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WESTERN RESEARCH APPLICATION CENTER

GRADUATE SCHOOL OF BUSINESS ADMINISTRATION / UNIVERSITY OF SOUTHERN CALIFORNIA
LOS ANGELES, CALIFORNIA 90007
(213) 746-6133

Fireproofing & Safety

Symposium

"PROCEEDINGS"

May 27, 1971

prepared by the staff of

WESTERN RESEARCH APPLICATION CENTER

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FOREWORD

SYMPOSIUM PURPOSE:

To help acquaint the business community with new materials and techniques, many of which have been and are being developed and produced as a result of NASA-sponsored research, for improving Fireproofing and Fire Safety with the goal of minimizing fire hazards and reducing costs. The Southern California area is one of the most fire prone regions of the United States. The many devastating fires to which the area has been subjected in recent years has greatly focused attention and interest on this very serious problem.

FOR WHOM:

1) Construction people and builders
2) Manufacturers of products having a fire hazard or fireproofing requirement
3) Building materials suppliers
4) Fire prevention personnel
5) Insurance underwriters
6) Many others

WHERE:

Chamber of Commerce Building
404 South Bixel Street
Los Angeles, California

SPONSORS:

1) USC/WESRAC
2) NASA
3) Los Angeles Chamber of Commerce
4) Small Business Administration

PROGRAM COORDINATOR:

Charles R. Dole, Manager, Engineering Applications, WESRAC, (213) 746-6171.

PROGRAM AGENDA

8:30-9:15 - REGISTRATION

9:20-9:40
"WELCOME TO SYMPOSIUM"
SPEAKER: Dr. J. Ehrenreich
Director, USCRIBE
University of So. Calif.

9:20-9:40
"FIREPROOFING AND TECHNOLOGY TRANSFER"
SPEAKER: A.K. Oulie
Director, WESRAC
University of So. Calif.

9:40-9:45
"ANNOUNCEMENTS & PROGRAM OVERVIEW"
MODERATOR: C.R. Dole
Mgr., Engineering Applications
WESRAC/USC

9:45-10:15
"INTRODUCTION TO PROGRAM SUBJECT - FIREPROOFING"
SPEAKER: Dr. M. Gerstein
Chmn., Dept. Mech. Eng.
Assoc. Dean Engr. Sch.
University of So. Calif.

10:15-10:30 - COFFEE BREAK

10:30-11:15
"UTILIZATION OF AVAILABLE SKILLS & MATERIALS IN FIRE PREVENTION"
SPEAKER: Dep. Chf. H. W. Martin
Fire Marshal
Los Angeles, Calif.

11:15-11:45
"HOW TO REDUCE YOUR FIRE INS. RATES"
SPEAKER: M. DuBain
Sr. V.P., Prop. Underwrit.
Fireman's Am. Fund Ins. Co.

11:45-12:15 - NO-HOST RECEPTION

12:15-1:15 - LUNCH
(Chamber of Commerce Dining Room)

1:15-2:00
"NEW FIRE RETARDANT FOAMS AND INTUMESCENTS"
SPEAKER: Dr. J. Parker
Chem Res. Proj. Office
NASA/Ames Res. Center
Moffett Field, Calif.

2:00-3:00
"OTHER NASA DEVELOPED MATERIALS & SOME INDUSTRIAL APPLICATIONS"
SPEAKER: Dr. M. Radnofsky
Crew Systems Division
NASA/Manned Space Center
Houston, Texas

3:00-3:15 - COFFEE BREAK

3:15-4:00
"FIRE RETARDANCY USING APPLIED MATERIALS"
SPEAKER: Dr. R. Feldman
President
Thermo Systems, Inc.
St. Louis, Missouri

4:00-4:45
"FIRE RETARDANCY WITH STRUCTURAL MATERIALS"
SPEAKER: R. E. Gardner
Western States Tech. Rep.
Koppers Co., Inc.
Pittsburgh, Pa.

4:45-5:00
"SUMMATION AND WRAP-UP"
MODERATOR: C.R. Dole

WESRAC/USC
FIREPROOFING & SAFETY SYMPOSIUM
EXHIBITORS

COMPANY	REPRESENTATIVE
Assn. of Asphalt Roofing Contr. Los Angeles, Ca.	R. Henry
Avco Corporation Lowell, Mass.	D. M. Patterson
Chem-Cal Co. San Gabriel, Ca.	R. Joy
Flamort Chemical Co. San Francisco, Ca.	G. M. Hearst
Furring & Lathing Information Bureau North Hollywood, Ca.	W. F. Pruter
Halprin Supply Co. Los Angeles, Ca.	N. Stein
Hitco, Materials Div. Gardena, Ca.	B. Caruso
Koppers Co. Inc. Orville, Ca.	G. Chasteen
Los Angeles Fire Department Los Angeles, Ca.	__. Scott
NASA/Ames Research Center Moffett Field, Ca.	J. A. Parker
NASA/Manned Spacecraft Center Houston, Texas	
NASA/Marshall Space Flight Center Huntsville, Ala.	
National Pacific Roofing Co. Canoga Park, Ca.	J. Greenleaf
Thermo Systems Inc. St. Louis, Mo.	R. Feldman
WESRAC Los Angeles, Ca.	J. Wolcott

"WELCOME TO SYMPOSIUM"

Speaker: Dr. Joseph W. Ehrenreich
Director, USCRIBE
University of Southern California

Dr. Joseph W. Ehrenreich
Director, USCRIBE
Professor of Business Economics
University of Southern California

Dr. Ehrenreich is Director of USC's Research Institute for Business and Economics and Professor of Business Economics in the USC School of Business Administration. Dr. Ehrenreich joined USC seven years ago after serving as Director of Planning and Research for Prudential Insurance Company.

One of his first actions at the University was to sponsor the development of WESRAC. He did this because of his interest and concern in advancing society through the application of advanced technology.

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"FIREPROOFING AND TECHNOLOGY TRANSFER"

Speaker: A. Kendell Oulie
Director, WESRAC
University of Southern California

A. Kendell Oulie, Director
Western Research Application Center
University of Southern California

Mr. Oulie was educated at the University of California, Harvard University and Stanford University Law School. He holds degrees of Bachelor of Arts in Economics from California and Master of Business Administration from Harvard.

His business experience includes management positions with the General Petroleum Corporation (MOBIL), Manager of Marketing Research with the Union Oil Company, and Director of Corporate Planning of the Garrett Corporation (Airesearch). He has been Director of WESRAC since its establishment in the Graduate School of Business Administration at U.S.C.

My job on the program is to relate WESRAC to this symposium and to tell you why WESRAC, the Western Research Application Center, at USC presumes to sponsor a program on fireproofing and fire safety.

In the first place, WESRAC provides computerized access to the largest technology collection in the West. It is a national resource. It has been established here to get this world-wide technology on new ways to do things into the economy. We do this by providing efficient, quick, economical access to these products of completed and on-going research, development, and experimentation. However, to get industry and business to use this resource, we find, requires education. Industry does not seem to have the habit of looking to see if someone else has already done work on their problem or in their area of interest before starting their own project. We want to change this habit so that duplication of effort in expensive, skilled fields of endeavor is eliminated.

Related to today's subject of fire is the fact that one of the principal collections WESRAC uses is the very broad and comprehensive ten-year-old and growing NASA data bank. NASA has had very great exposure to heat and fire safety problems as we all know. Literally hundreds of reports have been prepared on different aspects of dealing with fire problems. These are usually on new methods, new tools and new materials. Several of our speakers today will refer to this work, and much of the information you will hear can be expanded by use of WESRAC resources.

Since we have found in the past that only 10% or 20% of our audience has any idea what WESRAC is or does, we have prepared a brief film to tell you. I believe it will be worth your attention for the 14 minutes it takes to run.

Title of film shown: "Have You Heard About WESRAC?"

"ANNOUNCEMENTS AND PROGRAM OVERVIEW"

Moderator: Charles R. Dole
Manager, Engineering Applications
WESRAC/USC

Charles R. Dole, Manager
Scientific & Engineering Applications
Western Research Application Center
University of Southern California

Mr. Dole has been with WESRAC for the last 3 years as Manager of the Engineering Department. Prior to joining WESRAC, he served in the U.S. Air Force for 22 years, and later worked for the Jet Propulsion Laboratory in the Space Sciences Division on the unmanned Ranger, Surveyor, and Mariner projects.

Mr. Dole Holds a Bachelor's degree in Civil Engineering from the University of Southern California and a Master's degree in Meteorology from the University of California at Los Angeles. He has also pursued graduate management studies at George Washington University and the University of Maryland.

"INTRODUCTION TO PROGRAM SUBJECT - FIREPROOFING"

Speaker: Dr. Melvin Gerstein
Chairman, Dept. of Mechanical Engineering
Associate Dean, School of Engineering
University of Southern California

Dr. Melvin Gerstein
Chairman of the Department of Mechanical Engineering
University of Southern California

Dr. Melvin Gerstein has conducted active research in the field of combustion related to fire hazards and propulsion systems for the past 20 years. This work has included research pertinent to aircraft and spacecraft fire hazards, safety in test and launch vehicles and combustion research in reciprocating, turbojet, ramjet and rocket engines.

Dr. Gerstein is currently involved in studies of aircraft fire hazards. He has been retained as a consultant on fire hazards in the Apollo and Manned Orbiting Lab spacecraft.

Prior to joining the University of Southern California, Dr. Gerstein was associated with NASA at the Lewis Research Laboratories in charge of advanced programs in propellant chemistry. His work as Assistant Propulsion Division Chief at NASA has resulted in major contributions to the basic understanding of jet propulsion design. Dr. Gerstein was also Division Chief in charge of physical science research at the California Institute of Technology, Jet Propulsion Laboratory.

Dr. Gerstein received both his Bachelor's and Doctorate at the University of Chicago in chemistry.

It is a very real personal pleasure for me to introduce the technical portion of this symposium on fireproofing. It would seem logical to start by defining the term "fireproofing." Webster defines "fireproof" as "relatively incombustible," which doesn't really help us very much. Presumably we mean the development or treatment of materials to prevent of inhibit ignition, or to prevent or inhibit flame propagation. In a general treatment of fire safety, one would devote a great deal of effort in removing or isolating ignition sources. When dealing with the subject of fireproofing, however, we must assume that ignition sources exist. These may range from sparks to arcs, over-heated wires to large flames. In discussing fireproofing, it is necessary that we consider the nature of the ignition source - in fact, the nature of the total environment. A fireproof material under one set of circumstances may be readily combustible under another. Those who have been concerned with the hazards associated with high oxygen concentrations have certainly encountered materials which were fireproof in air, but burned readily in pure oxygen.

Fireproofing treatment initially, and widely used at the present time, consisted of treating materials with inorganic salts. Borates and phosphates are, and have been, widely used for this purpose. A simple test involving the application of a standard flame directly to the material can be used as illustrated in Figure 1. If the treatment has been successful, flame will not propagate away from the region of the torch and, when the torch is removed, flaming or glowing of the material will stop very quickly. The fireproofing additive, if a borate or phosphate or similar inorganic material, may interfere chemically with the free radical chemistry necessary for flame propagation. In addition, the low melting oxides of boron and phosphorus provide a barrier between the organic material and the ambient air. While the flame is being applied, it is possible that flammable vapors are released and consumed by the flame. If large amounts of flammable material were released, the flame would flare up, which is not desirable. If small amounts were released, the vapors would be consumed, and no additional hazard would be created.

Tests of this type have been used to rate materials. Let us consider, however, a different condition. In Figure 2, we assume that a source of heat is applied to the material indirectly, either by means of a flame, as shown, or some other heat source. The flammable vapors produced are not consumed by the flame and diffuse away from the surface creating a concentration gradient. Typical gradients for slow, intermediate and rapid gas evolution are illustrated in Figure III. In Figure IIIa, the rate of gas evolution is too lean to burn except very near the surface where surface quenching might inhibit ignition and flame propagation. An ignition source near the surface would not be a hazard. There may well be, as illustrated in Figure IIIb, an intermediate gas evolution rate which would produce a flammable mixture. Ignition could occur and a fire might continue to burn as long as the heat source was present to produce flammable vapor in spite of the fireproofing material which may be present. The fire occurs above the surface and the fireproofing material might not be effective if it is not vaporized. Although such a material might pass a flame test it would still represent a fire hazard in the presence of a less active heat source.

Finally, in Figure IIIc a very rapid gas evolution is illustrated. Such a situation may not present an ignition hazard near the surface but the large amounts of vapor produced could form flammable mixtures and ignite far from the surface. Flash fires resulting from smoldering fabrics are often the result of this type of behavior. A relatively fireproof material which does not itself ignite can release enough flammable vapor to create a hazard in the vapor space. The problem is compounded if the vapors released are also toxic or debilitating.

These experiments have considered an external ignition source. The heat source itself may also be the source of ignition. Figure II could easily have represented a thermal ignition experiment. Here, too, the problem is quite complex since two gradients are involved, a concentration gradient and a temperature gradient. Some of the important factors are illustrated in Figure IV. The upper curve is a plot of the ignition temperature of the vapor (Tig) versus fuel concentration (F). It is assumed that some minimum temperature exists and that ignition becomes more difficult at higher and lower fuel concentrations. The solid line in the lower curve represents a fuel concentration (F) curve versus height above the surface. On the basis of the Tig vs F and h vs F curves it is possible to generate a curve shown as a dotted line which represents the required ignition temperature at any point above the surface. The ordinate remains height above the surface, h, and the abscissa becomes Tig. If the actual temperature due to the heat source exceeds Tig at any point, ignition will occur. In Figure IV, if the fuel gradient curve had been a temperature gradient curve, ignition would have occurred. Once ignited, of course, the flame might propagate over the entire sample. Since both fuel and temperature gradients are important it is easy to see that such an experiment would be quite sensitive to rate of heating, heat transfer rates, diffusion rates and other experimental variables.

The problem becomes even more complicated if there is a flow across the surface. One example from the work of Gerstein and Hyde (Ref 1) is illustrated in Figure V. The configuration is illustrated schematically. It consists of an air flow of velocity V_∞ parallel to the surface. The flammable vapor leaves the surface at right angles to the flow and to the surface at a velocity V_o as a mass flow, $\rho_o V_o$. The value of V_o would depend on heating rate, for example and represents a quantitative measure of the rate of flammable vapor evolution. The lines indicate the existence of a flammable mixture at two differnet stations along the surface, 0.4 ft from the start and 1 ft from the start. For a given air velocity, 10 ft/sec, a higher gas evolution rate is required at 0.4 ft than at 1 ft. The boundary layer is thin at 0.4 ft and the air dilutes the mixture which is flammable further away. At any specific location, more heat or a greater gas evolution rate is required as the air flow velocity increases. Between the two curves there is a region where ignition could not take place if the material was small (0.4 ft) but could take place if the material were large. These calculations can easily be related to shorter materials and lower velocities so that the conclusions are general. It is evident that the occurrence of ignition is strongly dependent on the complete environment and not on any single factor. The fireproofing expert must take this into account and define the conditions under which his material or his treatment is applicable.

More recently, fireproofing techniques have involved the use of specially formulated polymers or additives of an organic nature combined with the plastic or fabric. The freon type halocarbons containing bromine, chlorine and fluoring have been used for this purpose and various halogenated monomers have been polymerized to form fireproof plastics. Depending upon the decomposition characteristics of the polymer and the relative release of fuel components and inhibitor components, the preceding discussions may still be applicable. Other factors must also be considered. Some work of Gerstein and Stine (Ref 2) with mixtures of fuels and carbon tetrachloride is relevant. Consider the case of Figure 2 but assume that the vapors released consist of a mixture of fuel and inhibitor. Flammability limit curves such as illustrated in Figure VI result. We have plotted the partial pressure of inert or inhibiting material versus the partial pressure of fuel. At $P_{inert} = 0$ we would have the normal lean and rich flammability limits in the absence of inhibitor. At some value of P_{inert} and above all mixtures would be non-flammable. Figure VII shows how such a curve can be generated. If the initial material had a composition N_1, heating of the vapor could generate the curve shown. At some stage, since the inhibitor comes off less rapidly than the fuel a flammable mixture results indicated by X. As the initial composition is changed, the behavior changes until finally a composition is reached at which ignition does not occur during the entire heating period. The sample of initial composition N_4 would be judged as non-flammable or fireproof. Examine Figure VIII to see what happens as this "non=flammable" mixture is diluted by air. Dilution reduces both P_{inert} and P_{fuel} but the ratio P_{inert}/P_{fuel} remains constant. Dilution is represented by a straight line through the origin from the location of the final mixture. It is shown in Figure VIII by a series of arrows. The non-flammable mixture crosses into the flammable range and ignition is possible. Again, the purpose of this example has been to emphasize the importance of defining the exact conditions of the test and environment before the labels of fireproof or non-flammable are applied.

I have not tried to summarize the large body of literature on fireproofing. Rather I have taken advantage of the prerogative of an introductory speaker to raise questions rather than answer them. Specifically I have tried to emphasize the great importance of defining the exact conditions under which a material is fireproof and the awareness that "fireproof" materials can burn or lead to fires under conditions different from those evaluated by a single test. I have not touched on the many other problems faced by the fireproofing experts including the physical and structural properties of the materials, possible toxic gases released by thermal decomposition, cost and fabrication difficulties. The papers which follow illustrate that major progress has been made in the field of fireproofing. Much more still needs to be done.

REFERENCES

1. Gerstein and Hyde, "A Boundary Layer Model For Pilot Ignition of Cellulosic Solids in a Wind (to be published). Based on Engineers Degree Thesis, August 1970, University of Southern California.

2. Gerstein and Stine, "Anomolies in Flash Points of Mixtures of Halogenated Hydrocarbons and Flammable Liquids (to be published).

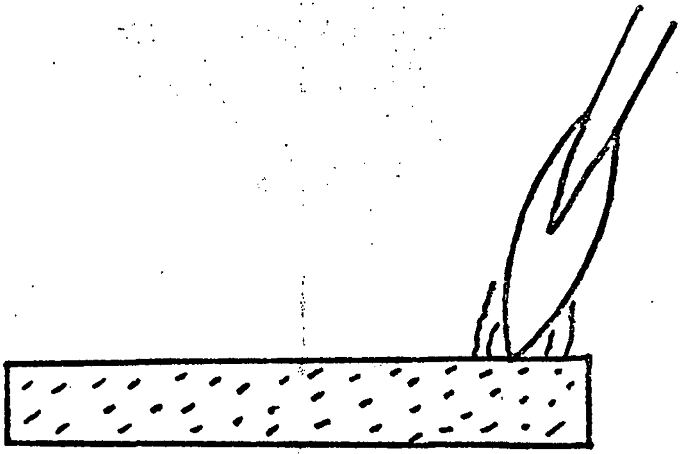

Figure I. Simple Flame Test

I

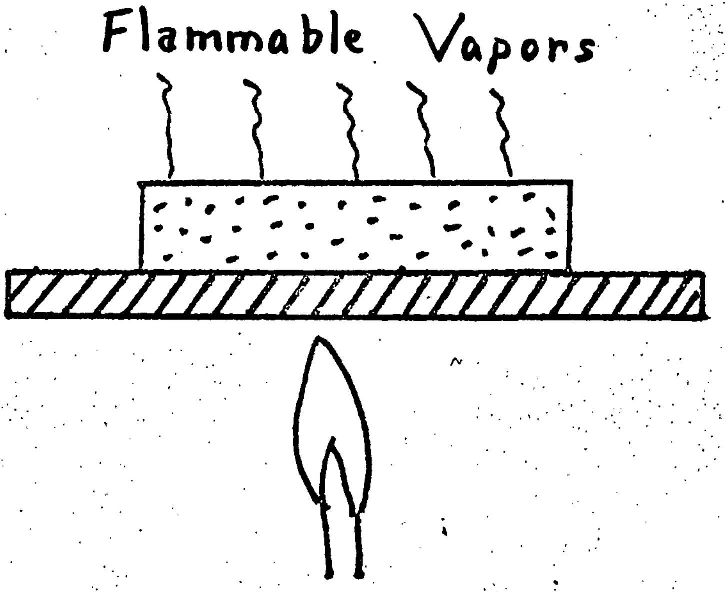

Figure II. Indirect heating of material.

