24.	468.	2307.	1.48	6116.	21.8	18.66
25.	456.	2371.	1.55	6214.	22.3	18.46
26.	442.	2400.	1.62	6297.	22.8	18.35
27.	431.	2454.	1.69	6376.	23.3	18.26
28.	418.	2505.	1.76	6437.	23.8	18.17
29.	407.	2555.	1.83	6505.	24.2	18.06
30.	395.	2593.	1.89	6565.	24.6	17.94

Table XLVII

COMBUSTION PRODUCTS FORMED FROM BF UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL BF
SAMPLE MASS AVG 18.1455
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 1 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO_2(%)	HC(PPMV)	NOX(PPMV)	O_2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	36.	0.	0.00	56.	0.1	20.79
2.	169.	11.	0.01	497.	0.4	20.78
3.	271.	38.	0.03	662.	0.4	20.69
4.	338.	83.	0.05	1243.	0.5	20.68
5.	402.	139.	0.07	1590.	0.7	20.67
6.	445.	196.	0.10	1939.	0.9	20.65
7.	471.	257.	0.13	2312.	1.1	20.56
8.	485.	329.	0.16	2532.	1.3	20.41
9.	493.	410.	0.19	2698.	1.6	20.40
10.	493.	493.	0.22	2811.	1.8	20.45
11.	492.	592.	0.26	2891.	2.0	20.37
12.	491.	684.	0.29	2974.	2.2	20.35
13.	489.	783.	0.32	3038.	2.4	20.30
14.	486.	874.	0.36	3072.	2.6	20.26
15.	482.	965.	0.39	3108.	2.7	20.25
16.	477.	1057.	0.43	3121.	2.9	20.19
17.	473.	1145.	0.47	3165.	3.1	20.13
18.	471.	1233.	0.50	3174.	3.3	20.12
19.	465.	1324.	0.54	3219.	3.4	20.09
20.	463.	1409.	0.58	3234.	3.6	20.01
21.	455.	1498.	0.62	3274.	3.8	19.95
22.	450.	1581.	0.66	3285.	4.0	19.94
23.	443.	1666.	0.70	3301.	4.1	19.89
24.	434.	1742.	0.74	3320.	4.3	19.86
25.	427.	1818.	0.78	3314.	4.5	19.86
26.	419.	1890.	0.83	3316.	4.7	19.82
27.	409.	1957.	0.87	3310.	4.9	19.80
28.	400.	2023.	0.92	3316.	5.0	19.71
29.	390.	2081.	0.96	3323.	5.2	19.63
30.	381.	2138.	1.00	3332.	5.4	19.49

Table XLVIII

COMBUSTION PRODUCTS FORMED FROM FSF-1 UNDER FLAME EXPOSURE CONDITIONS

```
MATERIAL FSF-1
SAMPLE MASS AVG 15.4184
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 1 IN.

AVERAGE
-------

TIME(MIN)      DS      CO(PPMV)    CO2(%)     HC(PPMV)   NOX(PPMV)       O2(%)

    0.         0.          0.       0.00          0.         0.0        21.00
    1.       117.         38.       0.07        284.         1.4        20.80
    2.       253.        145.       0.14        761.         2.8        20.75
    3.       347.        250.       0.22       1157.         4.2        20.67
    4.       403.        366.       0.31       1525.         5.5        20.52
    5.       438.        499.       0.39       2010.         6.6        20.35
    6.       459.        649.       0.47       2374.         7.6        20.15
    7.       464.        819.       0.55       2695.         8.5        20.11
    8.       470.        951.       0.63       2899.         9.4        20.10
    9.       483.       1074.       0.71       3095.        10.2        19.96
   10.       495.       1187.       0.80       3299.        11.2        19.78
   11.       500.       1298.       0.88       3476.        12.0        19.60
   12.       501.       1402.       0.97       3628.        12.8        19.38
   13.       494.       1505.       1.05       3715.        13.6        19.45
   14.       485.       1602.       1.14       3796.        14.3        19.26
   15.       473.       1694.       1.22       3823.        14.9        19.13
   16.       459.       1778.       1.30       3854.        15.6        18.99
   17.       444.       1857.       1.39       3857.        16.2        18.86
   18.       429.       1935.       1.47       3857.        16.8        18.77
   19.       411.       2008.       1.56       3850.        17.4        18.64
   20.       397.       2078.       1.65       3835.        18.2        18.53
   21.       383.       2146.       1.73       3823.        18.8        18.41
   22.       368.       2208.       1.81       3816.        19.2        18.33
   23.       353.       2270.       1.90       3797.        19.8        18.13
   24.       341.       2331.       1.97       3782.        20.2        18.04
   25.       329.       2387.       2.06       3774.        20.7        17.94
   26.       317.       2441.       2.13       3752.        21.2        17.80
   27.       308.       2495.       2.22       3733.        21.7        17.64
   28.       297.       2553.       2.29       3718.        22.0        17.50
   29.       288.       2613.       2.36       3691.        22.4        17.40
   30.       280.       2674.       2.43       3687.        22.9        17.40
```