II

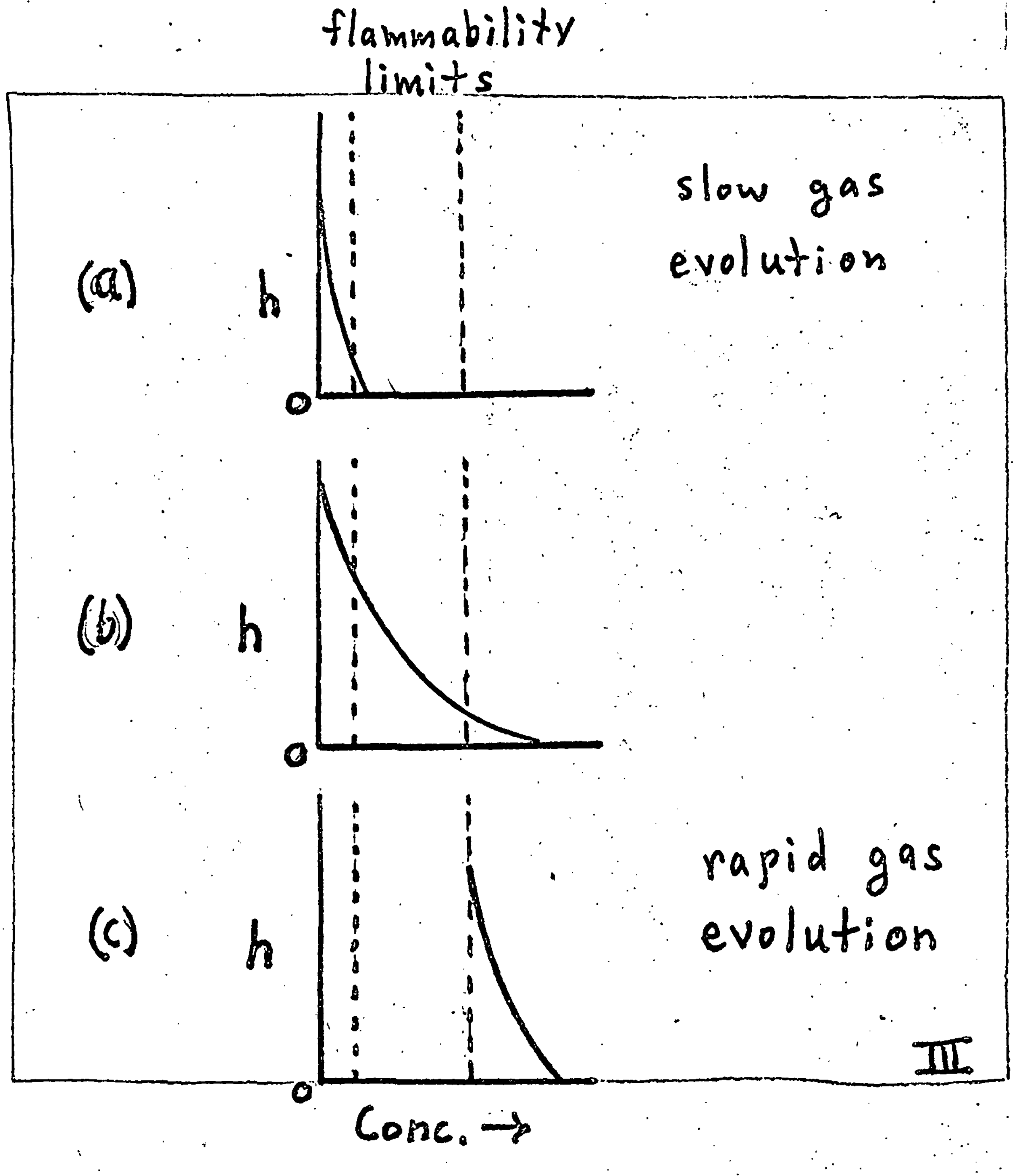

Figure III. Concentration Gradients near a Heated Surface

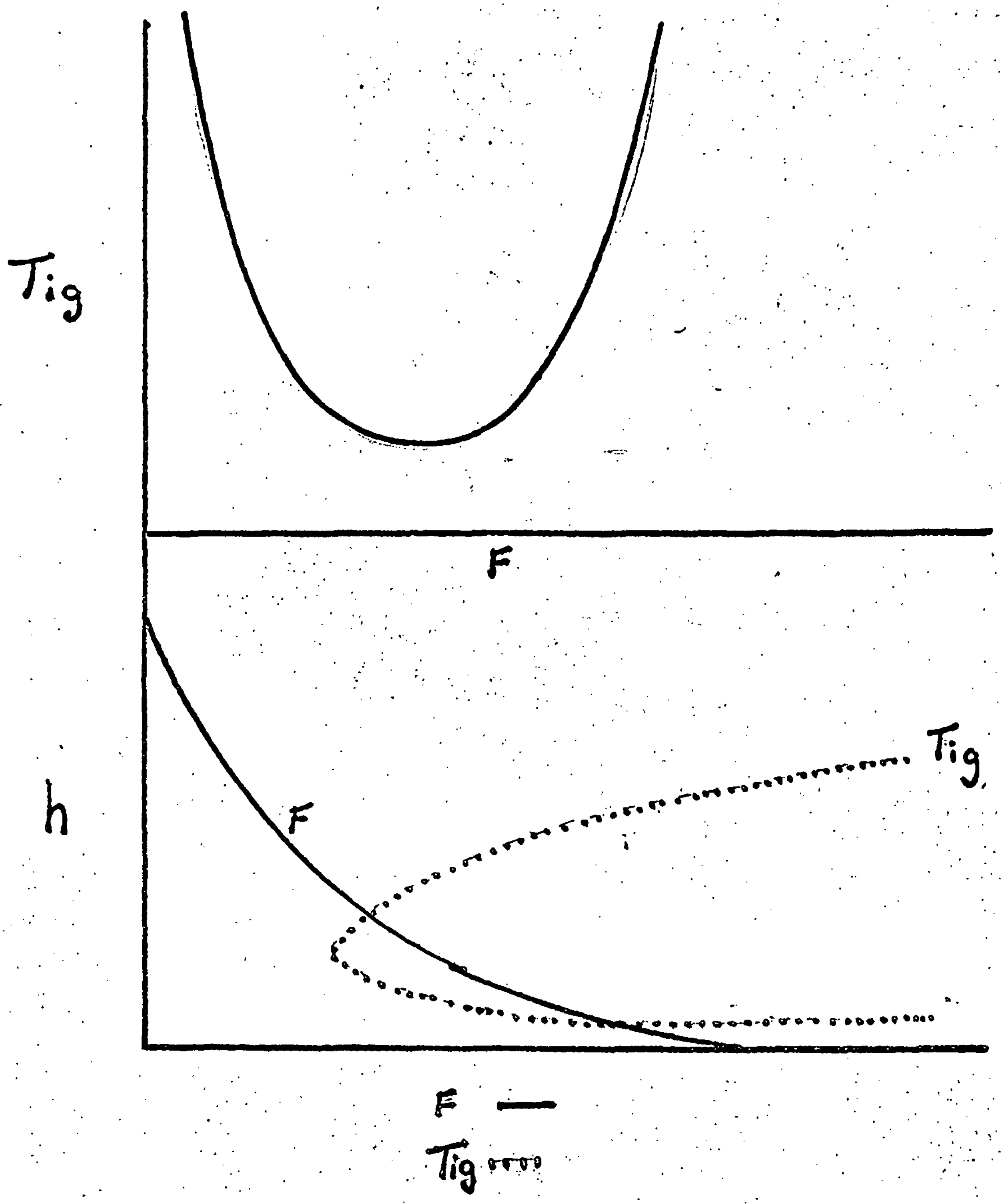

Figure IV. Thermal Ignition Conditions

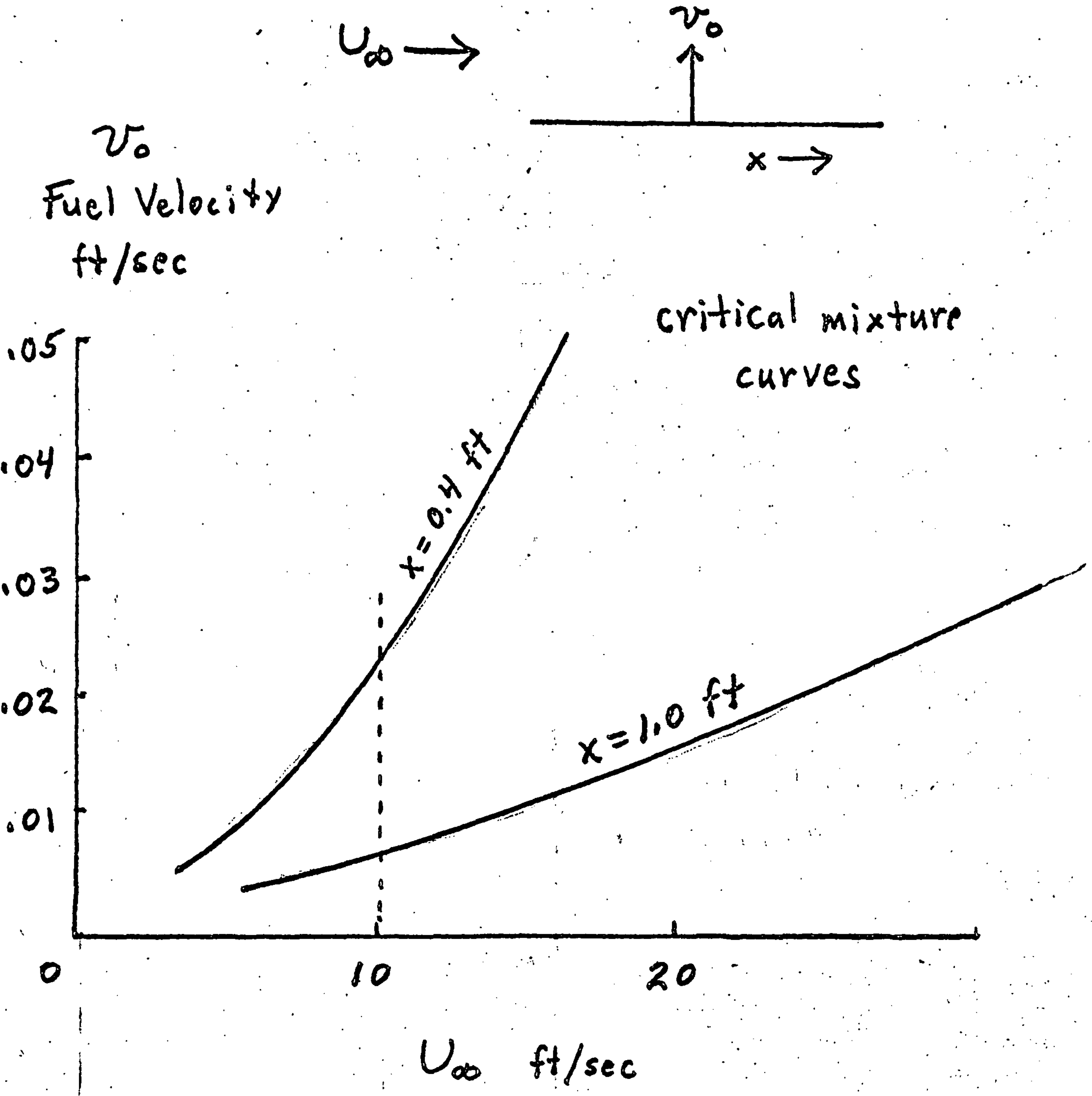

Figure V. Effect of flow on formation of Critical (flammable) Mixtures.

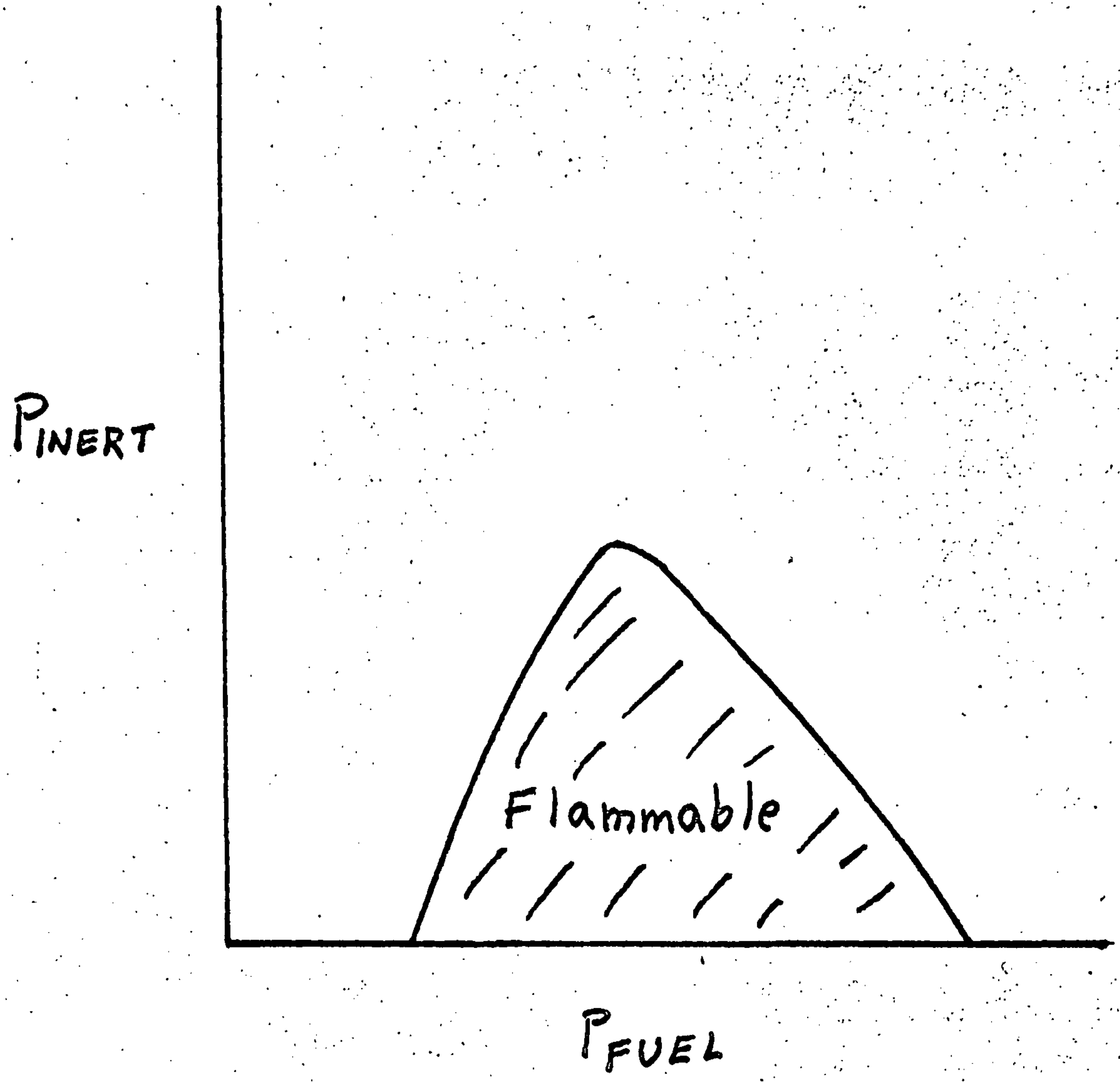

Figure VI. Flammability Limit Curve

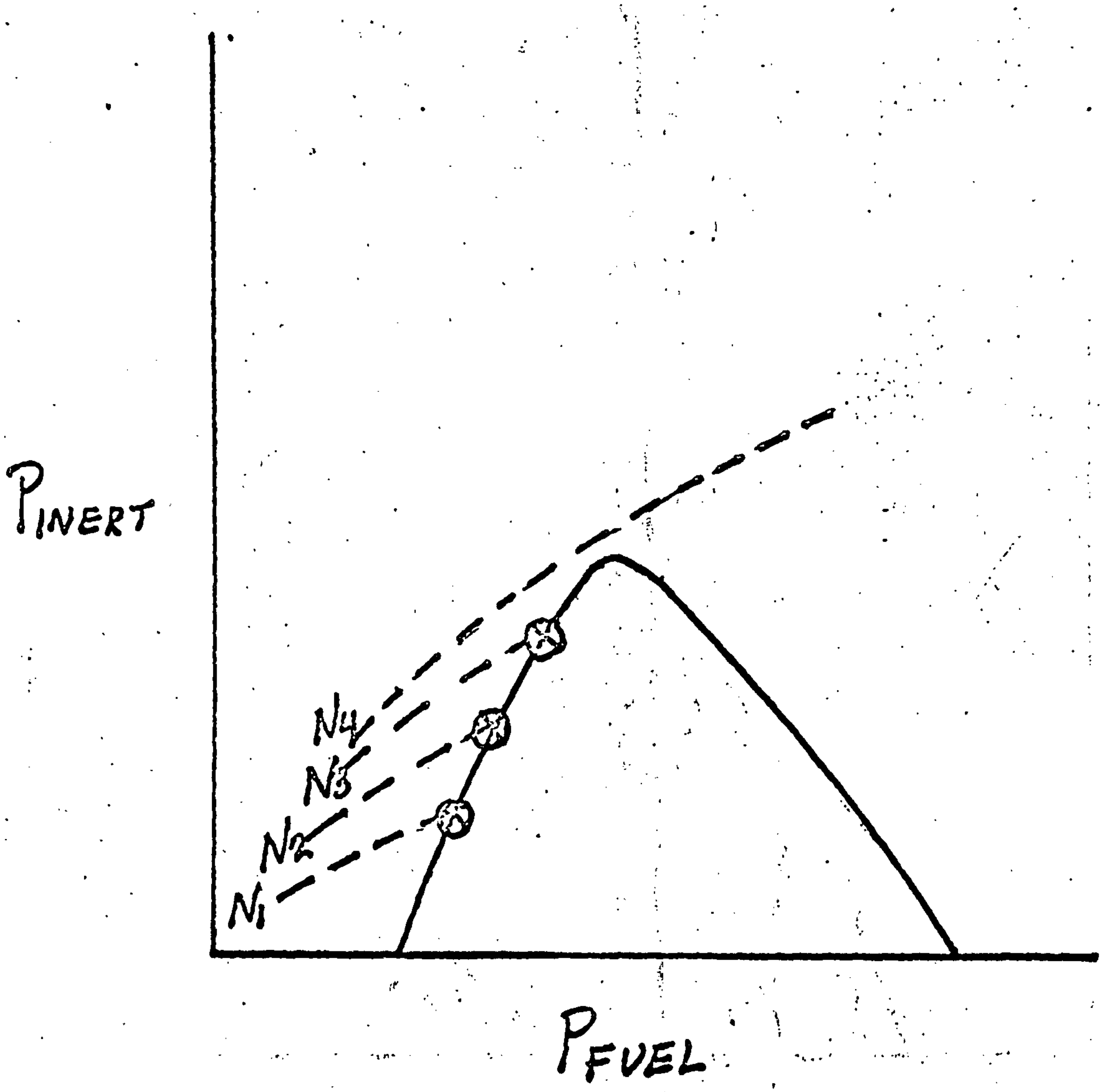

Figure VII Generation of Flammability Curve

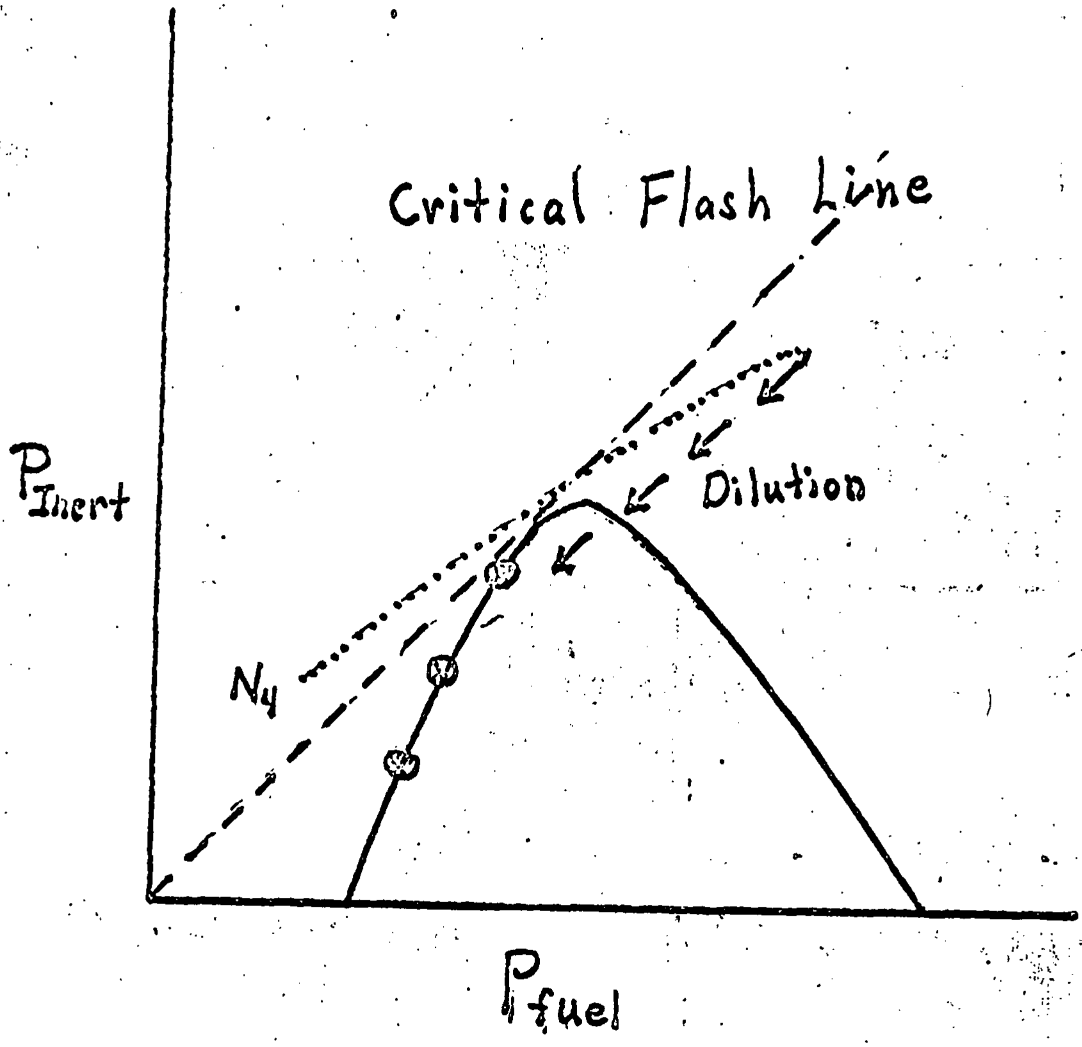

Figure VIII. Dilution Effects which make a non-flammable mixture - flammable

"UTILIZATION OF AVAILABLE SKILLS & MATERIALS IN FIRE PREVENTION"

Speaker: Deputy Chief Harry W. Martin
Fire Marshal
Los Angeles, California

Harry W. Martin
Deputy Chief and Fire Marshal
City of Los Angeles Fire Department

Currently the Fire Marshal and Commander of the Bureau of Fire Prevention of the Los Angeles City Fire Department, Mr. Martin has been a member of the Fire Department for 28 years. He has also lectured on fire protection and engineering at various seminars at the University of California at Davis, UCLA, USC, Chabot College at Hayward, and Phoenix College at Phoenix, Arizona.

Mr. Martin attended Los Angeles City College and Cal State in Los Angeles where he majored in civil engineering with minor studies in physical sciences and public administration.

Mr. Martin has been a consulting fire protection engineer and expert witness in legal action in numerous states.

FIRE PROTECTION FOR LARGE OFFICE BUILDINGS

I. Planning Stage

- A. Determine type of occupancy
- B. Special requirements for different occupancies.
- C. Consider water supply available to building
    - 1. Supplemental fire protection may be required where access is restricted
    - 2. Supplemental protection may consist of on-site hydrants
- D. Distribution of water supply in building for fire fighting
    - 1. Combination standpipes
        - a. Wet standpipe system
        - b. Connected to fire pumps
        - c. Fire Department connections for second source of supply
        - d. Gravity tanks may be required according to building height
        - e. For use by Fire Department
    - 2. Interior standpipes
        - a. For use by building occupants
        - b. Connected to combination system and gravity tank
- E. Exits (types)
    - 1. Enclosed stairway
    - 2. Conventional smoke-proof enclosure
        - a. Located on exterior wall
        - b. No opening directly into interior of the building

        3. Mechanically ventilated smoke-proof enclosure
            a. Located in building core
            b. Involves a system of smoke detectors and mechanical ventilation
    F. Emergency power
        1. Required to light exits and exit signs during power failure
        2. Supply power to mechanically ventilated smoke tower
    G. Extinguishing systems
        1. Sprinklers required in below grade areas
        2. May be required in lieu of other protection

II. <u>Construction Stage</u>

    A. Water supply
        1. Extend standpipe as building goes up
        2. Provide fire pump
    B. Special problems
        1. Vertical and horizontal access limited
        2. Accumulation of combustibles
            a. Trash
            b. Packing material
            c. Lumber
        3. Flammable liquids
            a. Paint spraying
            b. Adhesives
        4. Welding and heating devices being operated

5. Special detection and extinguishing systems may be incomplete

6. Communications system in building often lacking

III. Final Testing of Fire Protection Systems

A. Standpipe system

1. Each riser flowed from topmost outlet at 30 p.s.i. for one minute

2. Fire pump

a. Operated for one hour

b. Started three times automatically and three times manually

c. Tested to 150% of its rated capacity for 15 minutes

B. Emergency power system

1. Tested upon completion

2. Must provide rated capacity

C. Mechanically ventilated smoke-proof enclosure

1. All smoke detectors checked

2. Ventilation and pressure differentials checked

3. All accessory equipment must function properly

IV. Maintenance

A. All fire protection systems to be tested at least every five years.

1. Combination standpipes

2. Wet standpipes

3. Automatic sprinkler systems

    4. Smoke detection systems
    5. Fire protection assemblies
        a. Fire doors
        b. Fire dampers

B. Emergency power system

    1. Tested weekly
    2. Written record to be kept of tests

C. Tests when required shall be conducted by qualified person

    1. Building engineer
    2. Specially trained personnel
    3. Private outside agency

D. Fire Department to be notified in advance of such tests.

"HOW TO REDUCE YOUR FIRE INSURANCE RATES"

Speaker: Myron DuBain
Senior Vice President
Property Underwriting
Fireman's Fund Insurance Co.
San Francisco, California

Myron DuBain
Senior Vice President of Property and Casualty
Fireman's Fund American Insurance Company

Mr. DuBain joined Fireman's Fund Insurance Company in 1946 and since then has held several executive positions with the company. Among them are the Vice President with senior executive responsibility for Inland Marine operations, senior executive responsible for Inland Marine and Commercial Multiple Peril operations, senior executive for all Property and Multiple Line operations, and his present position of the senior underwriting executive for Property, Casualty and Multiple Line operations which he has held since 1968.

Mr. DuBain is a member of the Factory Insurance Association, the Fire Insurance Research and Actuarial Association, and the Oil Insurance Association.

He received a bachelor's degree from the University of California at Berkeley in 1943 and attended the Stanford University Graduate School of Business Executive Program in 1967.

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HOW TO REDUCE YOUR FIRE INSURANCE RATES

To correct any mistaken impressions that could result from the title of my address, I should make it clear that I am not an insurance rate technician. We have rating technicians who devote their entire time to the principles and applications of rating schedules and individual risk rate make-ups. My own involvement is limited to the broad general principles and overall results of the detailed rating system in our various property and casualty lines.