Table XLIX

COMBUSTION PRODUCTS FORMED FROM FSF-1 UNDER NONFLAME EXPOSURE CONDITIONS

```
MATERIAL FSF-1
SAMPLE MASS AVG 15.3274
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 1 IN.

AVERAGE
-------

TIME(MIN)        DS        CO(PPMV)     CO2(%)       HC(PPMV)    NOX(PPMV)        O2(%)

     0.           0.             0.       0.00             0.        0.0          21.00
     1.          76.             1.       0.01           238.        0.1          20.92
     2.         190.            31.       0.02           706.        0.3          20.90
     3.         283.           109.       0.06          1217.        0.5          20.85
     4.         350.           197.       0.11          1671.        0.8          20.64
     5.         393.           284.       0.17          2168.        1.1          20.52
     6.         429.           384.       0.21          2570.        1.3          20.44
     7.         452.           498.       0.26          2807.        1.6          20.42
     8.         471.           619.       0.31          3030.        1.8          20.34
     9.         487.           748.       0.37          3219.        2.0          20.27
    10.         499.           905.       0.42          3373.        2.2          20.13
    11.         504.          1037.       0.47          3485.        2.4          20.15
    12.         506.          1177.       0.53          3606.        2.6          20.08
    13.         501.          1307.       0.59          3665.        2.8          19.90
    14.         493.          1438.       0.65          3721.        2.9          19.85
    15.         480.          1560.       0.71          3752.        3.0          19.90
    16.         466.          1668.       0.77          3780.        3.2          19.89
    17.         449.          1767.       0.84          3762.        3.3          19.80
    18.         432.          1860.       0.89          3761.        3.4          19.79
    19.         416.          1950.       0.97          3754.        3.5          19.74
    20.         401.          2034.       1.02          3743.        3.7          19.76
    21.         388.          2119.       1.08          3718.        3.9          19.68
    22.         378.          2200.       1.14          3688.        4.0          19.63
    23.         369.          2282.       1.20          3659.        4.2          19.58
    24.         361.          2360.       1.26          3647.        4.3          19.47
    25.         354.          2418.       1.31          3611.        4.5          19.41
    26.         348.          2515.       1.37          3576.        4.6          19.32
    27.         341.          2599.       1.43          3549.        4.8          19.26
    28.         334.          2681.       1.49          3502.        4.9          19.19
    29.         326.          2763.       1.54          3456.        5.1          19.09
    30.         318.          2857.       1.61          3433.        5.3          18.98
```