I might also remind you that insurance companies are in business to make money, although the level of profit we seek is modest. Nevertheless, we do have a profit--as well as a public service--motive, just as those of you who are in the construction trades or who are building and plant owners.

Fire insurance premiums are essentially the product of losses plus the necessary expenses of the insurance company to do business. In any major rating classification, the class itself establishes its own rates over long experience periods. I emphasize that the rating system recognizes long experience periods because in high-valued properties, a large single loss can distort the short-term averages. Of course an individual loss would not, in itself, have sufficient credibility for ratemaking purposes.

The important thing is that if losses go up, insurance rates are going to have to go up. So the simplest way to reduce your fire insurance rates is to reduce your fire insurance losses, and to get others to do likewise.

With that primer in ratemaking, let's take a closer look at how the insurance underwriter looks at property insurance.

Historically, the attitude of underwriters toward buildings of fire resistive construction has been quite favorable and the underwriting treatment accorded them quite liberal. Until recent years, most underwriters would not hesitate to freely commit their full capacity on fire resistive structures, subject to minimal inspection requirements.

The practices in the building trade were generally toward heavy masonry construction, the combustibility load of such things as high-rise office buildings was light and, generally, good fire cut-off standards were followed between floors. Consequently, subject to underwriting of the occupancy plus an assurance that any special hazards were adequately recognized and cared for, this was considered very desirable business. The loss experience was good and the rates reflected this until they reached almost minimal levels.

Today, things are different. During the past few years, we have seen some drastic changes in construction methods and materials. We are now seeing an increasing number of multi-million dollar fires in so-called fire resistive buildings occurring out of these changes in construction and materials.

Since the end of World War II, our booming economy has created a huge demand for more and better office, plant and storage space. Many new, attractive materials have been appearing on the market with resultant changes in building methods in order to utilize them. Sky-rocketing labor costs have resulted in the development of labor-saving construction techniques.

The financial squeeze put on municipal governments dictated a broader tax base, so it became politically expedient to allow building code variances in order to speed up development of commercial properties. In some major cities building codes have been completely revised, and not always for the better.

This combination of experimental designs, untried materials and relaxed code requirements has given us many buildings which no longer have the same high degree of fire resistance we once knew and which, in many cases, do not provide adequate life safety for occupants.

Let me give you two examples of the new type fire losses we are experiencing in many so-called fire resistive buildings.

A typical, modern 50 story skyscraper in New York was completed in early 1970. The building has a reinforced concrete center core which contains the elevator shafts, stair towers, rest rooms, utilities and air conditioning supply and return air shafts. Steel girders connect this core to columns at the outside wall of the building so that the floors are column-free except at the east and west sections.

Beams support the 2-1/2" thick concrete floor on fluted floor form units and are joined to the concrete floors by steel studs. Columns, girders, beams, and the underside of floors are protected by sprayed asbestos fibre to provide a four hour fire resistance for columns and three hour rating for filler beams and floors.

Walls are made up of aluminum panel window sections which also encase the outside columns. There is a 6" concrete block curtain wall 28" high built on the outer edge of the floor slab. This wall is located in line with the center of the wall columns so that the outer skin is 16" out from this wall. This separation creates vertical flues the height of the base or tower which is 143' maximum, which are interrupted at each floor level by an aluminum metal flashing designed to collect condensation and carry it through weep holes to the outside.

The inside face of the curtain wall, the space between the windows, and the space above the windows is insulated with 1" Dorvon FR 100 Polystyrene foam board. This insulation is covered on the inside by gypsum board only where visible. There is no covering on it above the hung ceiling. As a result, the protection between the concealed ceiling spaces of two floors consists of two 1" thick pieces of foamed polystyrene and a thin sheet of aluminum.

The concealed space between the hung ceiling and the floor above contains air supply ducts, lighting fixtures, power lines and conduit, telephone cables and communication cables.

During the application of finishing touches for occupancy of luxurious offices by a new tenant, on the 31st, 32nd, and 33rd floors, a guard on the 33rd floor saw smoke above the ceiling through an opening and reportedly pulled the fire alarm box on his floor. He then took the elevator to the first floor to notify the building guards of the fire.

Two guards and a telephone installer supervisor took the elevator to the 39th floor to notify other employees of the fire. Their elevator stopped at the 33rd floor, and smoke and flames rushed in. The elevator would not move from the floor with the result that the two guards perished and the telephone foreman was barely alive when rescued by firemen two hours later.

The Fire Department responded within three minutes from the time the alarm was received, but when they arrived, the 33rd and 34th floors were raging infernos with so much smoke and heat that the firemen could only operate on the floor for a short time.

It was five hours before the fire was brought under control and in those five hours, two lives were lost, 30 men were injured and damage totaled ten million dollars.

The 33rd, 34th, and 35th floors were burned out, with varying degrees of smoke and heat damage to many additional floors above and below. The fire spread to the exposed polystyrene foam in the south and east walls and emerged from the concealed space in the form of flaming droplets of flaming gases.

As the heat involved furniture stuffed with feather or foamed polyurethane, its progress accelerated because of the amount of combustibles and flammable gases given off. Tests made after the fire showed that the polyurethane foam gave off flammable gases at 212°F.

I would like to read to you excerpts from the official investigation report of this fire by the New York Board of Fire Underwriters.

"The reason for the severe fire in this fire resistive building can be understood if it is realized that the building classification is a misnomer. Buildings of this type erected in this plastic age should more correctly be called 'semi-combustible.' Except for the concrete and metal, almost everything in the building is combustible to some degree - foam plastic wall insulation, electrical cables, ceiling tiles, partitions and insulation on air handling units. The degree in some cases is small but added to the severe fire hazard caused by foamed plastic furniture, there is the recipe for this conflagration.

"The degree of damage to the steel frame is the result of several factors. It is reported that this steel came from England and became severely oxidized in transit. As a result, the sprayed asbestos fibre did not adhere well in many places and fell off along with the scale shortly after application. As a second factor, this insulation was removed in many locations where partitions were run to the underside of beams, where air ducts ran under beams, where clamps are attached, where wires scrape it. The situation that exists in a laboratory when this material is tested is not the same situation that exists in the field."

That last point is important. Time and time again we have blindly and in good faith accepted laboratory tests of the fire resistance of new materials, only to have the materials not prove out when it really counted. Well, I think underwriters have been burned once too often. We are going to be taking a much more critical look at both the design and materials characteristics of new construction, and we are going to be much more cautious in accepting and rating risks. The report I just referred to puts it this way:

"This fire has provided a major full scale test for new methods of construction. The transmission of fires between floors, the distribution of smoke throughout the building and the failure of structural elements prove the necessity of reviewing the present requirements and practices.

"Since this building is typical of a large number of buildings now being built, recommendations are being made on a general basis rather than applying specifically to this building."

The report lists 14 recommendations which I will not read now because of their length. I do have two or three copies which you may pass around, however, and additional copies may be obtained by writing to me at Fireman's Fund American Insurance Companies in San Francisco.

The second example involves a building in California in the course of construction. The structure had a total floor area of approximately 332,000 square feet. This was a one equals two story building of 6 inch reinforced concrete tilt-up walls with reinforced concrete pilasters which were to have been divided into four fire divisions separated by 6 inch reinforced concrete fire walls with fire doors and dampers covering openings. The floor was concrete and the roof was composition on wood decking on wood truss.

The building was to be for a fruit processing and cold storage operation. The entire east side of the building was divided into cold storage and cooler rooms constructed of half-inch plywood on 2 X 4 wood stud framing extending from floor to roof, with polyurethane foam insulation sprayed on all walls and dividers and on the underside of both the equipment decks and the roof.

At the time of the fire, the building was almost complete, with one section occupied and cut off from the other three sections. The three sections not yet occupied were not separated from each other in that the fire doors were not in operation.

The fire was caused by a welder's torch while sweating a water pipe to cooling equipment, igniting polyurethane foam insulation in the area of the cold storage rooms. The polyurethane foam insulation, while a good insulating agent, was of such high combustibility characteristics that the entire three uncompleted sections of the building were totally engulfed in flames within approximately nine minutes from the time the fire started.

Several workmen on scaffolding at the opposite end of the building from which the fire originated were barely able to escape in time to avoid injury. The three sections of the building which were still not occupied were practically a total loss. The ultimate loss was in excess of $4,000,000 on a building with a cost of $5,500.000.

Unfortunately, these two examples do not represent uncommon losses. A look at statistics for recent years reveals an ominous trend: a $15,000,000 grocery warehouse fire in Boston; a $3,000,000 fire at a school under construction in New Hampshire--and so the list continues.

The result of this can only be substantially increased fire and liability insurance rates, because of the exposure to life and property. It is not surprising that many insurance companies--including my own--are taking a closer look at the so-called fire resistive buildings which we have considered superior risks eligible for premium discounts under commercial package policies.

Instead of giving discounts, we may be asking for surcharges on some of these buildings, particularly until we are satisfied that the lag in rate making has caught up to the new loss trend. Indeed, in some cases, I would not be surprised to see available insurance capacity become an acute problem in some hazardous type construction unless there is considerable improvement in construction methods.

But the picture is not so bleak as it might seem. Rates can be reduced, and the key to reducing them lies in incorporating the many existing fire protection methods into the initial stages of building planning, with diligent follow-through in the construction phases. It is then that fire protection is least expensive and most effective--not when it is thrown in as an ill-planned afterthought.

I would call upon you to exercise your leadership in making fire protection an integral part of building design and construction, both through your own expertise and with the help of qualified engineering personnel readily available to assess the weaknesses and strengths of design. Most major insurance companies have experts ready to assist and advise in connection with proposed construction plans, and Fire Rating Bureaus in practically all jurisdictions have experts who will respond, upon request, in connection with building design and construction.

A prime example of the benefits to be reaped from advance planning is a recent fire at the University of California at Santa Cruz. Although losses totaled $150,000, fire prevention experts revealed that losses could have been substantially reduced if the building had been sprinklered--at a cost of $6,000.

A second method of reducing fire insurance rates is, of course, reduction of loss potential in existing structures. Essential to the success of any such program is installation and maintenance of adequate fire protection systems, combined with emergency-procedure training of personnel and pre-planning with local fire departments.

Equally essential is a periodic inspection of the premises, followed by correction of hazardous conditions--in other words, good housekeeping. Most important of all, perhaps, is proper use of the facility--a building should not be used for a purpose more hazardous than its design and construction permit.

Again, both insurance companies and Fire Rating Bureaus stand ready to provide assistance--and I would urge you to take advantage of the advice.

In view of the location of this conference and because I am sure many of you are from California and other West Coast areas, I would remiss if I did not mention the fire hazard in the aftermath of earthquakes. The danger is a very real one, as evidenced by such tragedies as the San Francisco disaster of 1906, but present building standards seem destined to increase, rather than reduce, the exposure from earthquakes.

We were very surprised to learn of the collapse or failure of several recently constructed modern buildings in both the Santa Rosa earthquake in 1969 and the San Fernando Valley quake which just occurred in February of this year. The distressing part is that investigation by eminently qualified engineers following the failure and collapse of some of these buildings clearly indicated they should not have been a surprise.

I would like to quote from page 58 of a study released by the United States Department of Commerce on the Santa Rosa, California earthquake of October 1, 1969.

"Research on materials has led to their more effective use in buildings, but not without side effects. Sprayed-on fireproofing around steel frames in lieu of poured-in-place concrete fireproofing has greatly reduced the inherent lateral force resistance of many structures, since the mathematically neglected concrete with the steel frame members formed, in effect, composite members.

"Research on concrete members has changed design practice to the extent that allowable unit-design stresses have increased as much as fivefold in recent years, creating new design problems such as overturning, multiple types of stress, concentration, and concrete splitting. Metal and glass skin exteriors have replaced brick and concrete panel walls, thereby reducing inherent strength and damping. Many other examples can be cited.

"The net effect of all of these developments has been to substantially reduce the inherent lateral force resistance of buildings, unless the designer included noncode-required bracing. This extra bracing is too often opposed on the basis of costs or a lack of understanding.

"In essence then, a designer who follows the letter of the law as expressed in the building code, but lack experience judgement when extrapolating code values to new types of structures, can inadvertently design a collapse-hazard structure which is legally safe. Collapse is more probable today than it was several decades ago, before changed practice had reduced a structure's uncounted strengths."

Thus, it is possible for a planned building to be considered legally safe, while it is, in reality, a collapse-hazard structure. Equally disturbing is the fact that code requirements have so changed within recent years that a framed concrete building today is permitted to have about half the lateral force resistance--earthquake bracing, if you will--than that required ten years ago.

On top of all this, we understand that the International Conference of Building Officials, publishers of the uniform building code, now has before it a proposal to further reduce the safety factor on concrete construction.

Gentlemen, as underwriters, we are concerned. I must tell you in all candor that it is not a function of insurance to insure deficiency in design or construction method.

"NEW FIRE RETARDANT FOAMS AND INTUMESCENTS"

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In 1968 Dr. Parker was awarded the NASA Exceptional Scientific Achievement medal for his pioneering research in reentry technology and on the ablation of heat shield materials. The results of this work have been used to provide protection from fire with a wide range of commercial application.

Prior to joining Ames as a Research Scientist in 1962, Dr. Parker was manager of the Chemistry Department of Armstrong Cork Company in Lancaster, Pennsylvania. He has also taught at the Philadelphia Area Colleges on the campus of Temple University and at the University of Pennsylvania.

He received his Bachelor's degree in chemistry from the University of Pennsylvania in 1948, and his Master's and PhD from the same university in chemistry in 1949 and 1951.

PROTECTION OF AIRCRAFT IN GROUND CRASH FUEL FIRES

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Presented by Dr. John A. Parker at the WESRAC-Fireproofing and Safety Symposium, May 27, 1971.
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INTRODUCTION

Passengers caught in an aircraft ground accident that has resulted in fire have only a very short time to escape. Those failing to exit quickly probably will die from exposure to heat and fumes.

As part of a program of development of fire-retardant materials at Ames Research Center, a concept for passenger survival has been studied which differs from those that have been considered in the past. Previous studies generally have stressed quick-evacuation techniques; some have dealt with possible ways to prevent or control the fire. In contrast, the study at Ames was directed toward the approach of surrounding the passenger compartment with a fire-retardant shell that would protect the occupants long enough for the fire to burn out or for fire-fighting equipment to reach the airplane and extinguish the fire.

This approach has been made possible by the recent development of two new fire-retardant materials: a lightweight foam plastic, called polyisocyanurate foam, and an intumescent paint. The intumescent paint is a material that expands to many times its original thickness when exposed to heat; thus, it insulates the surface on which it is applied. The thermal-protection mechanisms of these materials operate on the same ablative principles as those used to protect the astronauts during reentry. To demonstrate their use in a full-scale application, an airplane fuselage was fitted with the materials and tested in a jet-fuel fire.

This paper describes the fire-protection system and the fire test and presents an analysis of some of the results. It should be emphasized that this constitutes a progess report and that a number of problems remain to be solved before such a system can be used for passenger protection.

PREPARATION OF TEST FUSELAGE

Considerations for Passenger Protection. In the design of a test to demonstrate how these materials could be used to protect passengers, two factors influencing survival in a crash fire must be considered. First, the penetration of heat must be minimized. At the same time, a way must be devised to prevent the intrusion of smoke and toxic gases, which can be lethal even though the temperature is controlled.

A factor that influences both of these threats in the case of a survivable crash is the structural damage that results in rupture of the fuselage. Crash damage was not considered in the present test nor was the presence of windows, which also could be a point of heat and gas penetration. These factors have been purposely omitted because it was believed that the basic concept of passenger protection should be explored first. The effect of crash damage and the protection of windows will be included in future studies.

Installation of Fire-Protection System. Avco Systems Division of Lowell, Massachusetts, under contract to NASA, installed the fire-protection system and conducted the test. For the test Avco procured a surplus McDonnell Douglas C-47 airplane and removed a 7.9 m (26 ft) long section from the fuselage ~~(Figure 7).~~[1] They divided the section and capped either end by steel bulkheads, making two equal sections typical of traditional airplane construction. One half was left essentially unchanged; the other half was fitted with the thermal-protective materials to form a shell around the passenger compartment. Thus, the test would validate feasibility of a retrofit system for existing aircraft.

~~The details of the installation of the fire-protection system are shown in Figure 8~~. The circular frames were first painted with intumescent paint 0.13 cm (0.05 in.) thick. Next, a layer of loosely woven fiber-glass matting was bonded to the skin. The polyisocyanurate foam was sprayed over the matting and was built up to the full 6.4-cm (2.5 in.) depth of the frames and 5 to 8 cm (2 to 3 in.) over the floor structure. Excess foam was trimmed off. To finish the installation, a liner of fiber-glass-epoxy laminate 0.08 cm (1/32 in.) thick was cemented to the foam and then riveted to the frames. This laminate is similar to airliner decorative interior paneling. The floor foam was also covered with the laminate, and all joints were sealed to exclude smoke and gases. ~~The properties of the foam used in the test are given in table 1.~~

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[1] The tables and figures referenced are not included in this report.

In the unprotected section, the space between the aluminum skin and the interior paneling was filled with 5 cm (2 in.) of fiber-glass batting, a material typical of conventional aircraft insulation.

The steel bulkheads that divided the protected and unprotected sections and capped the two ends were insulated with a 2.5-cm-thick (1 in.) commercial firewall insulation covered with 8 cm (3 in.) of fiber-glass batting.

Instrumentation and Test Arrangement. The fuselage was instrumented to measure both the exterior and interior thermal environments. Thermocouples were used to measure temperatures both inside and outside the cabin. The exterior heat flux was measured by slug-type calorimeters.

~~The fire-test arrangement is illustrated in Figure 9.~~ The test was conducted at Otis Air Force Base, Massachusetts. The fuselage was placed directly on the ground and was flanked by two shallow pits about 9 by 15 m (30 by 50 ft). Water was placed in the bottom of the pits, and 9.5 m^3 (2500 gallons) of JP-4 fuel was floated on top of the water in each pit, forming two large fuel ponds. Water-cooled probes containing motion-picture cameras and gas-sampling equipment were positioned at either end of the test fuselage so that they could observe the interior of each section. The probes were arranged so that they could be withdrawn when temperatures became excessive. Several cameras were placed around the vehicle to record the test.

~~The exterior of the fuselage before the test is shown In Figure 10. The interior of the protected section before the test is shown in Figure 11.~~ Simulated exit signs and an optical target were installed to permit evaluation of possible smoke effects. The interior of the unprotected section appeared much the same as the protected section, except that no exit signs or optical target was installed.

Test Plan. The plan was to ignite both ponds of fuel simultaneously at several points to obtain a uniform buildup of flames over the surface of each pond. The quantity of fuel and configuration of the ponds were calculated to envelop the fuselage completely with flames and to expose the vehicle to maximum heat flux for 10 minutes. It was believed that the unprotected section would be destroyed within 1 to 2 minutes. The protected section hopefully would survive the fire, but fire trucks were stationed nearby in the event that certain monitored thermocouples indicated flame intrusion.

FIRE TEST

The test was made on August 13, 1970. Within ½ minute after ignition, the fire was fully developed. By this time, smoke had already started to penetrate the unprotected section. Occupants of this part of the cabin would have had to have evacuated the vehicle by this time to have survived. ~~Two views of the fire during the test are shown in Figure 12.~~

Throughout most of the test, the entire test section was completely engulfed in flames. Because of the volume of flames and smoke, visual observation of the test section was difficult. About 5 minutes after ignition, a light wind arose from the southeast and directed the flames so that occasionally the end of the protected section was visible. Accompanying this flame shift was a tremendous vortex action of flames around the entire fuselage. This swirling action continued for about 30 m (100 ft) upward. Peaks of the flames reached a height of approximately 60 m (200 ft).

Motion pictures of the interior of the unprotected section, although obscured by dense smoke, show flame penetration within 1 minute after ignition. After 2 minutes, the unprotected section apparently collapsed and was completely destroyed.

Meanwhile, in the protected section, the motion pictures showed no smoke, the gas-sampling probe showed no toxic gas, and the thermocouples showed no temperature change. A power failure prevented further motion pictures of the interior and necessitated removal of the probe containing the motion-picture cameras and the gas-sampling equipment after 5.5 minutes. The last gas sample was taken 5 minutes after ignition and still showed no toxic gases.

The fire lasted for 12 minutes, at which time the fire in the ponds burned out, and only residual flames remained around the edges where fuel had soaked into the dirt mounds surrounding the ponds.

Following the test, the visual comparison between the protected and unprotected sections was dramatic. ~~Figure 13~~ shows virtually no trace of the unprotected section, whereas the foam-protected fuselage is intact. The interior appears habitable, ~~as shown by Figure 14.~~ Some time during tailoff of the fire, flames reached a relatively unprotected floor seam along the top of the dirt mound supporting the test section. Heat penetrated at this point, and eventually resulted in a slight burn-through, which caused considerable blackening of the walls. This occurred after the main fire burned out and is attributed to the design of the test and not to a failure of the thermal-protective system.

Soon after the fire died down, fire hoses were played on the test section, to preserve it for study, and on the remaining flames around the edges of the ponds.

RESULTS AND DISCUSSION

Cabin Air Temperatures. The cabin air temperature histories were used to analyze the results. ~~These histories are plotted in Figure 15.~~ In the unprotected section, the air temperature rose to 300° C (600° F) in less than 2 minutes after the start of the fire and was climbing rapidly. By this time, the unprotected section was destroyed. In contrast, the temperature in the protected section changed very little for the first 6 minutes; then, as the heat finally penetrated, the temperature rose faster, reaching 150° C (300° F) as the fire burned out in 12 minutes.

To give an idea of the chance that passengers might have had of surviving inside the cabin, a curve labeled "Human tolerance limit" has been plotted. This curve is a composite of two studies of exposure of humans to extreme heat and represents more severe conditions than existed in our test. Also shown for comparison is the exposure envelope for the sauna-bath ritual, which calls for repeated exposures of 10 to 15 minutes at temperatures from 80° to 100° C (175° to 210° F). This is done for the health. The fact that the temperature in the protected section just reached the human tolerance limit (for more severe conditions) in 12 minutes, as the fire burned out, indicates that, if temperature were the only consideration, passengers could have survived for this time.

Generation of toxic gases is as important a consideration as temperature. Up to 5 minutes into the test, no toxic gases were generated. At this point, the gas-sampling probe was withdrawn; therefore, no measurements were made late in the test. During the last few minutes before burnout of the fire, segments of the fiber-glass-epoxy liner reached temperatures at which partial decomposition of the resin might have occurred. Gases might have been generated that could have been somewhat toxic. Although such gas generation was a possibility, the amount of toxic fumes was not believed to have been sufficiently high to have influenced survivability, even at 12 minutes.

If this test represented an actual airliner crash fire at an airport, fire-fighting equipment generally could have reached the airplane and extinguished the fire in less than 8 minutes. At this point in the test, conditions were much more favorable for survival than at 12 minutes, and there would be no question of either heat or toxic gases endangering life in the cabin. Thus, the concept of passenger protection was adequately demonstrated by this test.

Consider again briefly the analysis of the cabin air temperature. After the fire burned out in the ponds, small flames remained along the sides of the test section from residual fuel that had soaked into the dirt mounds surrounding the ponds. At 12.5 minutes after the start of the fire, the air temperature suddenly increased, indicating flame intrusion into the cabin. The cracks at the floor-wall intersection are believed to have occurred at this time. The cause of the cracks, which resulted from melting structure, is discussed later. The flame intrusion was probably rather small, being limited to the low flames remaining at the edges of the ponds. At 14 minutes, water hoses were played on the protected section and on the remaining flames, causing the cabin air temperature to drop rapidly.