Table L

COMBUSTION PRODUCTS FORMED FROM FSF-2
UNDER FLAME EXPOSURE CONDITIONS

MATERIAL FSF-2
SAMPLE MASS AVG 15.5350
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 1 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	109.	27.	0.04	173.	1.7	20.70
2.	272.	104.	0.09	455.	4.0	20.61
3.	383.	186.	0.16	706.	5.8	20.57
4.	451.	269.	0.23	963.	7.5	20.47
5.	494.	363.	0.29	1217.	9.1	20.40
6.	519.	461.	0.36	1473.	10.4	20.56
7.	526.	577.	0.43	1724.	11.5	20.47
8.	529.	680.	0.49	1905.	12.4	20.36
9.	520.	800.	0.56	2106.	13.5	20.25
10.	526.	902.	0.63	2240.	14.4	20.23
11.	529.	1006.	0.70	2350.	15.4	20.17
12.	532.	1104.	0.77	2428.	16.3	20.08
13.	529.	1206.	0.84	2499.	17.1	19.85
14.	522.	1299.	0.92	2591.	18.0	19.84
15.	513.	1391.	0.99	2630.	18.7	19.83
16.	503.	1477.	1.06	2693.	19.5	19.69
17.	494.	1560.	1.13	2736.	20.3	19.60
18.	486.	1639.	1.20	2754.	20.9	19.56
19.	478.	1713.	1.26	2777.	21.7	19.45
20.	467.	1786.	1.34	2783.	23.4	19.36
21.	459.	1853.	1.41	2804.	24.8	19.26
22.	449.	1916.	1.48	2819.	26.1	19.17
23.	440.	1977.	1.55	2813.	27.0	19.11
24.	431.	2034.	1.62	2832.	27.8	19.04
25.	422.	2089.	1.69	2846.	28.5	18.96
26.	413.	2140.	1.76	2850.	29.1	18.86
27.	404.	2189.	1.83	2840.	29.8	18.80
28.	394.	2237.	1.90	2854.	27.5	18.76
29.	384.	2283.	1.96	2850.	28.0	18.72
30.	375.	2325.	2.03	2857.	28.6	18.57

Table LI

COMBUSTION PRODUCTS FORMED FROM FSF-2 UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL FSF-2
SAMPLE MASS AVG 15.8328
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 1 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	49.	0.	0.01	62.	0.6	20.86
2.	164.	16.	0.01	320.	1.7	20.77
3.	256.	54.	0.03	557.	2.2	20.64
4.	322.	107.	0.05	825.	2.6	20.68
5.	378.	169.	0.08	1097.	2.8	20.66
6.	414.	235.	0.11	1341.	3.0	20.54
7.	436.	302.	0.15	1579.	3.2	20.53
8.	454.	381.	0.18	1779.	3.4	20.49
9.	470.	468.	0.22	1916.	3.6	20.38
10.	479.	555.	0.25	2040.	3.8	20.28
11.	484.	654.	0.29	2181.	4.0	20.11
12.	483.	753.	0.33	2244.	4.2	20.10
13.	480.	877.	0.37	2339.	4.5	20.11
14.	477.	977.	0.41	2403.	4.7	19.97
15.	472.	1079.	0.45	2458.	5.1	19.89
16.	470.	1183.	0.50	2525.	5.4	19.87
17.	464.	1286.	0.54	2568.	5.6	19.84
18.	458.	1385.	0.59	2593.	5.9	19.85
19.	449.	1486.	0.65	2610.	6.1	19.71
20.	439.	1578.	0.69	2651.	6.4	19.57
21.	430.	1667.	0.75	2658.	6.6	19.50
22.	421.	1749.	0.80	2665.	6.9	19.50
23.	411.	1825.	0.85	2670.	7.1	19.48
24.	401.	1893.	0.90	2667.	7.4	19.43
25.	392.	1957.	0.94	2672.	7.6	19.35
26.	383.	2018.	0.99	2669.	7.9	19.29
27.	373.	2068.	1.03	2653.	8.0	19.26
28.	364.	2119.	1.07	2650.	8.3	19.28
29.	355.	2163.	1.11	2626.	8.5	19.28
30.	346.	2203.	1.15	2630.	8.7	19.25