Sources of Cabin Heating. Although the system of foam, paint, and fiber-glass liner gave satisfactory protection, ways were explored to improve the system, with the objective of indicating how the weight might be reduced. The most useful information from this standpoint is the thermal data. Accordingly, these data were analyzed to identify and evaluate the sources of heating. To aid in the analysis, temperature histories at various locations in the cabin for the last 5 minutes of the test were plotted. ~~A typical history for three locations in the cabin is given in Figure 16. Shown in this figure~~ is the temperature of the air measured in the middle of the cabin, on the fiber-glass liner at a location alongside the air thermocouple, and in the foam 0.6 cm (1/4 in.) away from the fiber glass. Note that the temperature of the air was higher than that of the fiber-glass liner, and the liner temperature was higher than that of the foam. This means that the air was heating the sidewall of the cabin. This reversal in heat-flow direction was unexpected, and it indicates that most of the cabin heating came from heat leaks rather than through the main area of the side walls.

Two sources of heat leaks are identified by the temperature~~ histories shown in Figure 17~~. The temperatures were measured over a frame and on the fiber-glass liner opposite a region of the foam that had fissured. At both of these points, the temperatures were well above the air temperature. These temperature histories typify the two primary sources of heat leaks. The frames formed highly conductive heat-flow paths through the foam. Calculations indicate that about one-third of the total heat input to the cabin for the last 5 minutes of the test came through the frames. Fissuring of the foam was the second source of heat leaks. The sudden increase in fiber-glass-liner temperature indicates the appearance of a fissure in the foam. These fissures apparently were the primary source of heat leaks into the cabin, and, according to calculation, contributed over half the heating of the cabin. ~~A photograph of these fissures after the test is shown as Figure 18.~~ The deep cracks, some of which penetrated clear to the fiber-glass liner, were obvious heat-flow paths to the liner.

To minimize heating from the frames, the obvious solution would be to insulate the fiber-glass liner from the frame flanges. Because of its low thermal conductivity, isocyanurate foam would be a good material for this application. Calculations indicate that, if 1.3 cm (½ in.) of foam were placed between the frame flanges and the fiber-glass liner, the heat input from the frames could be decreased to one-fifth of the value with no insulation.

The problem of fissuring of the foam is one that needs further study. Tests have shown that isocyanurate foam in the lower-density range (30 to 40 kg/m³ (2 to 2.5 lb/ft³)) does not fissure. Laboratory studies made since the fire test show that the lower-density foam, because of its greater integrity, provides thermal protection equivalent to that of the higher-density foam (65 kg/m³ (4 lb/ft³)) used in the fire test. This means, of course, that the lower-density foam should give as good protection in a fire as was provided in the test by the higher-density foam. Use of the lower-density foam would have the advantage of providing a much lighter installation.

There are several possible explanations for the fissuring. The most obvious one is that the higher density creates greater stresses upon heating of the foam than the lower density. Spraying the foam, which undergoes an exothermic reaction upon curing, against cold aluminum structure might create built-in stresses that are relieved when the foam is heated. Other processing problems could also have led to the conditions that caused fissuring. These various possibilities must be studied to eliminate fissuring.

Floor-Line Failure. Another area for improvement is the design of the floor-line protection. In order to understand how to improve the design, the cause of failure during the fire test should be examined. ~~Figure 19 illustrates how the failure developed.~~ Dirt had been banked part way up the fuselage wall to create a mound that formed one side of the fuel pond. The mound stopped just below the floor line. This protected the bottom part of the fuselage from the fire, but left exposed a portion of the structure just below the floor line. Heat from the fire finally melted the exposed frames to which the floor beams were fastened. Thus, the support for the floor was removed and this caused the floor to sag just as the fire was burning out. This opened the floor-line cracks and allowed the flames to enter the cabin.

In the foam installation, the floor foam was placed on top of the floor structure, where it did not protect the primary structure. This installation proved satisfactory for the test of the protective concept, but an improvement in design of the protective system would be required for an operational installation. To protect the floor structure properly, the foam should be placed under the structure, ~~as shown in Figure 20.~~ The foam should surround the primary structure to protect it from melting.

Weight Penalty. Because of its ablative character, the fire-retardant foam generally provides increased fire protection with increase in density. Accordingly, the foam in the test fuselage was made heavier than usual, with the intent of providing protection equal to the protection that would have been obtained from a thicker application of lower-density foam in a larger airplane. Analysis of the data from the fire test indicates that the foam installation was heavier than needed for adequate fire protection.

Now consider the various factors that would permit a reduction in weight. First of all, as was mentioned previously, by minimizing the heat leaks, one could expect improved thermal performance, which would permit a reduction in weight. In fact, the indication was that the foam density could be reduced from 65 kg/m^3 (4 lb/ft^3) to about 40 kg/m^3 (2.5 lb/ft^3) with no reduction in performance. Also, by designing for a shorter protection time, such as 8 minutes instead of 12 minutes, the required protection and the corresponding weight could be further reduced.

Based on these considerations, an estimate was made of the weight penalty for installation of a fire-protective system in a typical modern-day airplane – an airliner with a gross weight of 180,000 kg (400,000 lb). The increase in weight is estimated to be 1.5 kg/m^2 (0.3 lb/ft^2) of protected surface area. This would increase the gross weight 770 kg (1700 lb). The corresponding increase in structural-weight fraction would be from 30.0 to 30.4 percent.

It should be pointed out that the protective system discussed in this paper would be essentially a retrofit installation for airplanes currently in service or in production. The foam would be added for the single purpose of fire protection. No advantage would be taken of its other useful characteristics, such as high compressive strength and compressive modulus or acoustical damping properties. To utilize the foam most effectively, the foam and structure should be integrated at the beginning of the structural design phase for a new airplane. With this approach, it is conceivable that the structural gain would permit the addition of foam with no weight penalty.

CONCLUDING REMARKS

A test that constitutes a first step in developing a system to protect passengers in a crash fire has been described. Many problems, such as protecting against fuselage rupture and providing protection for windows, must be solved before such a system can be used. Nevertheless, results of the test give promise of providing protection for passengers caught in a crash fire.

THE PERFORMANCE OF LIGHTWEIGHT PLASTIC FOAMS DEVELOPED FOR FIRESAFETY

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Presented by Dr. John A. Parker at the WESRAC-Fireproofing and Safety Symposium, May 27, 1971, Los Angeles, California

ABSTRACT

Research on the chemistry of ablation for protection of spacecraft during atmospheric entry has led to the development of a new class of fire-retardant materials; namely, lightweight plastic foams. The foams have been developed principally to protect aircraft structures and externally mounted fuel tanks from onboard fires in flight.

Fire-retardant foams have been made from urethane, isocyanurate, and polybenzimidazole. The density of the foams ranges from 2 to 30 lb/ft^3. Addition of randomly placed quartz fibers to the urethane and isocyanurate foams increases their density and improves the stability of the char formed on heating. For example, by adding fibers in a 10-percent concentration, the density of the urethane foam is tripled and the fire-protection capability is increased fivefold. The fire-protective capability of the isocyanurate foam system is twice that of the urethane foam and four times that of commercial isocyanurate fire-retardant foam.

The various fire-retardant materials are described in this paper, and the performance of these materials when exposed to a fuel fire is illustrated. Wherever possible, performance is compared with presently available commercial developments. Although the materials were developed primarily for aircraft use, a discussion is given of other possible areas of application.

INTRODUCTION

The work at Ames Research Center on fire protection and fire suppression was started in September 1967 and was motivated by the realization that the principles utilized in the protection of entry vehicles from aerodynamic heating could be used to give some measure of protection from both spacecraft and aircraft fires. The use of a low-density, polyurethane-based foam material to suppress a fire and to provide protection for the structure of an aircraft or spacecraft will be discussed and described.

In this program, certain ground rules were established that hopefully would avoid the normal long leadtimes between the generation of an idea and the production of a final useful product. First, a team of specialists from a number of organizational segments at Ames Research Center was gathered so that special skills could be concentrated on the problem in all disciplines needed. Second, it was stipulated that only commercially available materials were to be used in the first phase of the program to avoid the time delays in inventing and producing new material systems. These actions provided rapid progress and produced a useful product that could be improved further with additional work.

THEORY

The protection of any structure, entry vehicle, or aircraft against damage by heat can be accomplished by the same basic protective mechanisms. The source of heat is not important; heat generated by fire or by a hot gas cap surrounding an entry vehicle is much the same. To damage a structure, heat must be carried to the structure by either free or forced convection or by radiation. Therefore, in principle, any or all of the heat-protective mechanisms can be utilized to afford protection (fig. 11-1).

The simplest form of heat protection is one that provides a high resistance to heat flow between the heat source and the structure. Low-density foam with a low thermal conductivity provides this feature. Another important mechanism, often overlooked in fire protection systems but widely utilized in spacecraft thermal-protection systems, is the release of gases from the thermal-protective material when subjected to heat load. These gases serve to protect the system in two important ways. First, gases near the surface flow against the incoming heat, thus impeding the flow of heat to the surface. For example, in a spacecraft being protected against reentry heating, gases can block nearly all the convective heat flow. Second, in protecting against a fuel fire, gases can be made rich in halogens that can chemically scavenge the chain carriers by which fuel flames are propagated and thus serve as fire-extinguishing agents. This principle has been utilized in the polyurethane systems.

Another mechanism that affords protection against fires is a production of char resulting from the action of heat on the materials. If char with low thermal conductivity and high oxidation resistance can be formed, it will not only afford protection by virtue of low thermal conductivity, but the surface will reach a high temperature and thus will be capable of reradiating a large fraction of the incident heat load. This mechanism is utilized in the systems that are being developed. In the polyurethane foam material, polyvinylchloride has been added, which, when heated, causes the polyurethane to form a stable, tough char of low thermal conductivity. This idea came directly from work on thermal protection systems for reentry vehicles.

An important point about the systems to be discussed is that these systems react to an applied heat load to provide a number of protective mechanisms not present in a system that does not respond to a fire. Thus, these are not passive systems; rather, they are dynamic systems that provide protection when exposed to a fire.

MATERIALS

The properties desired in a foam system for fuel-fire protection are as follows.

1. Impact ignition

   a. Low density-void-filling capacity to eliminate atomization of combustible liquids

   b. Closed-cell foam structure with self-sealing skin to prevent outpouring of combustible liquids

   c. Pyrolysis at low temperature and at high rate to give hydrogen bromide, hydrogen chloride, or hydrogen fluoride and free radicals to inhibit ignition

2. Sustained fire protection

   a. Decomposes at moderate rate to give low molecular weight species to suppress flames

   b. Excellent low-heating-rate ablation efficiency to minimize heat transfer to aircraft structures

Several foam systems have been developed to provide a selection of materials with specific properties for various applications.

Urethane Foam (Ames Type 5I)

Urethane systems were examined and modified to yield the 5I composite foam, a base of α methyl glucoside and propylene oxide. A halogenated polymer, polyvinylchloride, which increases char yield and pyrolizes to release HCl gas that acts as a free-radical flame scavenger, was added to this basic polymer system. An inorganic salt, potassium fluoroborate, also was added to the foam system. The function of the inorganic salt is twofold: the salt produces fire-quenching or suppressing species, and the decomposition products of the salt potentially can react with the degradation products of the urethane foam.

The specific action of these alkali metal salts of fluoroboric acid is shown in figure 11-2. Degradation forms boron trifluoride, which can serve as a fire-quenching species and also react with the carbonaceous char to form carborane or boron carbide-like structures. A cross section of 5I foam undergoing thermal degradation and frozen in time is shown in figure 11-3. The outgassing of suppressant and scavenging species that cool the integral char structure can be seen as they are injected into the boundary layer. The highly emissive surface reradiates much of the incident flux, resulting in better sustained thermal protection (ref. 11-1).

The third additive that can be incorporated in foams to provide fire-quenching or suppressing species is microencapsulated volatile halogen-bearing molecules. With thermal degradation of the microcapsules, the halogen-bearing molecules are released, resulting in dilution of ejected gases and also providing species that can act as free-radical quenchers on the fuel-fire propagation species of the flame. A microcapsule, or balloon, and fire-retardant filler are shown in figure 11-4.

Urethane Systems (Fiber Loaded)

In areas where higher shear loads, both mechanical and thermal, are encountered, fiber-loaded 5I foam may be used. Of many fibers tested, short glass or quartz fibers (about 1/4-in. long) in a 10-percent-by-weight concentration performed very efficiently. The addition of these fibers usually will increase the density of foam approximately threefold. However, the improvement in other thermal physical properties may outweigh the weight penalty. In its density range (i.e., 5 to 6 lb/ft^3), this foam, designated 5I10AQ, performs very well under low heating rates.

Isocyanurate Rigid Foam

To obtain higher char yields than could be obtained with the urethane system, further research was needed. A new system, polyisocyanurate polymers, seemed to be one of the most promising (ref. 11-2).

An isocyanurate ring structure is formed by the cyclization of three isocyanate groups. The use of a polyfunctional isocyanate, such as diphenyl methane diisocyanate (MDI) or a polymeric isocyanate (PAPI), gives rise to a polymeric isocyanurate polymer. Polyisocyanurate polymers exhibit improved temperature stability when compared to a polyurethane polymer. The cyclization reaction is illustrated in figure 11-5.

The practical problem with the polyisocyanurate polymers for use in low-density foam materials is that of brittleness or friability of the foam structures. The brittleness is attributed to the cyclic structure that restricts motion in the polymer chain. The brittleness associated with the polyisocyanurate polymers has limited the use of this polymer sytem in low-density foam applications.

Investigations into methods to reduce the brittleness of the polyisocyanurate polymers were undertaken. The technique demonstrated to have the most utility is that of introducing urethane linkages into the polyisocyanurate polymer. The disadvantage of this approach is the introduction of less stable urethane linkages in the system, which can lead to flammable gaseous species evolved during thermal degradation; so the choice of polyol to be used and the amount are extremely important. First, the polyol fragment must result in a char independent of the urethane linkage. Second, the reaction to form a high-temperature stable structure should occur before the initial urethane linkage degradation to minimize volatile fragment formation. Third, the polyol should have a low hydroxyl number so as to convert as few as possible of the isocyanate groups to urethane linkages in the polymer system. Fourth, the polyol should have a high molecular weight and low functionality so as to impart mechanical flexibility to the polyisocyanurate-polyurethane polymer structure.

Acrylonitrile was selected as the grafting monomer because nitrile linkages cyclize to form high-temperature stable heterocyclic ring strutures when exposed to a thermal environment. Potassium fluoroborate, which improves char strength in polyurethane foams exposed to thermal environments (ref. 11-1), and zinc oxide, which aids in the curing of the acrylonitrile fraction, were added to the basic polymer system.

When a closed-cell foam is heated, the gas pressure in the cells increases. At approximately 250° F, the foam is softened to a degree that the increased gas pressure causes the foam to swell. Continued heating in air causes the foam to begin degrading to a carbonaceous char structure while outgassing various compounds and shrinking in size. These changes in size are plotted as a function of temperature in figure 11-6. It may be seen that the isocyanurate foam (X-ISO) maintains better dimensional stability than the urethane foam (Ames 5I). If the thermal gravimetric analyses (i.e., weight loss with increasing temperature) of these two foam systems are examined (fig. 11-7), it can be seen that the major reduction in weight occurs at a higher temperature with the X-ISO versus the 5I foam. At the higher temperatures, the increased weight of the X-ISO foam also can be seen, with the realization that this almost 50-percent increase at 1000° F represents the "char yield" that it was hoped to increase.

Increasing the char yield is shown to be a linear function of the molecular structure of the polymer (fig. 11-8 and ref. 11-3). It now can be seen that the consequence of the cyclization of three isocyanate groups to form the isocyanurate ring structure led to a higher number of multiple bonded aromatic linkages per gram. Therefore, the higher percentage of char yield could be foreseen.

Higher Density Rigid Foams

Polybenzimidazole (PBI) (fig. 11-8) currently is being investigated for possible use as a refurbishable spacecraft heat shield. In this application, a foam matrix of PBI would be impregnated with a suitable, fire-extinguishing, ablating material. When it is exposed to a heat source, the impregnated material would ablate away, leaving the PBI foam. The PBI would then be reimpregnated and reused.

Another high-density material that is being investigated for high-temperature applications is polyphenylene. Although not directly used for firesafety, polyphenylene material with a 90- to 95-percent char yield currently is being made at Ames and tested for possible brake-lining application.

TESTING RIGID FOAMS

Sustained thermal protection presents a need for more sophisticated tests than have been or are in use as screening tests at many laboratories. The usual small-scale tests provide only limited data that are useful primarily for classification of a new material. On the other hand, full-scale simulation tests are too expensive, unwieldy, and time-consuming for daily screening of candidate materials. Thus, a new test was required by which the fire-protective effectiveness of the newer class of foam composites could be evaluated.

A free-burning JP-4 fuel fire gives a total heat flux of approximately 30 000 Btu/ft^2-hr, of which the radiative component is approximately 90 percent (ref. 11-2). To achieve a test that would approximate this environment, a specialized thermal test fixture was developed. This thermal test (T-3) allows for limited control of environment and rapid screening of materials. Data are acquired for backside temperature as a function of time, and observations are made of the physical behavior of the sample in the environment.

A schematic drawing of the Ames T-3 thermal test facility is shown in figure 11-9. An oil burner is used to burn JP-4 jet aviation fuel at the rate of approximately 1-1/2 gal/hr in the firebrick-lined chamber, and the combustion products are exhausted out the top rear of the unit. The test facility has the following test areas: (1) directly over the combustion chamber, (2) in the flue to the rear of the combustion chamber, and (3) inside the combustion chamber under direct fire impingement. The flux levels available in each testing area are indicated in figure 11-9. For test area 1, the major portion of the heat flux (90 percent) is radiative. Area 2 is a reducing environment where the mode of heat transfer is distributed equally between radiation and convection. In area 3, the main mode of heat transfer is mainly convective, with direct impingement on the surface of the material.

The T-3 thermal facility is used for foam-screening tests. For most foam screening, area 1 is used, and the flow rate to the burner is adjusted to maintain 10 to 10.5 Btu/ft^2-sec (36 000 to 37 800 Btu/ft^2-hr) total heat flux. The area 1 temperature at the hot face of the sample is maintained at 1700° F mimimum throughout the test.

The foam samples used for the test are 12- by 12- by 2-inch specimens. The sample assembly is shown in figure 11-10. The samples are backed with 1/16-inch-thick 2024-T4 aluminum alloy bonded to the surface of the foam with an epoxy resin. The backplate has a 2.5-inch-diameter hole in the center, to which is bonded a 2-inch-diameter aluminum calorimeter of the same class and thickness. The aluminum back or supporting plate has a dual function. First, it represents a more practical approach to the application in which the foam will be used; and second, it acts as a supporting plate for the foam in the T-3 test and prevents any warping of the foam sample during test.

After a period of conditioning at standard laboratory conditions (1 week at 74° F and 50 percent relative humidity), the samples are tested in the T-3 thermal facility. A mask of asbestos millboard, 12 by 12 inches, with a 7-inch-diameter hole in the center, is placed against the face of the foam and then placed over area 1. The aluminum backface temperature is recorded continuously for the test duration.

Plotted in figure 11-11 are time-temperature histories for a bare control plate, the Ames-modified urethane system 5I (ref. 11-1), the Ames-modified polyisocyanurate system, and a conventional polyisocyanurate foam. The plot shows that the Ames-modified polyisocyanurate foam is far superior to the conventional polyisocyanurate foam presently available. Even the Ames-modified polyurethane foam gives backface temperature-time histories equivalent or better than the conventional polyisocyanurate foam. The major reason for the poor showing for the conventional polyisocyanurate foam is that deep fissures develop during thermal test. Application of the backplate or support plate to the conventional polyisocyanurate foam results in catastrophic thermal-stress failure, which is characterized by the loud sounds heard during tests. The rapid temperature rise for conventional isocyanurate foam results when fissures progress directly to the temperature-sensing disk area. Apparently, better performance results from samples in which fissuring progresses to the backplate adjacent to the center disk but not directly over the disk. Because the disk is shielded from the backplate, the temperature is not a true representation of the substrate temperature and is not shown on the figure. Even though Ames urethane foam has a char yield less than the conventional polyisocyanurate foam, it may be seen by the plot for backface temperature as a function of time that the Ames material is better than the conventional polyisocyanurate foam because of the superior char integrity of the Ames polyurethane. Therefore, it is significant that a high char yield must be obtained and that char integrity is necessary for sustained thermal protection. (See fig. 11-11 for the Ames isocyanurate foam.)

The physical properties of the modified polyisocyanurate foam are tabulated in table 11-I. The data require little comment other than to note the favorable properties of the polyisocyanurate foams. The tensile and compressive properties of the polyisocyanurate are superior to the Ames polyurethane foam. The most significant feature of the polyisocyanurate foam is the increased times to reach specific backface temperature.

Many factors enter into the improved backface temperature-time histories of the foam composites. These are reradiation from the frontface surface, transpiration cooling, thermal conductivity, endothermic decomposition, and surface recession and thermal conductivity. These factors were improved in the modified polyisocyanurate foam, as indicated by the higher char yield and integrity and lower thermal conductivity, resulting in longer time to reach specific backface temperatures..

NEOPRENE-ISOCYANATE FLEXIBLE FOAMS

To achieve a "nonburning" flexible foam system, Ames modified a neoprene-isocyanate foam by adding a halogenated copolymer, "Saran A," and postcuring the foam to 275° to 300° F to increase char yield; the resulting char yield was 38 percent at 1000° F. These foams were tested ballistically in assemblies such as the one in use at Wright Patterson Air Force Base (fig. 11-12). The internal reticulated foam is present to reduce hydraulic "ram effect" and internal ullage explosions. The candidate foam is placed outside the cell between a function plate and the back cell wall. When corrected for off-bore hits, the number of fires per round in the flexible foam is reduced to zero.

FLEXIBLE FOAM FIRE BLANKET

A utility thermal blanket using the neoprene-isocyanate flexible foam was developed; that is, a 1/2-inch-thick sheet of the flexible foam was placed between two sheets of asbestos, thus forming a sandwich of foam in asbestos. This blanket could be placed over stockpiled materials and afford protection in the event of a fire. To demonstrate the usefulness of the foam, an ammunition can was wrapped with the blanket (fig. 11-13) and immersed in a JP-4 fuel fire. The temperature of the 50-caliber ammunition inside the box was monitored, and the results are plotted in fig. 11-14. The temperature-time history for an unwrapped box also is shown on the same plot. Longer protection times could be expected from a blanket draped loosely over boxes of ammunition than for a single box wrapped tightly as it was for this test.

CONCLUSIONS

It has been shown that the use of low-density plastic foams can be modified for use in effective thermal protection systems. Further work in the areas of reduction of flame spread, smoke generation and classification, and toxic byproducts is continuing.

However, it must be emphasized that the effectiveness of many fire suppressant or extinguishing materials lies in the generation of a large quantity of gaseous products. For the most part, these gaseous products range from mildly to severely toxic.

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11-3. Parker, John A.; and Winkler, Ernest L.; The Effects of Molecular Structure on the Thermochemical Properties of Phenolics and Related Polymers. NASA TR-R-276, Nov. 1967.

TABLE 11-I.- PHYSICAL PROPERTIES OF AMES URETHANE AND ISOCYANURATE FOAMS

[TEST CONDITIONS — 75° ± 2° F, 50 ± 2 percent RH]

Physical properties of Ames urethane and isocyanurate foams	ASTM method	Ames urethane	Ames ICU
Nominal density, lb/ft^3	(D 1622)	2.5	2.5 to 2.7
Thermal conductivity:			
$Btu-in/ft^2-hr-^{\circ}F$	(C 177)	0.175	0.150
$W/cm-^{\circ}C$		0.00025	0.00022
Flame resistance	(D 1692)	Self-extinguishing	Self-extinguishing
Compressive strength:			
Parallel, psi	(D 1621)	25	27
Perpendicular, psi	(D 1621)	15	19
Compressive modulus:			
Parallel, psi	(D 1621)	600	1000
Perpendicular, psi	(D 1621)	360	500
Tensile strength, parallel, psi	(D 1623)	21	30
Shear strength, perpendicular, psi	(C 273)	15	14

TABLE 11-I.- PHYSICAL PROPERTIES OF AMES URETHANE AND ISOCYANURATE FOAMS - Concluded

[TEST CONDITIONS — 75° ± 2° F, 50 ± 2 percent RH]

Physical properties of Ames urethane and isocyanurate foams	ASTM method	Ames urethane	Ames ICU
Water absorption, volume, percent	(D 2127)	5	3.5
Backface temperature			
Time to 200° F, sec	Ames T3	210	366
Time to 400° F, sec	Ames T3	390	786

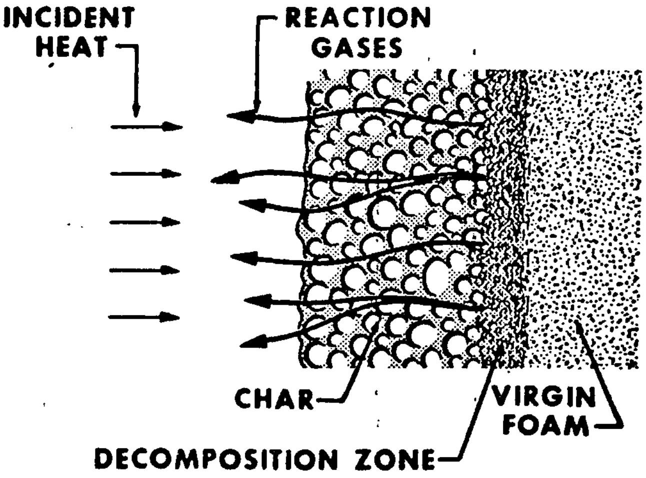

Figure 11-1.- Pyrolysis mechanism of char-forming ablators under unidirectional heating.

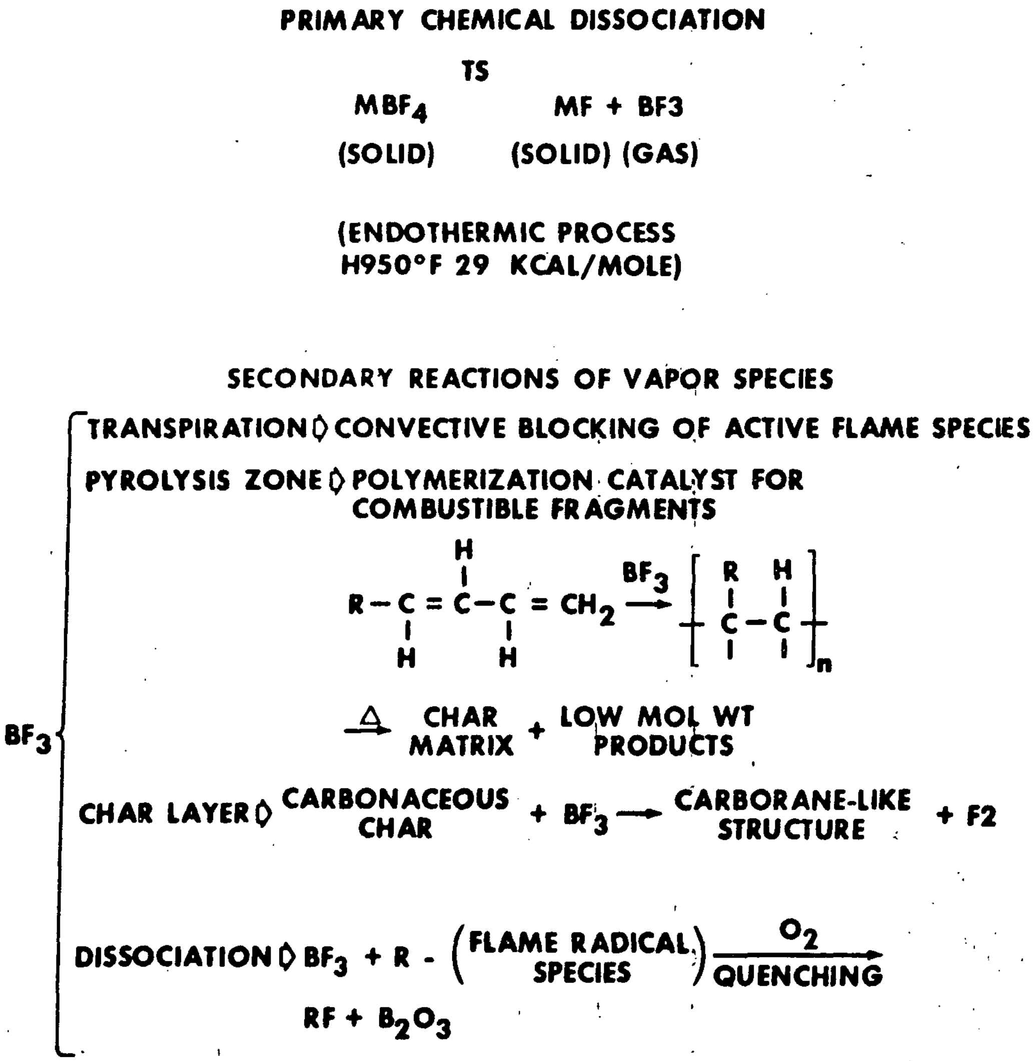

Figure 11-2.- Thermochemical action of alkali fluoroborules.

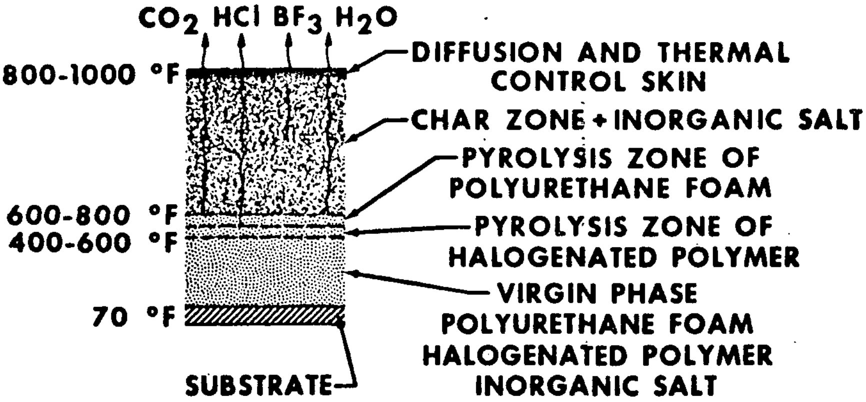

Figure 11-3.- Response of Inorganic salt + halogenated polymeracetate-modified polyurethane foam to the heating input of a fuel fire.

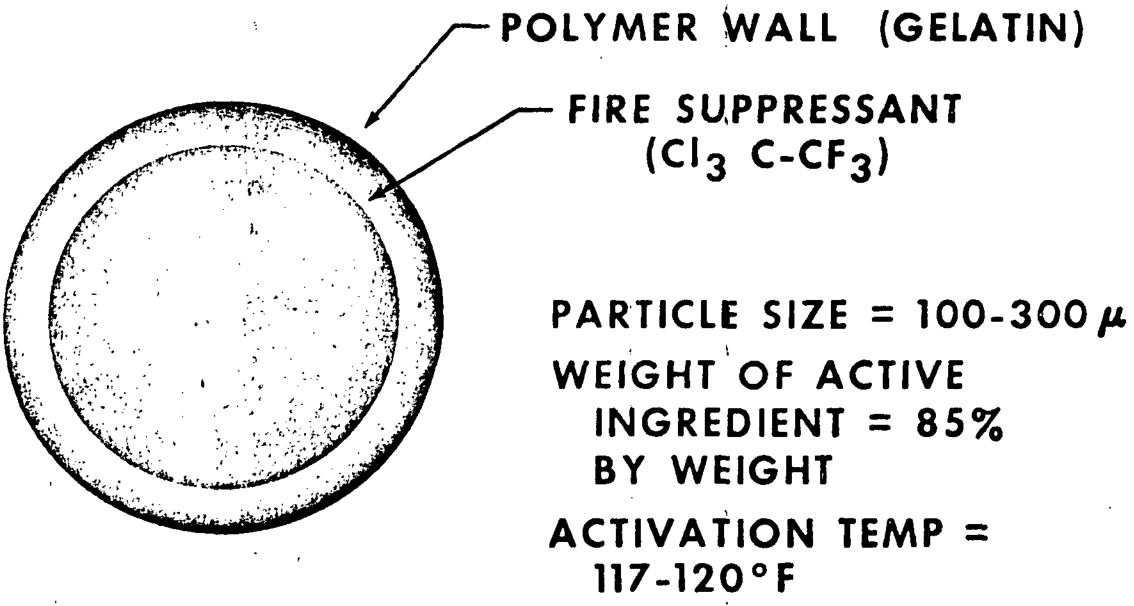

Figure 11-4.- Encapsulated fire-suppressant particle (microballoon).

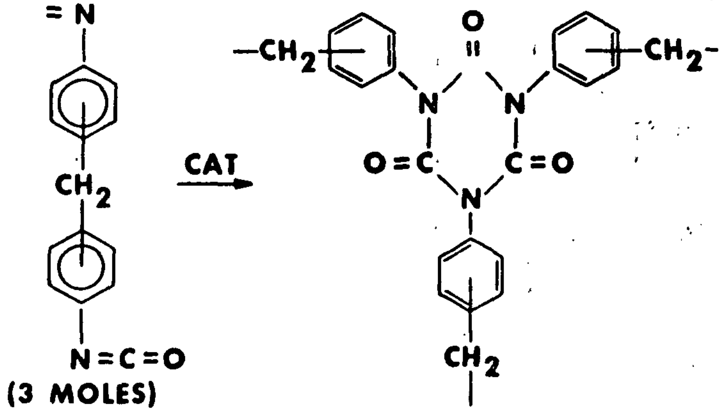

Figure 11-5.- Isocyanurate structure.

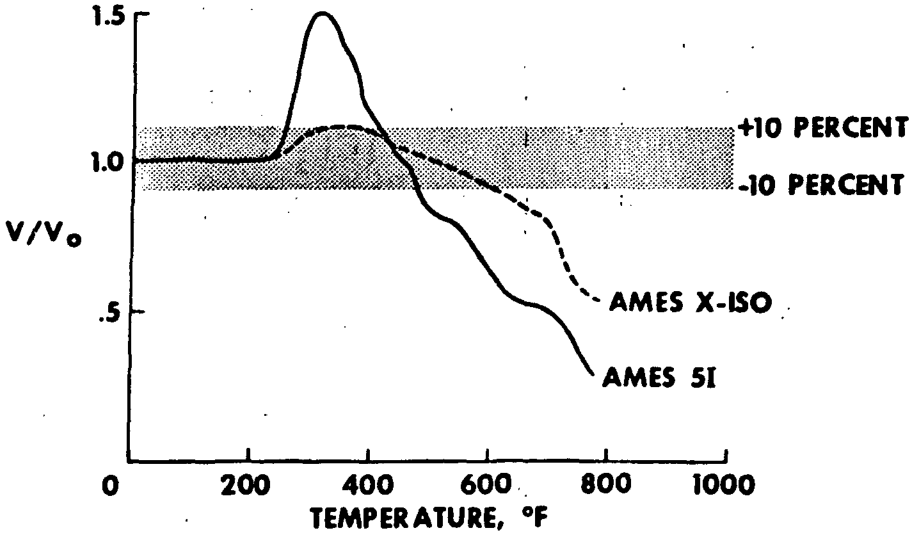

Figure 11-6.- Dimensional stability in air of Ames foams.

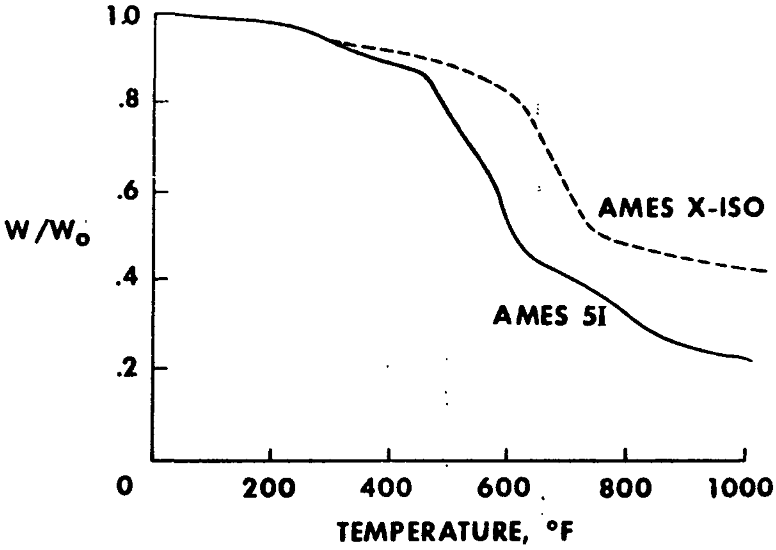

Figure 11-7.- Char yield in nitrogen of Ames foams.

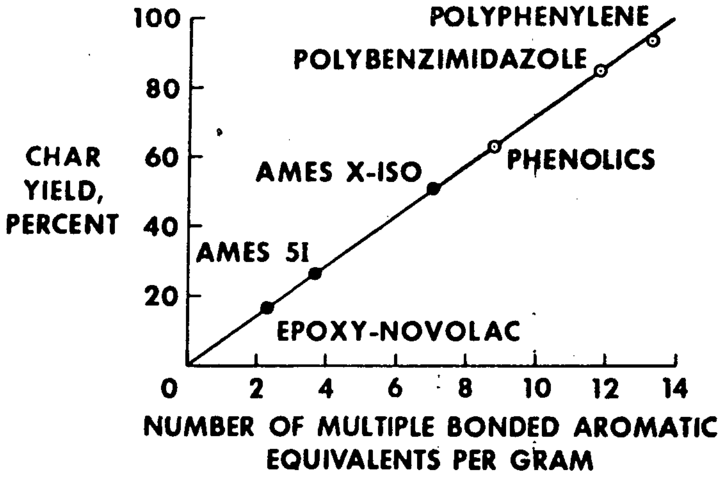

Figure 11-8.- Correlation of primary thermochemical char yield with molecular structure.

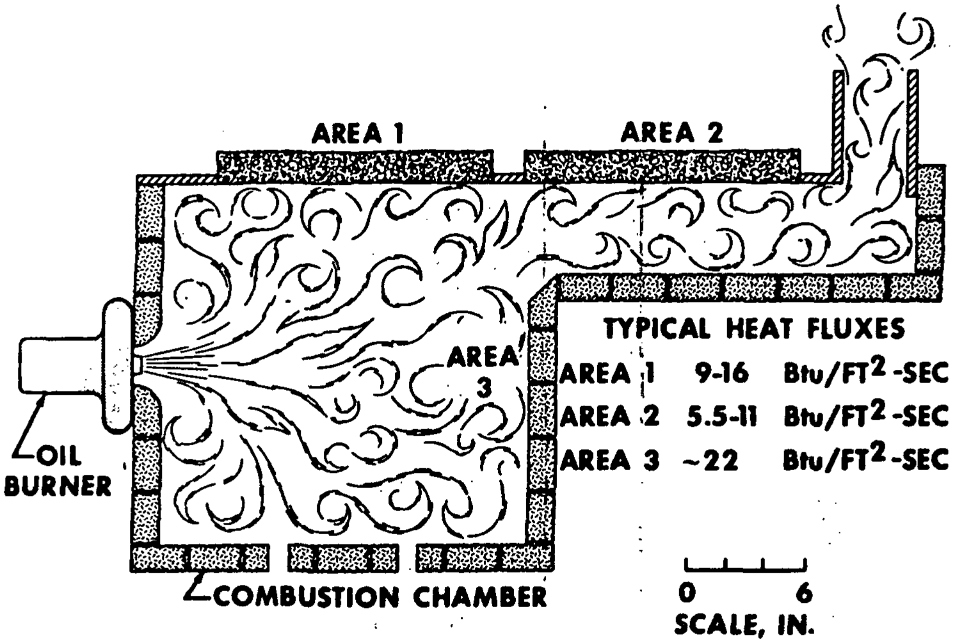

Figure 11-9.- Ames T3 thermal test facility (JP-4 fuel).

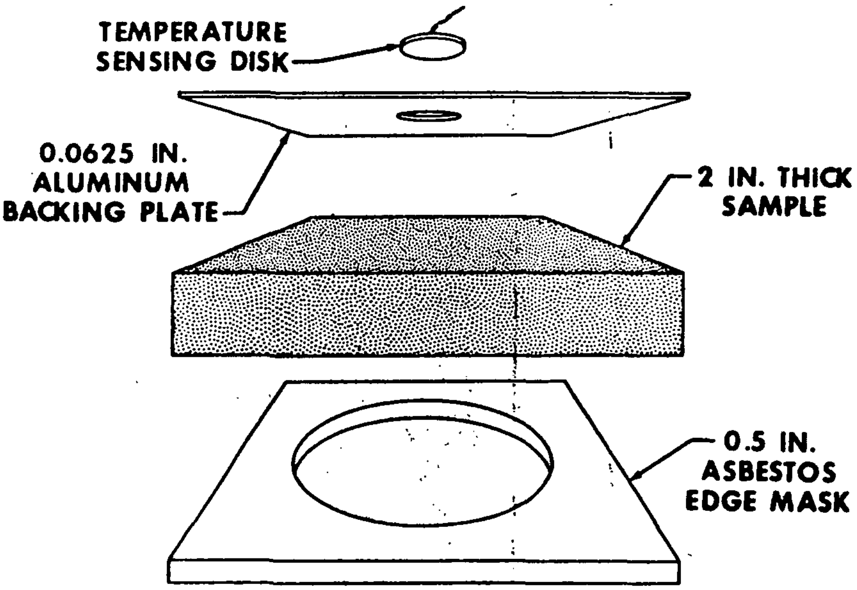

Figure 11-10.- Sample foam assembly.

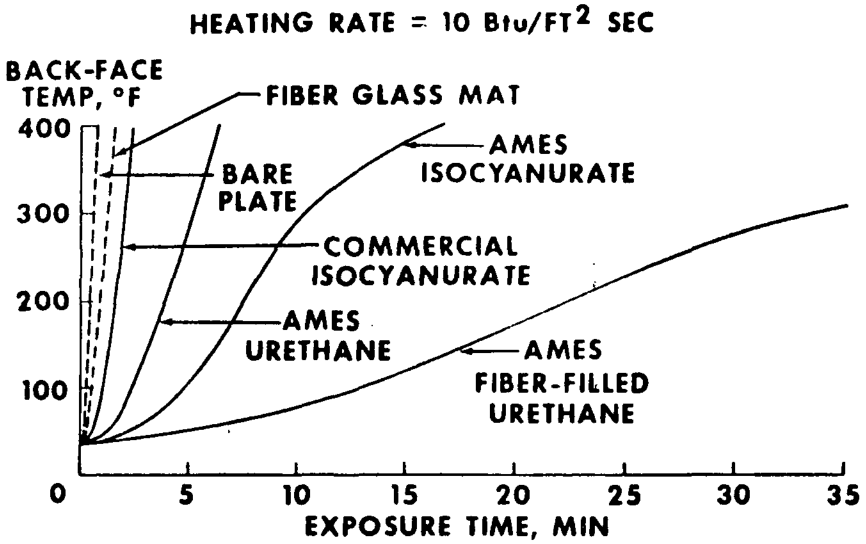

Figure 11-11.- Performance of various fire-retardant foams in JP-4 fuel fire.

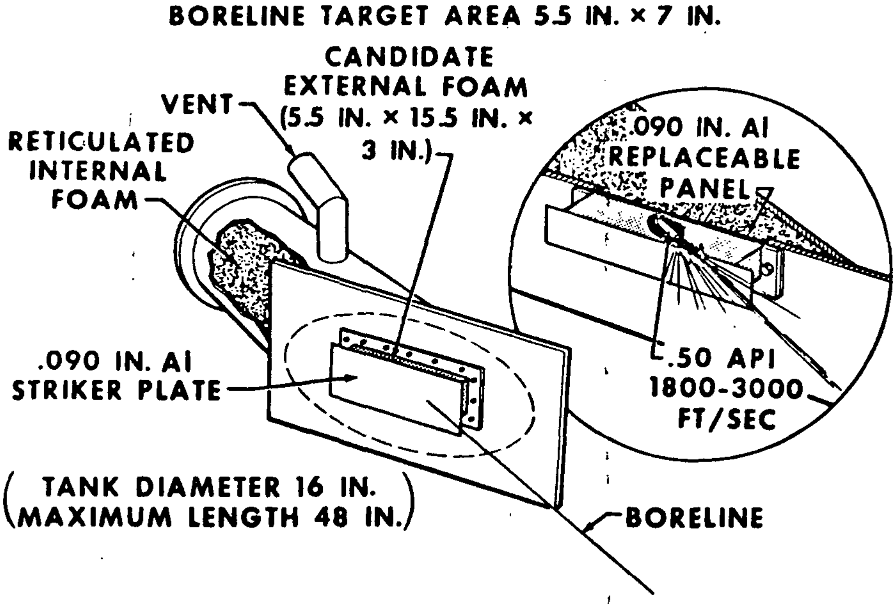

Figure 11-12.- Wright-Patterson Air Force Base test cell-17-gallon capacity tank.

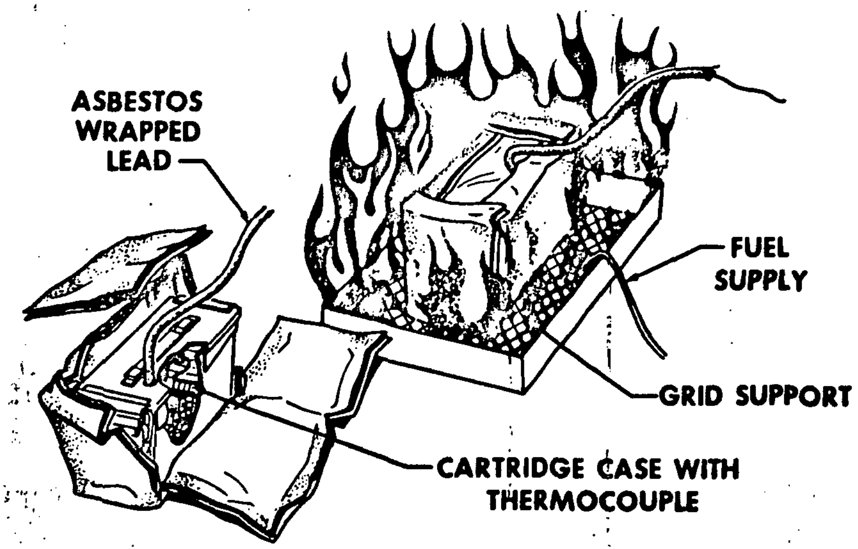

Figure 11-13.- Test of foam blanket to protect ammunition box.

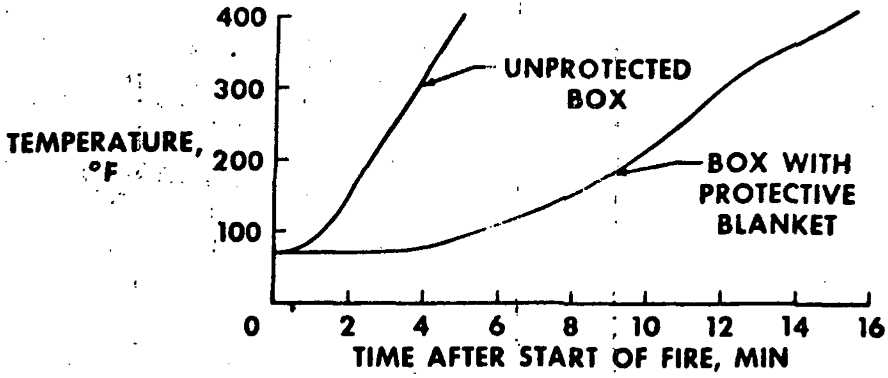

Figure 11-14.- Time-temperature history of 50-caliber cartridge in ammunition box, JP-fuel fire.