Table LII

COMBUSTION PRODUCTS FORMED FROM FSF-3
UNDER FLAME EXPOSURE CONDITIONS

MATERIAL FSF-3
SAMPLE MASS AVG 15.1045
IMPOSED EXPOSURE CONDITION FLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 1 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	97.	13.	0.03	147.	1.7	20.81
2.	239.	83.	0.08	495.	3.9	20.63
3.	344.	167.	0.15	826.	5.3	20.56
4.	415.	251.	0.22	1207.	6.9	20.50
5.	461.	357.	0.30	1527.	8.5	20.39
6.	481.	471.	0.37	1778.	9.8	20.28
7.	490.	603.	0.45	2062.	11.0	20.16
8.	492.	727.	0.52	2247.	12.1	20.05
9.	497.	832.	0.60	2431.	13.2	19.98
10.	505.	935.	0.68	2584.	14.3	19.93
11.	508.	1035.	0.76	2737.	15.4	19.77
12.	509.	1128.	0.83	2869.	16.3	19.61
13.	510.	1222.	0.91	2989.	17.3	19.50
14.	507.	1311.	0.99	3103.	18.6	19.37
15.	504.	1397.	1.07	3195.	19.5	19.33
16.	497.	1481.	1.14	3259.	20.3	19.21
17.	492.	1562.	1.22	3345.	21.2	19.13
18.	461.	1636.	1.29	3398.	21.9	18.99
19.	471.	1710.	1.37	3443.	22.7	18.85
20.	459.	1780.	1.44	3493.	23.4	18.82
21.	448.	1844.	1.52	3542.	24.5	18.77
22.	435.	1907.	1.59	3577.	25.2	18.56
23.	424.	1964.	1.67	3601.	25.9	18.47
24.	412.	2017.	1.75	3631.	26.5	18.37
25.	402.	2072.	1.82	3672.	27.3	18.24
26.	391.	2121.	1.89	3680.	27.9	18.17
27.	381.	2166.	1.96	3713.	28.5	18.06
28.	371.	2208.	2.03	3731.	29.1	17.95
29.	363.	2249.	2.09	3755.	29.7	17.88
30.	353.	2289.	2.16	3773.	30.3	17.75

Table LIII

COMBUSTION PRODUCTS FORMED FROM FSF-3 UNDER NONFLAME EXPOSURE CONDITIONS

MATERIAL FSF-3
SAMPLE MASS AVG 14.7400
IMPOSED EXPOSURE CONDITION NONFLAMING
FLUX 16.4 W/SQ. IN. (2.5 W/CM2), VERTICAL
DIMENSIONS 3 IN. X 3 IN. X 1 IN.

AVERAGE

TIME(MIN)	DS	CO(PPMV)	CO2(%)	HC(PPMV)	NOX(PPMV)	O2(%)
0.	0.	0.	0.00	0.	0.0	21.00
1.	47.	1.	0.01	96.	0.3	20.74
2.	146.	12.	0.02	381.	1.1	20.69
3.	238.	59.	0.05	668.	1.5	20.71
4.	319.	125.	0.09	958.	1.8	20.64
5.	373.	196.	0.13	1253.	2.1	20.54
6.	417.	268.	0.18	1542.	2.3	20.49
7.	448.	354.	0.23	1770.	2.7	20.36
8.	478.	451.	0.28	1966.	3.0	20.34
9.	506.	551.	0.33	2168.	3.3	20.27
10.	522.	677.	0.38	2302.	3.7	20.27
11.	528.	806.	0.44	2425.	4.1	20.23
12.	531.	920.	0.50	2505.	4.6	20.16
13.	524.	1033.	0.55	2619.	5.1	20.23
14.	515.	1142.	0.61	2625.	5.6	20.07
15.	506.	1247.	0.67	2667.	6.0	20.05
16.	487.	1345.	0.72	2697.	6.3	20.03
17.	476.	1437.	0.78	2701.	6.7	19.93
18.	464.	1522.	0.83	2718.	7.0	19.87
19.	453.	1598.	0.88	2712.	7.4	19.81
20.	443.	1663.	0.94	2718.	7.7	19.82
21.	433.	1735.	1.00	2706.	7.9	19.79
22.	424.	1790.	1.04	2718.	8.2	19.64
23.	415.	1850.	1.09	2693.	8.4	19.58
24.	406.	1897.	1.13	2703.	8.7	19.57
25.	398.	1944.	1.17	2670.	8.9	19.45
26.	391.	1993.	1.21	2669.	9.2	19.41
27.	382.	2028.	1.25	2643.	9.4	19.38
28.	373.	2069.	1.29	2642.	9.6	19.31
29.	365.	2107.	1.33	2631.	9.8	19.36
30.	359.	2131.	1.37	2622.	10.1	19.24