INTUMESCENCE: AN IN SITU APPROACH TO THERMAL PROTECTION

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Presented by Dr. John A. Parker at the WESRAC-Fireproofing and Safety Symposium, May 27, 1971, Los Angeles, California

ABSTRACT

The phenomenon of intumescence, the swelling of a substance upon the application of heat, has been used for many years in the form of surface coatings as a means of protecting fire-sensitive building materials. With regard to experience gained at the NASA Ames Research Center in the areas of polymer chemistry and ablation technology for thermal protection, intumescent systems that may serve to protect a variety of heat-sensitive components, such as fuels, explosives, structural materials, and even man, have been reexamined. In this paper, the evolution of intumescent coatings from the older carbohydrate-phosphoric acid systems, through the nitroaniline bisulfate salts originally used by NASA, to the newer nitroaniline-sulfonic acids, quinonedioxime-acid mixtures, and nitroanilinosulfones, is described. In the case of the nitroaniline derivatives, the intumescence is modeled as a thermal self-polymerization of the aromatic compounds passing through plastic states, being expanded by evolving gaseous products to form finely textured, low-density foams. These foams have low thermal conductivity, high emissivity, and good resistance to ignition. The gases that are evolved during the polymerization reaction and that are injected into the fire zone further serve as flame quenchers. The resulting polymeric foams are polyheterocyclic structures similar to polyquinoxalines or polyphenoxazines. The development of several useful coating systems to effect fire protection in a variety of applications is discussed. Potential applications ranging from the prevention of weapons cookoff to the improvement in the firesafety of building materials are illustrated in simulation tests.

INTRODUCTION

As a result of the disastrous fires aboard the Apollo spacecraft and on the aircraft carrier U.S.S. Forrestal in 1967, the attention of the Thermal Protection Group at the NASA Ames Research Center (ARC), whose previous task was the development of heat-shield materials and thermal-protection coatings for spacecraft, was directed to the study of protecting heat- and fire-sensitive materials in general.

One immediate goal was the development of a means of thermal protection for stored bombs to prevent detonation when the bombs are subjected to the heat of burning fuels. The bombs must be protected for a time that is sufficient either to deploy firefighting equipment or to jettison the bombs. To accomplish this short-time thermal protection, it was desired to coat the bombs with a material that would swell, upon heating, to form a thermally resistant insulating layer. This process or phenomenon of swelling with heat is called "intumescence" (ref. 12-1).

Many people are familiar with a form of intumescence in the novelty item known as Pharaoh's Serpents. Another example of this phenomenon is the classroom demonstration that is used to introduce the subject of carbohydrate chemistry to college freshmen. In this demonstration, the dehydrating action of concentrated sulfuric acid on sugar produces a voluminous amount of black, low-density, carbonaceous solid.

The use of the intumescent process in the form of coatings to provide thermal protection for flammable substrates is not new. As an example, such coatings have been applied to cellulosic ceiling tiles for nearly 20 years. Early versions of these coatings made use of a reaction similar to the sugar and acid mixture mentioned previously in that the coatings consisted of a mixture of a carbohydrate, such as starch, as a char-forming material and a dehydrating catalyst, such as ammonium bisulfate or ammonium phosphate, compounded with a binder. Upon heating, these materials initially released ammonia gas, and the resulting sulfuric or phosphoric acid subsequently acted on the carbohydrate to yield the low-density, carbonaceous char, formed by the action of the liberated ammonia and steam (ref. 12-2). Continuing efforts by chemical and coating manufacturers to improve the intumescent coatings, both in the use as coatings and as thermal protectors, have led to the use of various other carbonific substances that usually are drawn from the class of polyols, such as pentaerythritol and dipentaerythritol. Other gas-producing materials and catalysts, such as ammonium polyphosphate, melamine phosphate, phosphoramide, and dicyandiamide, also have been used in improved versions (refs. 12-1 to 12-3). The main drawback to the use of these previously developed coatings has been the lack of long-time stability to outdoor weathering. This deficiency has limited the use of those materials to interior or protected environments. What has been needed is a coating that is able to withstand continuous outdoor exposure — conditions of high humidity, rain, wide fluctuation in ambient temperature, and, for bomb application, exposure to salt spray.

With the advent of new high-temperature and oxidation-resistant polymers, such as polybenzimidazoles, polythiazoles, polyphenoxazines, and polyquinoxalines (refs. 12-4 to 12-7), the possibility was suggested that new kinds of char-forming materials might be developed to secure improved intumescent coating systems with high-temperature resistance that also would be nonburning, nonsmoking, and nontoxic, if a method could indeed be found by which these polymers could be made thermally and in place. A general and idealized sequence of reactions required to obtain stable heterocyclic polymers (in sufficiently low density to be useful) formed by the process of intumescence is shown in figure 12-1. The approach for this research was the selection of monomers or prepolymers that are stable to at least 300° to 350° F and that thermally react at temperatures greater than 390° F to give the thermally and oxidatively stable, aromatic, heterocyclic polymers. During the process, the evolution of some and the partial retention of a fraction of the gases that are byproducts of the condensation polymerization should form a low-density foam in situ. As indicated in figure 12-1, the polymerization reaction must proceed through a molten phase to secure the desired degree of plasticity during the expansion. To obtain efficient thermal protection, the polymerization and expansion reaction should occur preferably in the direction of the applied heating. Another important requirement of this polymerization process is that a sufficiently high degree of polymerization be obtained by the time the expansion is completed to obtain a mechanically coherent foam structure that will not collapse.

To secure a low thermal conductivity, the foam obtained by this process should be predominantly closed cell and of low density. The possibility should exist to select monomers or prepolymers that polymerize to give off gaseous byproducts that, in addition to effecting the foaming of the polymer, can diffuse into the flame boundary to block convective heat transfer (ref. 12-1) and interact with and suppress free-radical chain carriers that are characteristic of the flame-propagation process.

APPLICATION OF THE REACTIONS OF SUBSTITUTED NITRO-AROMATIC AMINES AS INTUMESCENT MATERIALS

The formation of voluminous, black, spongy foam from the action of heat on a mixture of sulfuric acid and p-nitroacetanilide had been described by Alyea (ref. 12-8). In the study made at ARC, a number of variously substituted nitro-aromatic amines were examined for intumescent properties (fig. 12-2).

As indicated in figure 12-2, the expanded black polymer was formed from both o-nitroanilines and p-nitroanilines, as well as from substituted derivatives. These materials gave excellent expansion of 70 to 240 times the original volume. The process was found to occur within a temperature range of 390° to 500° F. Acetylation of the amino group did not seem to affect the intumescent process. It was observed qualitatively that the resultant dark polymeric foam was extremely resistive to the erosive action of an intense hydrocarbon gas flame. Originally, the belief was held that this intumescent reaction of nitroanilines could be caused only with concentrated sulfuric acid; however, subsequently, it was found that the use of concentrated phosphoric and polyphosphoric acids also promoted the reaction.

The observation of the effect of heat and sulfuric acid on p-nitroaniline led quickly to the development of the associated bisulfate salt as a dry compound, which is useful as an intumescent agent. This compound was prepared easily from inexpensive, readily available materials. The preparation and properties of this material are shown in figure 12-3 (refs. 12-9 and 12-10). Upon heating the p-nitroaniline bisulfate to temperatures greater than 430° F, a yield of black foam of approximately 50 to 54 percent by weight is obtained that is stable to temperatures greater than 1020° F.

To investigate in detail the reactions that occur during intumescence, three analytical techniques were used. Thermogravimetric analysis (TGA) of the weight loss of a sample of p-nitroaniline bisulfate was made, elemental analysis of the thermally reacted material was obtained, and, in a separate experiment, the kinds of gases produced were determined by gas chromatography.

An 8-milligram sample of the p-nitroaniline bisulfate described previously was heated in dried, deoxidized nitrogen at a rate of 5.4° F per minute. The weight loss was determined by means of a Cahn recording electrobalance and plotted as a function of sample temperature (fig. 12-4). The empirical formula for the initial salt can be written as shown at the right of figure 12-4. The theoretical weights that correspond to the thermolytic process also are shown. Three distinct and sequential reactions can be seen to occur in going from room temperature to 430° F, at which point, a sudden intumescence is initiated. The weight loss associated with each of these three distinct processes is equivalent, on a mole basis, to the loss of one molecule of water. This loss produces a change in the composition of the residue material as indicated in the empirical formulas at the right of the thermogram. The water produced during this induction phase (that is, before intumescence) does not contribute to the foaming process but rather is injected directly into the adjacent gas boundary. As indicated in the thermogram, intumescence occurs at temperatures greater than 450° F with elimination of sulfur dioxide, and more water is eliminated at temperatures greater than 600° F.

Chromatographic analysis of the gases eliminated during the intumescence confirmed that sulfur dioxide and water, both good flame quenchers, were produced. Elemental analysis obtained on the black intumesced foam that was formed at 482° F was obtained as shown in figure 12-5. The analysis indicates that nearly all the sulfur is lost and all the nitrogen is retained.

Coatings were prepared using the p-nitroaniline bisulfate compound as the intumescing agent. The coatings performed quite well in the proper environment, as will be described subsequently. However, because of the nature of the material (a salt of a weak base and a strong acid), it was easily affected by the presence of moisture, giving an extremely acidic milieu that both affected the vehicle in which it was combined and corroded metallic substrates upon humid exposure. To circumvent these deficiencies, other intumescing agents were desired that were neither easily hydrolyzed nor acidic.

One of the primary reactions between sulfuric acid and nitroaniline is sulfonation of the ring. By keeping mixtures of these ingredients at temperatures below that of intumescence, fair yields of p-nitroaniline-o-sulfonic acid were prepared, isolated as an almost white powder. This compound was found to intumesce quite easily at 450° F and to give a char yield of 50 percent. The product of intumescence resembles and is similar in analysis to the materials obtained from p-nitroaniline bisulfate. The ring sulfonation in this second compound overcame the problem of hydrolytic stability encountered with p-nitroaniline bisulfate, but the problem of acidity remained. It was found that the ammonium salt of this sulfonic acid also would intumesce, but at a somewhat higher temperature (572° F). This material is prepared easily from the commercially available sodium salt by reaction with ammonium chloride. The TGA of this material is shown in figure 12-6.

The intumescent reaction of the p-nitroaniline-o-sulfonic acid, or the associated ammonium salt, is not discussed in this report. However, the sulfonation of the aromatic ring is probably not a necessary step in the intumescent reaction, and the ring-substituted sulfonic acid actually acts as an in situ source of sulfuric acid when this compound is heated. Thus, the reaction is similar to that of p-nitroaniline and sulfuric acid.

Continuing research into the reactions of nitrogenous aromatic compounds has produced two other intumescent systems of interest. These systems are bis-(4-nitroanilino)-sulfone that intumesces when heated alone, and p-benzoquinone dioxine that intumesces when heated with concentrated sulfuric or phosphoric acid. In all these types of intumescent reactions, the role of the acid apparently is primarily that of dehydration.

Although it has been speculated that the polymer formed during the intumescence of p-nitroaniline bisulfate may be a laddered polyquinoxaline or polyphenoxazine (ref. 12-11), no direct proof has yet been obtained. The materials obtained in the thermal reaction of all these classes of compounds are insoluble in all solvents tried, including concentrated sulfuric acid. Spectroscopic examinations have been inconclusive, and the scissioning reactions tried have, thus far, not yielded fragments that would aid in structure elucidation. The primary investigative means used has been the elemental analysis of the black materials obtained and has led to the speculation that structures of the products of the thermal reactions are combinations of recurring units shown in figure 12-7, all derivable from the starting materials by addition, dehydration, hydrolysis, rearrangement, and ring closure to varying degrees depending on the temperature to which the material is exposed. These structures are similar to those proposed by Szita and Marvel (ref. 12-12) and Stille and Freeburger (ref. 12-13) for polymers derived from more complex starting materials in nonintumescing systems.

COATINGS

Two intumescing agents described in the previous section, p-nitroaniline bisulfate and the ammonium salt of p-nitroaniline-o-sulfonic acid, were formulated into practical, useful, coating systems. The key to the successful formulation of these coatings has been the selection of a binder system that does not interfere with the intumescent process, is compatible with the intumescing agent, and will not contribute significantly to the flammability of the system. The vehicle should be either thermoplastic or easily degraded thermally in the same temperature range in which intumescence takes place.

The use of the p-nitroaniline bisulfate salt also required that the vehicles selected as binders be relatively stable to strong acid. Water-based vehicles that are commonly used in paints were also eliminated from consideration with the bisulfate salt because of their hydrolytic instability. Two vehicles were selected for use with the p-nitroaniline bisulfate: nitrocellulose and a phenolic resin modified acrylonitrile-butadiene polymer. The formulations are given in tables 12-I and 12-II. The formulation using the ammonium salt of p-nitroaniline-o-sulfonic acid is shown as 45B3. This material did not have the rather strict limitations of vehicle selection as with the first salt, because it is neither acidic nor hydrolytically unstable. These coatings were prepared by common paint-making techniques and were suitable for conventional brush or spray applications. The air-dried coatings had good initial properties.

TESTS AND POSSIBLE APPLICATIONS OF COATINGS

Measurements in a typical JP-4 fire with free convection showed that heating rates applied to surfaces immersed in such fires are approximately 30 000 Btu/hr/ft^2, approximately 90 percent in the form of radiation. This fact made it possible to run screening tests on candidate intumescent coatings in the beam of a solar simulator (fig. 12-8) that is capable of the delivery of 30 000 Btu/hr/ft^2 to a 2-inch-diameter specimen at a distance of approximately 4 inches from the focus.

This arrangement was used to screen various thicknesses of the intumescent coatings described previously. The spectral distribution of the solar simulator beam, which has its peak in the visible portion of the spectrum, did not match that of the JP-4 fire, which peaks at approximately 2.5 microns; however, the thermal-protection process appears to be independent of this difference in spectral distribution.

Intumescent coating formulation 341 was applied in thicknesses from approximately 0.007 inch to approximately 0.065 inch on a 0.060-inch-thick cold-rolled steel substrate. The test specimens, which were 1 inch in diameter, were surrounded by thermal insulation to eliminate edge effects, and a thermocouple was mounted on the backface to provide the time-temperature history.

The test of an intumescent coating specimen in the solar simulator beam is more severe than a JP-4 fire for two reasons. Although the average heating rate at the surface is 30 000 Btu/hr/ft^2, the intumescence causes the surface to grow outward toward the focus where the heating rate is higher. Furthermore, there is a radial energy gradient in the beam, and the irradiance is slightly higher on axis than the average value over the area of the test specimen.

A history of the substrate backface temperature during the test in the solar simulator is shown in figure 12-9. The bare metal without the coating reached 400° F in approximately 20 seconds. On a similar metal substrate with the intumescent coating, the intumescence began within approximately 10 seconds and was nearly complete within 20 seconds.

The thermal insulation provided by the intumescence caused a much slower temperature rise of the metal substrate. The increasing slope that occurred later shows the effect of the intumescence growing closer to the focus of the solar simulator, where it experiences a much higher heating rate.

The results of numerous tests in the solar simulator beam and in JP-4 fires are given in figure 12-10. These results show how the time required for the substrate to reach a given temperature varies with intumescent coating thickness. Temperatures of 300° and 400° F were chosen as limits for presenting these data. The relationship is linear, as might be predicted, because the thickness of the intumescence after heating is directly proportional to the thickness of the coating before heating. As can be seen in figure 12-10, the times to reach 300° and 400° F are shorter for the solar simulator tests than for the fuel fires, demonstrating the greater severity of the solar simulator tests.

The fact that the coating formulation 341, using nitrocellulose as the binder, intumesces to give a thick, stable, closed-cell polymer that is highly resistant to heat leads immediately to the possibility of its application in such places as an airplane where fuel lines or hydraulic lines exist in fairly restricted volumes. A fire in such a location would be extinguished if the intumescence filled the available volume. To test this, a simulated section of fuselage was built, and two 2-inch-diameter tubes (simulating fuel lines) were installed through holes in the section. This test setup (fig. 12-11) was 12 inches wide and 5-1/2 inches deep. The ends and one side of this box were sprayed on the inside with the intumescent coating to a thickness of 0.040 inch. A fuel pan containing 200 cubic centimeters of JP-4 was placed under the box, and the fuel was ignited. The fire caused the intumescent coating on the surface to fill the available volume, thus extinguishing the fire before 30 cubic centimeters of the fuel had been consumed.

Because of the nature of the p-nitroaniline bisulfate salt and its high loading in formulations 341 and 410-1A, these coatings did not retain good properties upon long exposure to humid environments. The acidity of this salt caused corrosion of metallic substrates and deterioration of the vehicles. However, in certain controlled or protected environments, or if suitably protected by a top coating, the coatings have great utility as just described.

The intumescent coating, formulation 45B3, is composed of the ammonium slat of p-nitroaniline-o-sulfonic acid dispersed in a binder composed of equal parts of a polysulfide polymer and an epoxy resin. After application, the coating has a hard, glossy, abrasion-resistant surface. It has good adherence to the substrate.

The coating has been tested for its effectiveness in protecting a structure from fire. The heating of a 1/16-inch-thick steel plate with and without the protection of the coating is shown in figure 12-12. The tests were made in a specially constructed furnace that exposed the samples to a controlled JP-4 fire. With no protection, the temperature of the plate rose to 400° F in less than 1 minute. When the plate was protected with an 80-mil-thick coating, the heating of the plate to 400° F was delayed for 5 minutes.

The effect of a high-humidity, high-temperature environment on the thermal performance of the coating has been measured. The results of this test also are shown in figure 12-12. The temperature history of a coated steel plate that had been exposed for 30 days to high humidity (90 percent) at a temperature of 100° F is compared with the temperature history of the coated plate that had been conditioned in the laboratory atmosphere (50-percent humidity, 73° F). The comparison shows that exposure to the humid environment had no significant influence on the thermal protection afforded by the coating. The small difference between the curves is within the limits of experimental reproducibility for this test.

Samples of the coating also have been exposed for a 90-day period to the natural weather conditions on the roof of the laboratory. Coating samples on 3- by 6-inch steel plates were placed at a 45° angle above the horizontal, facing south. During the period of exposure, approximately 9.7 inches of rain fell. The coating was darkened by the exposure, but its intumescence was not affected. Figure 12-13 is a photograph comparing an exposed test sample with a control sample, both of which were heated in an oven to complete intumescence following the exposure. No important difference in the intumescent characteristics of the two samples is evident. The coating thus shows good stability under humid environments for at least a 10-day period. Two environmental tests are continuing.

A slightly modified version of the 45B3 formulation was applied to a simulated bomb casing consisting of a section of 5-inch pipe with 1/4-inch wall thickness. The time for the interior wall of the pipe to attain a temperature of 400° C, the critical temperature for the explosive charge, was approximately 8 minutes. The time for an uncoated section of pipe to reach the same temperature was approximately 30 seconds. The intumesced coating appeared to have acceptable char integrity and adhesion, which were better than other coatings tried. A full-scale test using 500-pound bombs is currently in progress.

Many applications of intumescent coatings are possible; for example, on electric motor casings; in fuel and chemical plants and tank farms; and on engine canopies, ventilator grids, and building exteriors. At the present state of development, it is not recommended that these coatings be used in populated or unventilated areas because of the quantities of sulfur dioxide released.

Preliminary specifications for the various coating systems have been established and are available from NASA headquarters.

A research contract has been let to study further intumescent coating systems, especially the relationship of the properties of several classes of polymers as vehicles, in combination with certain selected NASA-developed intumescing agents. The influence of polymer type, cross-link index, glass transition temperatures, and other properties on the intumescent process is expected to result from such a study.

Other ongoing research within NASA will study the chemistry of intumescence and the synthesis of other intumescing agents, with the objectives of developing materials more suitable for use in viable environments and developing a range of activation temperatures. Another possible result is the use of the intumescent materials as an inexpensive, refurbishable, heat-shield material.

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of Dr. A. C. Poshkus, who prepared the ammonium salt of p-nitroaniline-o-sulfonic acid under a NASA-National Research Council Resident Research Grant, under the direction of Dr. John A. Parker.

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TABLE 12-I.- VOID-FILLING THERMAL PROTECTION COATING

[Formulation 341]

Material	Weight
Part A	
Nitrocellulose, ethanol-wet (12% N)	8.0
Methyl ethyl ketone	28.6
Part B	
p-nitroaniline bisulfate	43.7
Toluene	19.7
Butyl acetate	19.7

TABLE 12-II.- THERMAL PROTECTION COATING

(a) Formulation 410-1A

Material	Weight
Phenolic modified acrylonitrile-butadiene rubber solution	29.4
p-nitroaniline bisulfate	44.0
Cyclohexanone	14.5
Methyl ethyl ketone	12.15

(b) Formulation 45B3

Material	Weight
Part A	
Polysulfide polymer	14.1
Ammonium p-nitroaniline-o-sulfonate	57.0
Methyl ethyl ketone	28.9
Part B	
Epoxy resin, liquid	14.1
Toluene	14.7
Part C	
Tri(dimethylaminomethyl)phenol	2.8
Toluene	2.8

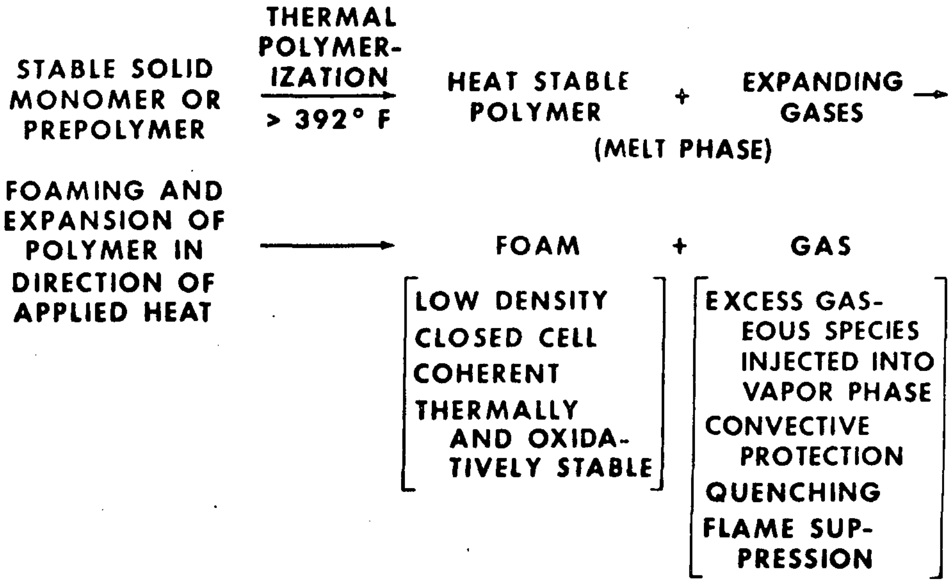


Figure 12-1.- General sequence of reactions producing intumescence.