DISTRIBUTION LIST

	No. of Copies
Naval Ship Engineering Center, Code N65197 National Center, Building No. 2 Room 5E52 Washington, D. C. 20362	2
Naval Sea Systems Command, Code N00024 Department of the Navy Washington, DC 20360 Attn: NAVSEA 03511	2
Naval Surface Weapons Center, Code N60921 Silver Spring, Maryland 20910 Attn: Dr. Angel	1
Naval Research Laboratory, Code N00173 Washington, DC 20390 Attn: Chemistry Div. Code 6100	1
Naval Research Laboratory, Code N00173 Washington, DC 20390 Attn: Non-metallics Div.	1
Naval Ship Research and Development Center, Code N00162 Bethesda, Maryland Attn: Non-metallics Code 284	1
Office of Naval Research, Code N00014 Ballston Tower #1, Code 472 Arlington, Virginia 22217	1
Naval Sea Systems Command, Code N00024 Department of the Navy Washington, DC 20360 Attn: NAVSEA 024	1
Defense Documentation Center, Code SL4200 Cameron Station Alexandria, Virginia 22314	12

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Flame- and Smoke Retardant Polymer Systems		5. TYPE OF REPORT & PERIOD COVERED Final Report May 1976 - September 1977
		6. PERFORMING ORG. REPORT NUMBER MRC-DA-722
7. AUTHOR(s) Leo Parts, Robert D. Myers, Catherine A. Thompson, and Norman F. May		8. CONTRACT OR GRANT NUMBER(s) N00024-76-C-5336
9. PERFORMING ORGANIZATION NAME AND ADDRESS Monsanto Research Corporation Dayton Laboratory, 1515 Nicholas Road Dayton, Ohio 45407		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Navy, Code N00024 Naval Sea Systems Command SEA 0253D Washington, D. C. 20362		12. REPORT DATE 3 February 1978
		13. NUMBER OF PAGES 127
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) DCASD, Dayton Building 5, Code S3605A Dayton, Ohio		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release. Distribution Unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Carbon dioxide
Carbon monoxide
Combustion products
Fire-retardant coating
Fire safety
Flame propagation
Flame retardant
Hydrogen chloride
Intumescent coating
Mastic
Neoprene
Nitrogen oxides
Polymers
Polyvinyl chloride
Smoke
Smoke retardant

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Means for enhancing the fire safety of molded polyvinyl chloride (PVC) and neoprene foam were explored. These included incorporation of fire- and smoke-retardant additives into both polymer systems and the use of intumescent coatings with the PVC system.

Ferric and cupric acetylacetonates, used together with magnesium carbonate in PVC, reduced smoke optical density in laboratory tests by ∿55%. These additives had no adverse effect on ignitability. The concentrations of NO_x, HCl, and hydrocarbons

No. 20 ABSTRACT (cont'd)

formed from the flame- and smoke-retardant polymer compositions, burned under laboratory-scale fire test conditions, were generally lower than those observed with the reference polymer composition. However, these additives enhanced carbon monoxide formation and the rate of flame propagation.

Four intumescent coatings of different types were evaluated with the PVC compositions. An alkyd-based intumescent paint exhibited best performance. It had no significant effect on smoke formation, and it reduced the formation of CO and the rate of flame propagation.

Ferric acetylacetonate and poly(ammonium phosphate), incorporated into neoprene foam, reduced smoke optical density under flame exposure conditions only 10%.