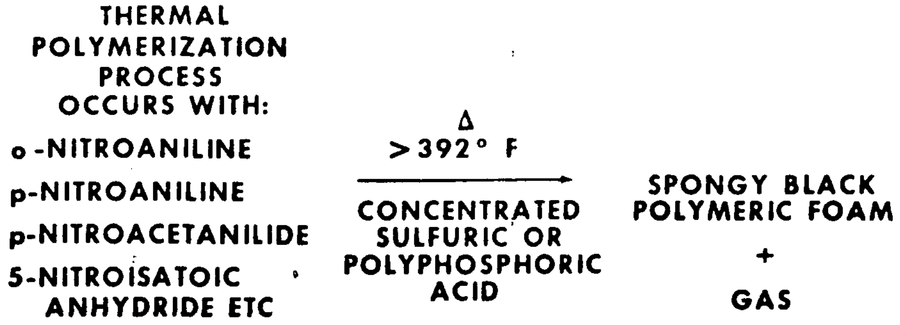
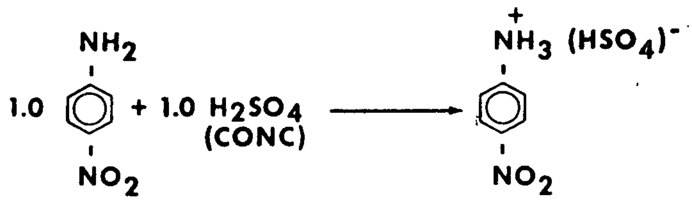


Figure 12-2.- Intumescent reactions of substituted nitro-aromatic amines.



p-NITROANILINE		p-NITROANILINE BISULFATE
293° F	MELT POINT	392° F (DECOMP)
138	MOL WT	236 (CALCULATED) 236 (MEASURED)
YELLOW SOLID	APPEARANCE	LT YELLOW SOLID (SOLUBLE IN ALCOHOLS, KETONES INSOLUBLE IN BENZENE, TOLUENE, ETHER)

Figure 12-3.- Synthesis and characterization of intumescent intermediate p-nitroaniline bisulfate.

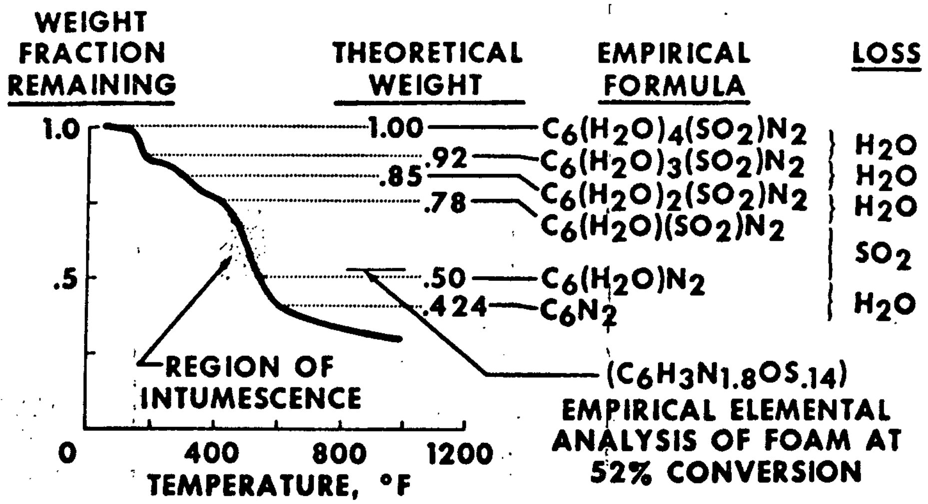


Figure 12-4.- Typical TGA of p-nitroaniline bisulfate (5.4° F/min in N_2).

C	H	N	S	O
59.65	2.51	20.77	3.64	13.43%

WHICH CALCULATES TO GIVE AN EMPIRICAL FORMULA:

$$C_6 H_3 N_{1.8} O_{1.0} S_{.14}$$

Figure 12-5.- Elemental analysis of black intumesced polymeric foam formed from p-nitroaniline bisulfate at 482° F.

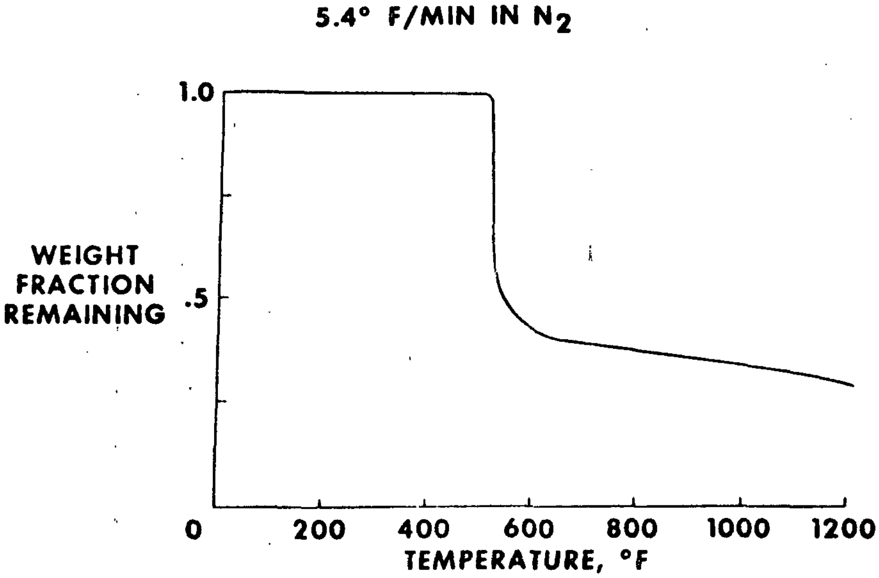


Figure 12-6.- The TGA of p-nitroaniline-o-sulfonic acid, ammonium salt (5.4° F/min in N_2).

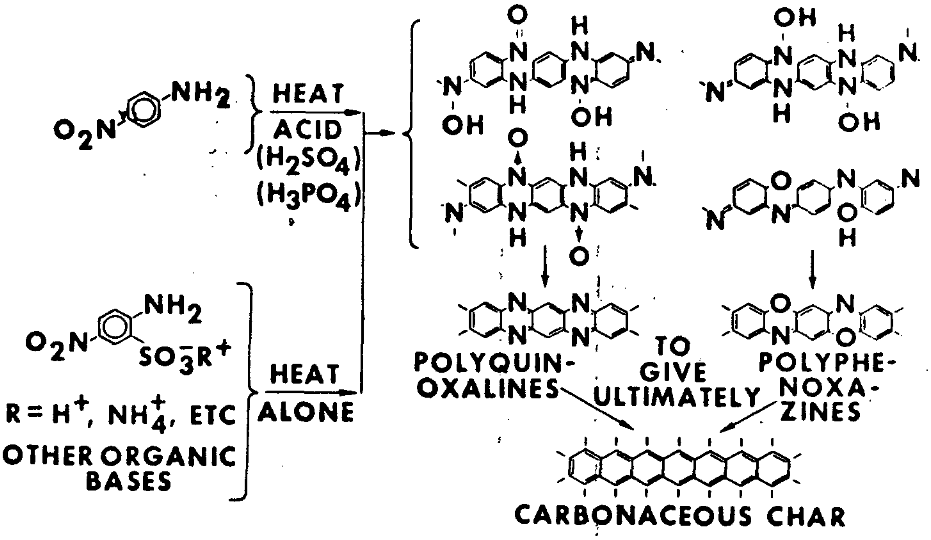


Figure 12-7.- Proposed generalized mechanism for polymerization.

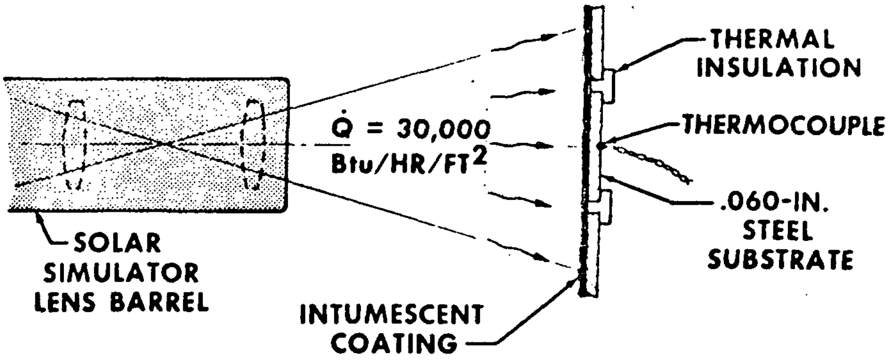


Figure 12-8.- Arrangement for tests of intumescent coatings in solar simulator beam.

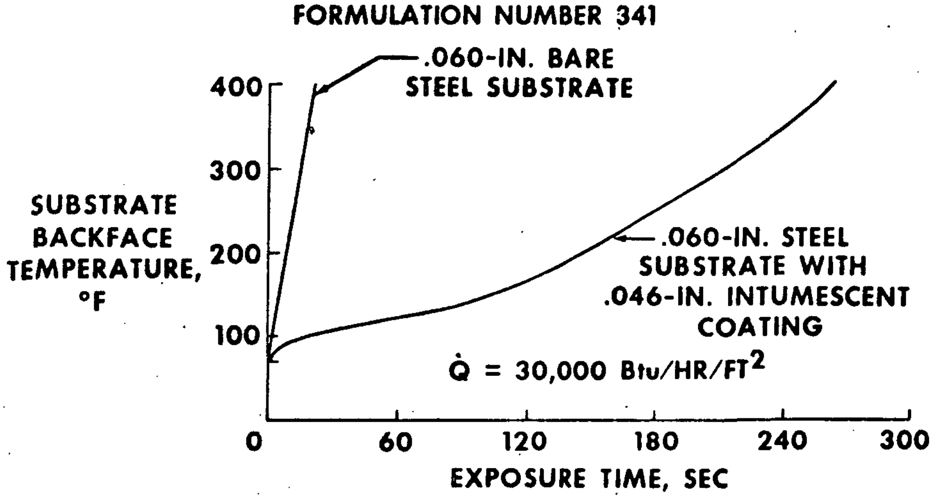


Figure 12-9.- Comparison of bare steel and intumescent coated steel in solar simulator radiation tests (formulation 341).

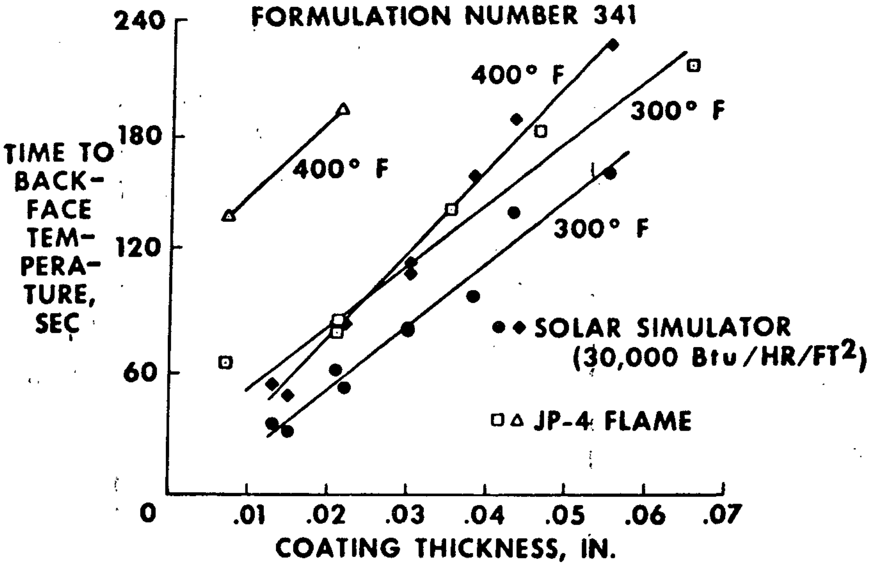


Figure 12-10.- Effect of intumescent coating thickness on backface temperature rise (formulation 341).

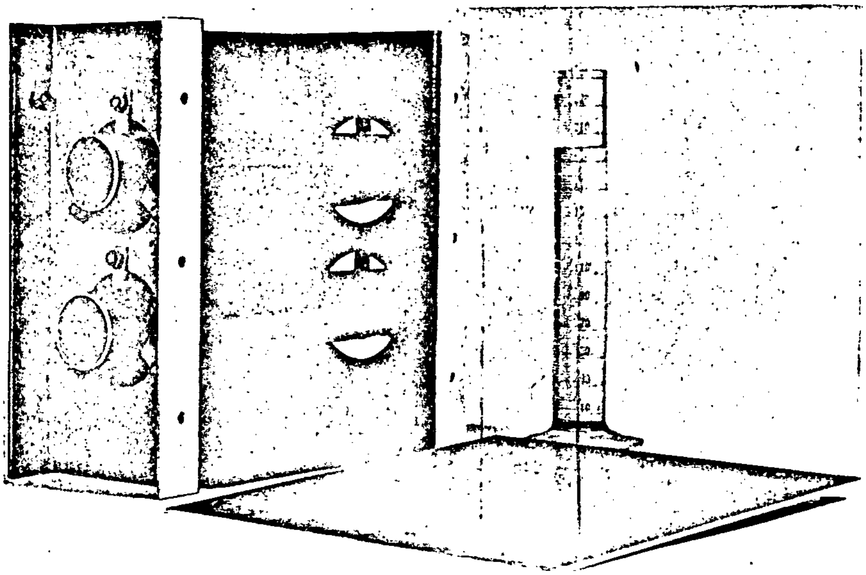


Figure 12-11.- Test setup of simulated fuselage section coated with void-filling thermal protection coating (formulation 341).

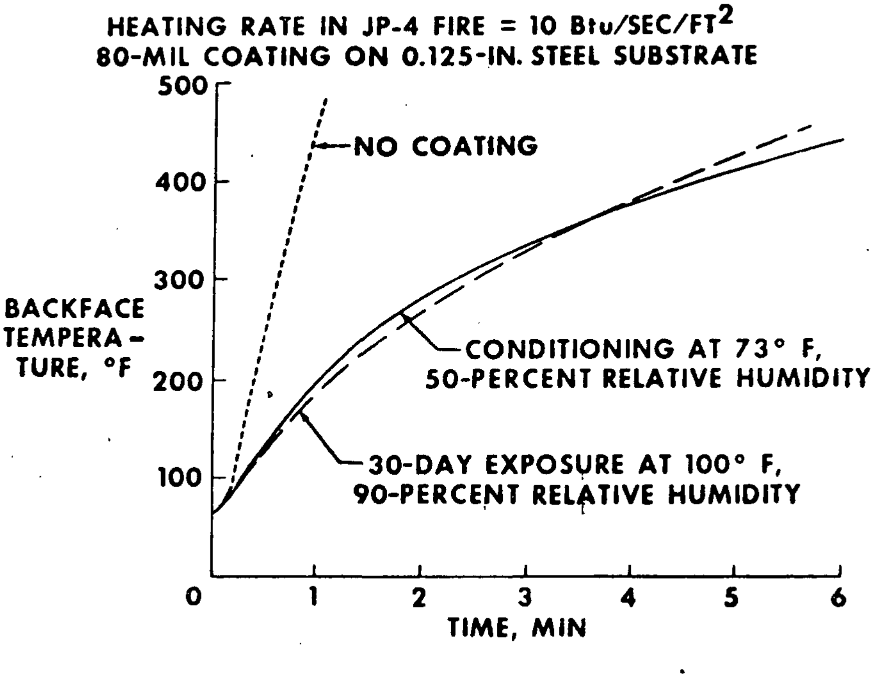


Figure 12-12.- Fire-protective effectiveness of 45B3 intumescent coating.

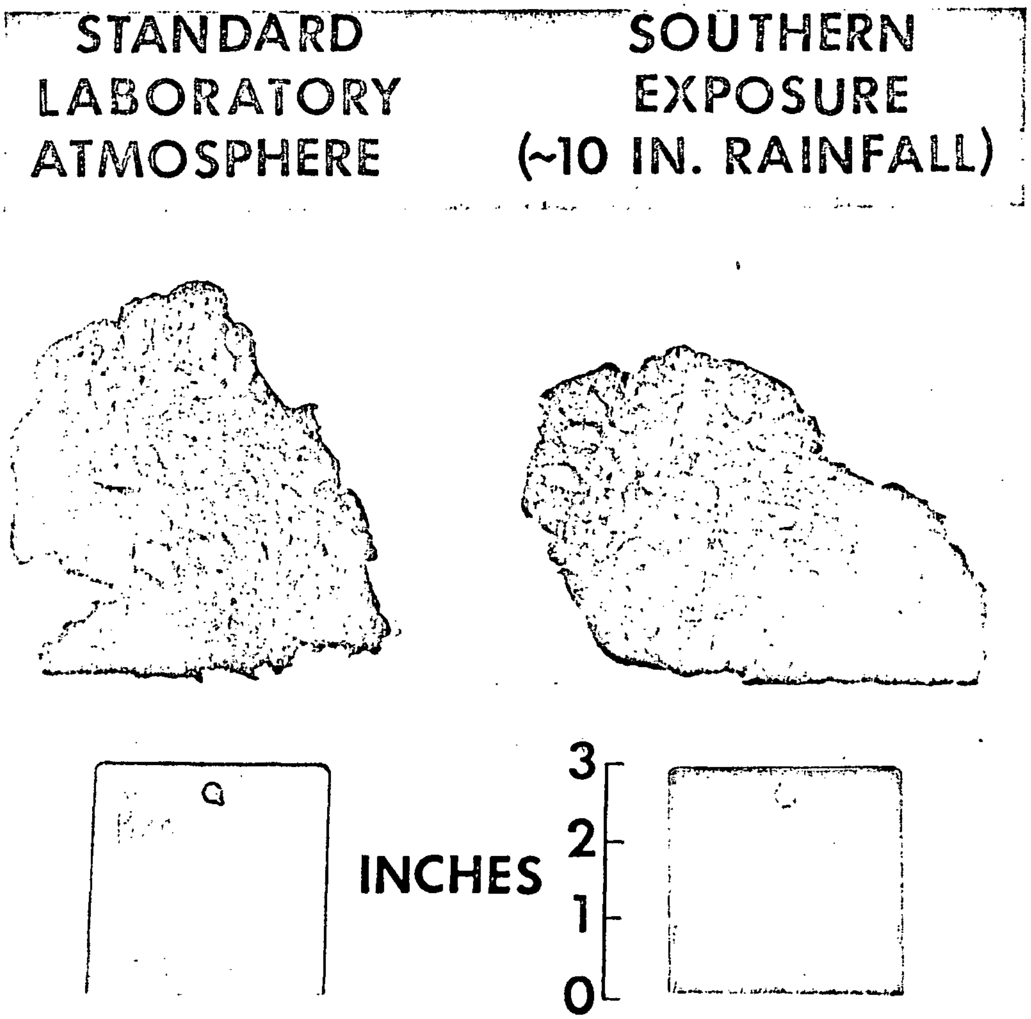


Figure 12-13.- Intumescence of 45B3 coating after 90-day exposure to outdoor environment (coating thickness 40 miles.)

"OTHER NASA-DEVELOPED MATERIALS & SOME INDUSTRIAL APPLICATIONS"

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As Chief of the Supporting Development Branch of Crew Systems Division, Dr. Radnofsky is responsible for all work in the nonmetallic materials substitution program for Apollo crew provisions and in support of such other programs requiring materials development. After the Apollo explosion in 1967, Dr. Radnofsky headed up NASA's massive research and development effort in the areas of fire prevention and protection.

Dr. Radnofsky served from 1961 to 1966 as Assistant Chief of the Apollo Support Office and as the Systems Manager for the Apollo Suit Program, Crew Systems Division, where he was responsible for monitoring Apollo Suit Programs. In July, 1966 he transferred to NASA Headquarters as Senior Systems Scientist with the Office of Manned Space Flight where he worked on advance missions analysis in the areas of materials and human engineering.

Dr. Radnofsky received both his Bachelor's degree in Physical and Biological Sciences, and his Master's degree in Physiology from Boston University. In Mar. 1967, he was awarded an honorary doctorate from the University of Taiwan.

MATERIALS THAT WON'T BURN
A PRODUCT OF SPACE RESEARCH WITH NONSPACE APPLICATIONS

by

M. I. Radnofsky E. W. Gauldin

One of the prime goals of the manned space program is, and always has been, to make NASA-sponsored technology available for the general benefit of an earth-bound populace. It is a goal of which you may be only dimly aware--but let us hope that at the conclusion of these remarks, you will join with us in enthusiastically seeking new applications for space age materials and technology.

Since the inception of the manned spaceflight program, NASA has been actively engaged in a search for nonflammable materials to be used within the spacecraft. This NASA search, conducted with the assistance of industry, had led to a progression from the relatively unsophisticated flameproof materials available ten years ago to the great variety of fibers, cellulosics, elastomers, and composites which can now be fabricated into nonflammable or fire-retardant end items.

The ability to fabricate has, of course, necessitated the development of a technology capable of evaluating and properly utilizing the specialized materials now available. With this technology in hand, we believe that many of the nonflammable and fire-resistant materials developed for spacecraft usage can, when properly adapted, make a significant contribution to the industrial, construction, transportation industries, to the public services, and to domestic and institutional concerns.

We have made a small, but we believe significant, step by carving out several small slices of this large pie for special attention; fire suits and protective garments, aircraft refurbishment, and housing modular fireproof testing. Each of these programs will be discussed in some detail in this paper.

It is, of course, necessary in any evaluation and test program of this type to know first of all what nonflammable materials are available, then to assess their properties, and finally, to choose those materials with properties, including cost and availability, most applicable to the particular end use. So we will begin our discussion with materials which are available and which are either nonflammable or fire-retardant under specific conditions.

Some of these materials, developed specifically for the space program, are nonflammable even in oxygen atmospheres. This type of nonflammability would result in "over kill" for domestic application, unless this nonflammability is coupled with such desirable traits as low cost and excellent physical characteristics.

Fibrous Materials

Undoubtedly, the highest degree of nonflammability can be obtained with inorganic fibers such as asbestos and fiberglass. Assemblies containing asbestos exhibit a high degree of resistance to the conductive passage of heat and are used in the spacecraft to fabricate containers for flammable contents.

The fiberglass used most extensively within the spacecraft is called Beta, a fiber characterized by an extremely fine diameter. Textile structures can be fabricated from Beta to provide the maximum in flexibility and performance within the limits of the inherently low abrasion resistance of fiberglass. Various techniques have been used successfully to improve the abrasion resistance of Beta--techniques which have generally centered around the use of coatings, applied to either the woven fabric itself or to the individual yarns before weaving.

Several treatments have been developed which, when applied to aromatic polyamide fibers, yield fabrics that are nonflammable in air and in moderately enriched-oxygen atmospheres. Two of these materials, Durette and Fypro, are discussed in detail under specific fireproofing applications. These treated fabrics exhibit the same excellent physical and fabrication characteristics as the base material, and can be supplied woven, knitted, or as batting. Natural colors of the fibers are golden, dark brown, and black; however, developmental efforts to dye the fibers with colors of requisite fastness are underway.

A phenolic-type fiber called Kynol, which retains its whole identity when exposed to flame temperatures up to 2500°F, has recently been developed. This fiber was originally used mostly as felts and battings, but spinnability has been improved to the extent that conventional knitted and woven fabrics are now available. Suits made from these fabrics have been demonstrated to be highly protective outer garments for firemen and race drivers.

A more recent candidate is a fire-retardant wool (treated with a chemical process called Proban) which meets many of the characteristics desirable for aircraft and other vehicle interiors. This material does not burn in air, is available in a wide range of colors, and can be considered for any application in which wool is a potential candidate. A similar process, called THPC, is used to impart fire-retardant qualities to cotton and cotton-based fabrics.

For purposes of completeness, several materials that are used in the spacecraft but are not presently considered for domestic applications are discussed briefly. Polybenzimidazole is an excellent fabric from almost every point of view, including nonflammability, but it is presently comparatively expensive. Teflon fabric is nonflammable, but has unsatisfactory drape and low tensile strength. Metallic fibers are expensive and lack durability. A new fabric from German Enka closely simulates cotton and is nonflammable, but as yet, is available only in experimental quantities.

Nonflammable Paper and Paperboard

A cellulosic material, developed by the Scheufelen Paper Company of Germany and processed primarily as a paper, carbonizes in the presence of a flame but does not propagate the flame. This nonflammable characteristic is evident both in air and oxygen-enriched atmospheres. This paper lends itself well to printing and, with some minor exceptions, has physical properties that are comparable to conventional paper.

This paper can be processed into a continuous roll of 0.5 inch thick foam, similar to papier-mache. When placed on a ceiling, for example, the foam has both the appearance and function of conventional acoustic tile and offers the additional advantage of nonflammability.

In addition to the Scheufelen paper, a process called Laminite which treats cellulose-base fiberboard with ammonium aluminum sulfate has been evolved. The resultant material is minimally flammable in oxygen and nonflammable in air. It can be formed wet, coated, cemented, and joined like a composite; yet, it is lightweight and inexpensive.

Elastomers

Elastomers developed for the space program are fluorocarbons, basically copolymers of hexafluoropropene and vinylidene fluoride. Although the elastomers are themselves minimally flammable, through the judicious use of compounding ingredients and plasticizers, nonflammability and a wide range of physical properties has been achieved. Notable among these elastomers are Fluorel (developed by the Minnesota Mining and Manufacturing Company and available from the Mosites Rubber Company and Raybestos-Manhattan Incorporated) and Viton (developed by E. I. duPont de Nemours and Company (Du Pont)). The compounded elastomers can be foamed, cast, molded, or extruded. The materials can also be applied as a paste, a coating, or a spray solution.

Mineral pigments in a wide variety of colors can be formulated into fluorocarbon-based paints. Panels fashioned of elastomer-backed nonflammable paper, to which decorative patterns have been applied, have been manufactured. The inclusion of asbestos in the backing provides insulating properties. Such a lightweight, fireproof sandwich affords much flexibility in decorative panel design. Elastomeric coatings can be applied to polyurethane foams and to cellulosic materials such as paper, wood, and sponge, thereby effectively fireproofing the materials for structural and insulative applications.

The capability for coating or replacing electrical components and accessories with Fluorel has been developed and has been used to some extent in the space program. The material can be molded to form wire ties, conduits, circuit breakers, and electrical connectors. When mixed with asbestos for increased nonflammability in oxygen atmospheres, the Fluorel can be applied as a conformal coating over electrical parts, presenting a firebreak in case of ignition from electrical sources.

Foams

There has been much activity in the area of nonflammable insulating foams. An asbestos foam has been developed by the Rex Asbestos Works of Germany. This material is marketed in batting and sheets, is inexpensive, and should be useful for general insulation applications.

The Monsanto Corporation has developed a polyimide foam; however, it is considerably more expensive than asbestos. The Scott Paper Company developed Pyrelle foam, a polyurethane with good weight-to-thickness ratio. This material is also inexpensive and commercially available. They have recently improved upon this product with a "Super-Pyrelle" which exhibits improved nonflammable properties, while retaining good physical characteristics.

A definite need exists for an insulation material which can be foamed in place. The Avco Corporation has developed, under NASA contract, an isocyanurate foam which is nonflammable in air atmospheres. Although easy to apply, this material is, at the present time, expensive. The Ventron Corporation has developed a glucose-based polymer which can also be foamed in place, which is self-extinguishing in air, and which is extremely low in cost.

The DuPont Company is developing a high resiliency polyurethane foam which can be foamed in place, and which is nonflammable in air. Potential for use of this foam looks good. This company has also developed a polyimide and mica paper-like material which foams and forms a hard char when heated. This material may have application for sealing metallic ruptures in the event of an externally caused fire.

Plastics

For replacements in areas where molded plastics are used, NASA, in conjunction with industrial sources, has developed a number of nonflammable substitutes. The Whittaker Corporation has developed a nonflammable polyquinoxalate, and North American Rockwell has developed a polyimide with Du Pont. These materials are at the present time expensive; however, as the more obvious applications are exploited, the cost should become more competitive with commercially available plastics.

Specific Applications

While these are the more promising candidates, they are by no means all of the materials which can be used to coat or replace flammable components. Additional materials and new and advanced technology become available every day. Working with these materials, we at NASA, in conjunction with a number of leading material and coating manufacturers, have developed methods and material combinations keyed to specific flameproofing applications.

Ceiling and Wall Panels

Existing ceiling and wall panels have been coated with Fluorel-impregnated fiberglass, with an overlay coating of transparent Kel-F applied for soil and stain resistance. The Fluorel surface can be furnished in an array of decorative designs. Panel backs have been coated with a mixture of 75 percent Fluorel/25 percent asbestos to prevent heat transfer as well as to provide fire protection.

This technique is applicable to wall and ceiling panels of all types; although, in the interest of expediency, it is believed to be more practical to supply the Fluorel/fiberglass/Kel-F combination for direct adhesive application to the panels. Pigmented Fluorel can also be applied directly to existing panels as a paint to provide fireproofing qualities to interior wall surfaces.

Another approach is the replacement of existing ceiling panels with new panels, fabricated completely from nonflammable materials. To achieve this end, we are taking two approaches--corrugated boards and a honeycombed composite structure.

The Laminite Corporation is involved in the development of a nonflammable corrugated board. The feasibility of this approach has been demonstrated and we, together with Laminite, are presently working toward improving the physical characteristics, including weight reduction. We are also experimenting with a number of different techniques for applying a decorative finish to the panel surface.

The Hexcel Corporation has been concerned with the development of a nonflammable honeycomb structure. This honeycomb will be sandwiched between two nonflammable "skins," with the exterior skin surface decorated and protected against soil and staining. A number of candidate materials, such as fiberglass Nomex, and aluminum are being considered for honeycombing to achieve optimum physical properties. We are striving for the ultimate in panel construction, seeking panels which are light in weight, insulative, nonflammable, and exhibiting good strength, durability, and acoustical properties.

Interior Furnishings

NASA has developed a 20-mil Fluorel sheet, backed with Durette knit, to simulate a leather-like finish. This material can be made porous by a special process called "poralating" to impart "breathe" qualities to the material. This material is completely nonflammable, durable, and available in almost any desired color. It is intended for such uses as fabricating chairs, headboards, toilet kits, back covers, or in any other area where leather or naugahyde-like materials are used.

To fill the need for upholstery fabric, a number of airlines have switched to Proban-treated woolens. This treatment does not adversely affect the wool, but enables the treated woolens to meet Federal Aviation Agency flammability regulations. This material, available in a wide array of decorator colors and weaves, has equal application for any interior refurbishment. In addition to the wool, any of the treated fabrics, such as Durette and Fypro, are available in weights and weaves such as to make them likely candidates for upholstery fabrics. To illustrate such an application, the Monsanto Company, supplier of the Durette processed fabric, has refurbished an Aero Commanded aircraft with golden Durette fabric. This material was used to replace upholster curtains, and baggage-compartment liners. Durette wears well and is available in plushes, brocades, and sculptured patterns as well as in conventional knits and weaves.

Polyurethane chair and sofa cushions can be fireproofed by spraying the foam with Fluorel. This process is relatively inexpensive, costing only about a dollar a cushion for processing. Such a cushion, further protected with nonflammable upholstery, armrests, and headers, will eliminate one particular area in which fires can begin or propagate. Mattresses present an even greater fire hazard. This same processing can be used for fireproofing foam mattresses.

Nonflammable blankets can be made from Kynol, Fypro, or Durette batting, quilted to covers of Fypro or Durette. Pillows can also be fabricated of Kynol, Durette, or Fypro battings, or from treated polyurethane foam. Pillow cases can be made from THPC-treated cotton. The use of these items with nonflammable mattresses and chairs can eliminate another fire-hazard category, particularly when applied to institutions and homes in which patients are bedridden.

Curtains and draperies can be readily, and in many instances inexpensively, fabricated from fire-retardant fabrics. In addition to utilizing those fabrics discussed as candidates for upholstering, fiberglass and fire-retardant nylons, in a wide range of colors and weaves, can be fabricated into extremely attractive window coverings.

Another development in nonflammable composites that can be cited as a definite advance toward fireproofing structural interiors has been fabricated. This nonflammable layup, when used as a curtain, provides a firebreak against flame propagation from one interior area to another.

This curtain material is composed of three layers: Durette batting sandwiched between two layers of Fluorel-coated Durette. These fabrics are either quilted together or edge sewn, weigh approximately 1 lb/sq yard, and drape beautifully. Use of this layup as a fire break between utility and habitable areas of aircraft, institutions, nursing homes, and hospitals can be easily envisioned. The curtain could also be used to block off any hazardous or fire-prone areas, thereby providing safer passage for evacuees and preventing the spread of fire to occupied areas.

The nonflammable plastic substitutes can be molded into nonflammable trays, panels, medicinal bottles, light fixtures, utensils, physical therapy equipment, chairs, and wastebaskets, as well as cabinets and countertops.

Floor Coverings

Nonflammable carpet material has presented somewhat of a challenge. The best developed to date is 100 percent wool with a fire-retardant latex backing. American Enka has developed a fire-retardant rayon that can be fabricated into carpet materials which looks promising. NASA is presently investigating methods of spraying carpet backs with Fluorel, but this will be a relatively expensive process.

Among the more promising efforts underway is an attempt to adapt the Proban treatment to wool carpets. This adaptation has been successful with wool shag rugs, but sufficient THPC penetration into the carpet pile to achieve nonflammability has not been accomplished so far.

Fluorel can be molded and cut into nonflammable floor tiles, which are durable and comfortable underfoot. Metallic flock or particles (up to 50 percent by weight) can be used as a filler for the tile material, both to reduce the cost and to provide aesthetic appeal. These tiles have potential for use in heavily traveled or habitable areas or in locales where a fire hazard exists.

The use of rubber or vinyl matting as a floor covering can present a hazard during a fire. Nonflammable Fluorel can also be calendered or molded into mats of varying thicknesses and supplied in a variety of colors. Fiberglass laminated onto the back of the mat decreases the cost and provides better tear strength and durability. Treads can be molded into the Fluorel surface for areas where slippage would present a hazard. Such mats are not only nonflammable, but protect flammable floor materials against flame propagation. This same and extremely versatile material can be also used as a substitute for rubber in such applications as balls, shower curtains, exercise devices, restraints, and surgical gloves.

Paper Products

The multiplicity of functions performed by paper of all kinds in aircraft, commercial and industrial buildings, residences, hospitals, institutions of all types, and nursing homes is obvious. Nonflammable paper can substitute for a large majority of these applications.[1] Available in a wide variety of thicknesses and colors, this paper can replace flammable writing paper, maps, legal documents, charts, towels, tray covers, paper cups, headrests, napkins, and trash liners. Even books, brochures, and magazines can be printed on this nonflammable paper.

Nonflammable paper can also be printed or embossed to produce a variety of designs, which should make it useful for such items as wall paper and lamp shades.

One particularly interesting area is the use of nonflammable paper and board for fabricating educational and recreational equipment. Work has been done in duplicating such items as playing cards, commercial games, and playroom equipment. These items are presently planned for use in the Skylab Program, but should also have particular use in the types of applications under discussion.

Nonflammable paper can also be used effectively to fabricate disposable clothing and footwear for hospital, industrial, and institutional staff members and attendants. More durable clothing can be fabricated from nonflammable fabrics; however, the expense involved would tend to obviate their disposable function.

Protective Clothing

The applications for clothing designed to protect personnel required to work or operate in hazardous or fire-prone areas span every industry and service, and are of concern to every citizen. From the racing driver to the steel worker, from the astronaut to the fireman, all must be, as we must be, concerned with personal safety. Protection of the man has been the prime impetus behind nonflammable materials development for the space program; our astronauts "blast-off" in nonflammable spacesuits. When the suits are removed inflight, they don coveralls of Teflon fabric, essentially nonflammable in an oxygen atmosphere.

We have fabricated gloves, shoes, underclothing, coveralls, helmets, shirts, and indeed clothing of all descriptions and from every available fabric in an effort to determine the optimum fire protection for all such applications.

NASA-Sponsored Firesuit Program

A brief description of our firesuit fabrication program will serve to illustrate the type of effort involved and point up criteria for materials selection.

It was decided to concentrate on two types of protective firefighters clothing--structural and proximity. Structural clothing may be defined as that normally worn by personnel engaged in firefighting activities. It is designed to be protective in nature, including safeguards against temperature extremes, possible exposure to sparks, flashing and embers, steam or hot water, sharp objects, abrasion and other hazards encountered during fires and emergencies.

Proximity clothing is designed to protect personnel from radiant heat as may be encountered when working close to extremely hot fires.

Should rescue of personnel be required, this suit may have to withstand intermittent exposure to direct flames.

To properly evaluate a choice of materials for the various suit layers, we designed and fabricated two types of both the structural and proximity suits. The first structural type consisted of a strong durable Durette outer layer, a Fluorel-coated Durette vapor barrier, and a detachable inner insulative liner. The second type consisted of a combined Fluorel-coated vapor barrier/Durette fabric outer layer, a second protective nonflammable layer, and again, a detachable insulative liner. The insulative liner is made up of two layers of Fypro and a layer of Durette batting. The first proximity suit consisted of an aluminized Durette outer layer, a Fluorel-coated Durette vapor barrier, Durette insulation, and a Fypro fabric liner. The second type is aluminized asbestos, backed with a coating of Fluorel to act as a vapor barrier. This suit also incorporates insulative materials for thermal comfort.

In accordance with recommended manufacturing practices, we incorporated abrasion patches on the shoulders and yokes of the structural firefighters suits; we used strips of reflective tape for visibility; a pocket was incorporated onto the upper right chest sized to contain an air mask; two box-type pockets were integrated onto the left and right sides of the coat front, and each jacket has a turn-up collar for face and neck protection. Two inch wide Velcro is used to secure the jackets.

In addition to the basic firefighting clothing, we have also designe several types of clothing not heretofore known in the firefighting industry. One concept consists of a pair of nonflammable Durette coveralls intended to be worn as off-duty clothing. In the event of a fire call, a pair of nonflammable insulative "chaps" are donned quickly over the legs of the coveralls. The structural firefighters coat completes the ensemble. Another coverall concept designed and fabricated by NASA is completely lined, nonflammable, and can be quickly donned in emergencies.

To illustrate another approach, we designed and fabricated nonflammable thermal underwear which can be worn in cold climates under regular clothing when fire protection is required.

In the area of ancillary clothing, we have fabricated nonflammable overboots, gloves, mittens, and a protective cap to be worn over the head and under a standard firefighter's helmet. We have also designed a proximity suit hood which incorporates a protective visor, pairs of proximity gloves, and aluminized overboots. In addition to this fabrication, we have on the drawing board, plans to fabricate standard firefighters hard boots from nonflammable materials. We also intend to mold helmets from nonflammable plastics.

Naturally, one of our greatest concerns in the fabrication of these suits was to make sure that we had a functional design; one which would perform as well or better than conventional gear. To accomplish this goal, we have worked very closely with both the Houston Fire Department and representatives of the International Association of Firefighters. We have also worked with the National Bureau of Standards and with other industrial and government groups interested in this problem of providing better protective clothing for this nation's firefighters.

Members of the Houston Fire Department have been wearing these garments during their normal firefighting activities on a daily basis for over five months now, and the response from the individual firemen has been extremely enthusiastic. The garments were adjudged to be extremely functional, and with minor changes, many of which are individual preferences, the designs are pretty well firmed up. The firemen wearing the structural suits have developed such confidence in their protective qualities that they are approaching closer and closer to the fire, the distance restricted only by a lack of face protection.

A more dramatic illustration of the protective qualities of these garments has been provided by a series of tests conducted by the Houston Fire Department Training Institute. In these tests, pit fires, utilizing various types of fuel, have been extinguished by firemen wearing

NASA's firefighting clothing. We have photographic coverage which amply demonstrates the protection afforded the firemen wearing these garments.

These garments were demonstrated at the Firefighters Symposium held at Notre Dame University and attended by firefighters from all over the United States and Canada. They have also been the subject of several journal articles receiving wide distribution among firemen and concerned industrial personnel.

Response has been extremely enthusiastic; we have received more than 100 inquiries requesting information and inclusion as test subjects in our test and evaluation program. We are proceeding with a small scale procurement of garments for evaluation at selected test sites throughout the country. The ultimate aim of this evaluation study is a specification for the design and fabrication of improved firefighters clothing, based on the use of nonflammable or fire-retardant materials in their construction.

NASA Housing Module Test Program

To demonstrate the many possibilities for use of these materials in the building and interior furnishings industries, we have constructed five miniature housing modules to be used in a controlled flammability test program. Each module will be constructed and selectively furnished so that instrumented comparisons can be made between the variety of these new fire-retardant materials.

Promising nonflammable materials will be used for roofing, side panels, flooring, insulation, carpets, paints, and curtains. Flammability test sequences will involve the use of realistic ignitors and fuels located in predetermined areas, with full photographic coverage to be made available to the building industry.

NASA Aircraft Refurbishment

Another area of application of these technological advances is the aircraft industry. We assisted the Air Force in refurbishing two T-39 aircrafts and are ourselves refurbishing one NASA Gulfstream aircraft.

Two MSC personnel, working on-site in Winnepeg, Canada, helped to accomplish part of the T-39 effort, and while there, trained personnel to complete the refurbishment.

To fireproof the T-39 ceiling panels, a Fluorel/fiberglass/Kel-F skin was laminated to the existing wooden panels. Kick panels were completely replaced by a Pyrelle foam/fiberglass/decorative Fluorel/ Kel-F composite.

All seat cushions were fireproofed with ammonium dihydrogen phosphate (ADP) and Fluorel spray. The seats are now being upholstered with THPC-treated fabrics. Armrests were covered with Fluorel-coated Durette, simulating naugahyde, and seat side panels were protected with Fluorel-based paint.

The fiberglass curtains were installed, and wool carpets were installed in the passenger compartment. Fluorel-coated fiberglass matting was used as a nonflammable floor covering in the vestibule area and on the outside stairs leading into the aircraft. Deep treads have been molded into the Fluorel surface to assure good traction.

Refurbishment of the Gulfstream follows the same general philosophy, but utilizes several different materials in a more extensive refurbishment, taking advantage of more advanced fabrication techniques.

The Gulfstream walls and ceilings presently are covered with a vinyl fabric. All of this covering will be stripped and new nonflammable fabrics developed especially for this program substituted. The new headliner fabric will be a Fluorel-coated fiberglass, off-white, and textured. The walls will be covered with Fluorel-coated Durette fabric, backed with a thin Pyrell foam padding.

All seats within the aircraft will be completely redone; flotation cushions will be fabricated and fireproofed, new upholstery installed, arm rests and foot rests recovered, nonflammable head rests fabricated, and seat bottom shrouds painted with Fluorel.

All curtains will be replaced with curtains fabricated from nonflammable fabrics. The firebreak curtains discussed earlier will be used at the entryway to the aircraft. The naugahyde simulating Fluorel-coated Durette will be used to fabricate a curtain protecting the area where the hydraulics are stored. The other curtains are standard, with the exception of the nonflammable fabrics used in their construction.

All existing floor coverings will be replaced, including the padding. Wool carpeting over fireproofed padding will be used in the passemger area, and a Fluorel-coated fiberglass with treads molded onto the surface will be used to replace the present vinyl floor covering in the vestibule area.

All of these materials have been developed, evaluated for feasibility of installation and fabrication, color-keyed to the aircraft decor, procured, and delivered ready for installation.

In addition to these programs, MSC has available on-site a United Airlines 737 fuselage which will be used to conduct an aircraft flammability test program. This program will be similar to, though on a somewhat larger scale, the housing module test in that the fuselage will be sectioned according to a predetermined plan, refurbished with nonflammable materials varying by compartment and test location, instrumented and artificially ignited. Again, results of these tests, with full photographic coverage, will be made available to the aircraft industry.

Concluding Remarks

From the foregoing discussion, it is obvious that almost any conceivable construction, furnishing, clothing, or utility device can be fabricated from metallic or nonflammable nonmetallic materials. Starting with this positive approach, such factors as commercial availability, wear and aesthetic qualities are no problem. Cost primarily becomes the only limiting factor in achievement of safety.

An additional word for those of you interested in detail of what I've discussed only briefly, we have the following reports available: a 3" volume called "Comat," plus brochures, specifications and instructions for processing, as well as a source list of everything I've discussed. If you desire any of the material, contact WESRAC, and they will in turn call me if necessary and/or will contact the cognizant service center involved to supply you with the information you desire.

"FIRE RETARDANCY USING APPLIED MATERIALS"

Speaker: Dr. Rubin Feldman
President
Thermo Systems Inc.
St. Louis, Missouri

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President, Thermo Systems, Inc.
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Dr. Rubin Feldman is the founder and president of Thermo Systems, Inc. in St. Louis, Missouri. The company produces Thermo-Lag which he originally developed for the National Space program. It has been used on all space vehicles for space shots as an inner heat shield since 1960.

Prior to his present position, Dr. Feldman was the chief Thermo-Dynamicist at Emerson Electric Company in St. Louis for 15 years.

Dr. Feldman received his PhD in chemical engineering from Johns Hopkins University.

ABSTRACT

The last decade has witnessed many advances in the technology of fire protection. Archaic building codes are gradually being revised to conform to the rapidly developing state-of-the-art. Factory Mutual and the Underwriters' Laboratories, the traditional test agencies upon whose listings all major insurance companies rely, are continuously updating their simulation procedures to bring them on par with new developments.

THERMO-LAG represents an example of advanced technology transfer from the Little Joe, Surveyor, Comsat, re-entry and Apollo age to everyday fire protection needs. Utilizing the TSI-patented principle of sublimation cooling for thermostatic temperature control, THERMO-LAG meets a wide range of fire retardancy and heat transmission control requirements. Properties vary from flexible tape for conduits and electrical cables to rigid coatings for column protection, with a broad spectrum of sublimation temperatures available. THERMO-LAG can be applied in the field or in the factory, utilizing mass production techniques, yielding a product that is reliable, effective, widely available and low in cost.

COMMERCIAL THERMO-LAG MATERIALS FOR PROTECTION FROM FIRE

DESIGNATION	DESCRIPTION	APPLICATION	MAJOR END USE
THERMO-LAG 220	Coating - Fire Retardant	Brush Roll Spray	Fire Retardant Warehouse Shelves, Containers (Wood and Cardboard)
THERMO-LAG 220	Concentrate	Pressure Spray Trowel Roll	Heat Transmission Control . . . Hollow Metal Structures . . . Safes
THERMO-LAG 330	Coating - Fire Retardant	Brush Roll Spray	Same as 220 - in Areas where Special Adhesion and Chemical Resistance are Required
THERMO-LAG 330	Tape - with Contact Adhesive	Wrap Roll	Conduit . . . Wire Bundles . . . Areas where Instant Fireproofing is Required
THERMO-LAG 330	Concentrate Coating	Pressure Spray Trowel Roll	Heat Transmission Control . . . Beams, Columns, Joists, etc. (Style and Functional)

SELECTED THERMO-LAG CHARACTERISTICS

		MATERIAL	
		THERMO-LAG 220	THERMO-LAG 330
		PAINT MASTIC	PAINT MASTIC TAPE
UL RATINGS OBTAINED IN ASTM E84 TUNNEL:	FLAME SPREAD	0	5
	FUEL CONTRIBUTED	0	0
	SMOKE DEVELOPED	0	0
	SPREAD RATE — SQ. FT./GAL.	250	250
MATERIAL REQUIRED:	WOOD	0.005 INCH	0.005 INCH
	CARDBOARD	0.005 INCH	0.005 INCH
	PAPER	LESS THAN 0.005 INCH	LESS THAN 0.005 INCH
	PLASTIC	0.005 INCH	0.005 INCH
	STEEL*	TO SUIT NEEDS	TO SUIT NEEDS
	OTHER SUBSTRATES	INQUIRE	INQUIRE
SOLVENT OR THINNER:		WATER	MEK OR TOLUENE
APPLICATION:		BRUSH, SPRAY ROLLER, DIP, TROWEL	BRUSH, SPRAY ROLLER, DIP, TROWEL
COLOR:		TO SUIT NEEDS	TO SUIT NEEDS
SUBLIMATION TEMPERATURE:		220°F	400°F
WASHABILITY:		EXCELLENT	EXCELLENT

RESULTS FROM ASTM E119, FM STD 4975 AND OTHER TESTS, AVAILABLE UPON REQUEST.

ADVANTAGES
OF
THERMO-LAG

- **PERFORMANCE**
- **SAFETY IN USE**
- **LOW COST**
- **EASE OF APPLICATION**

U.L. LISTED

FM **TESTED AND APPROVED**

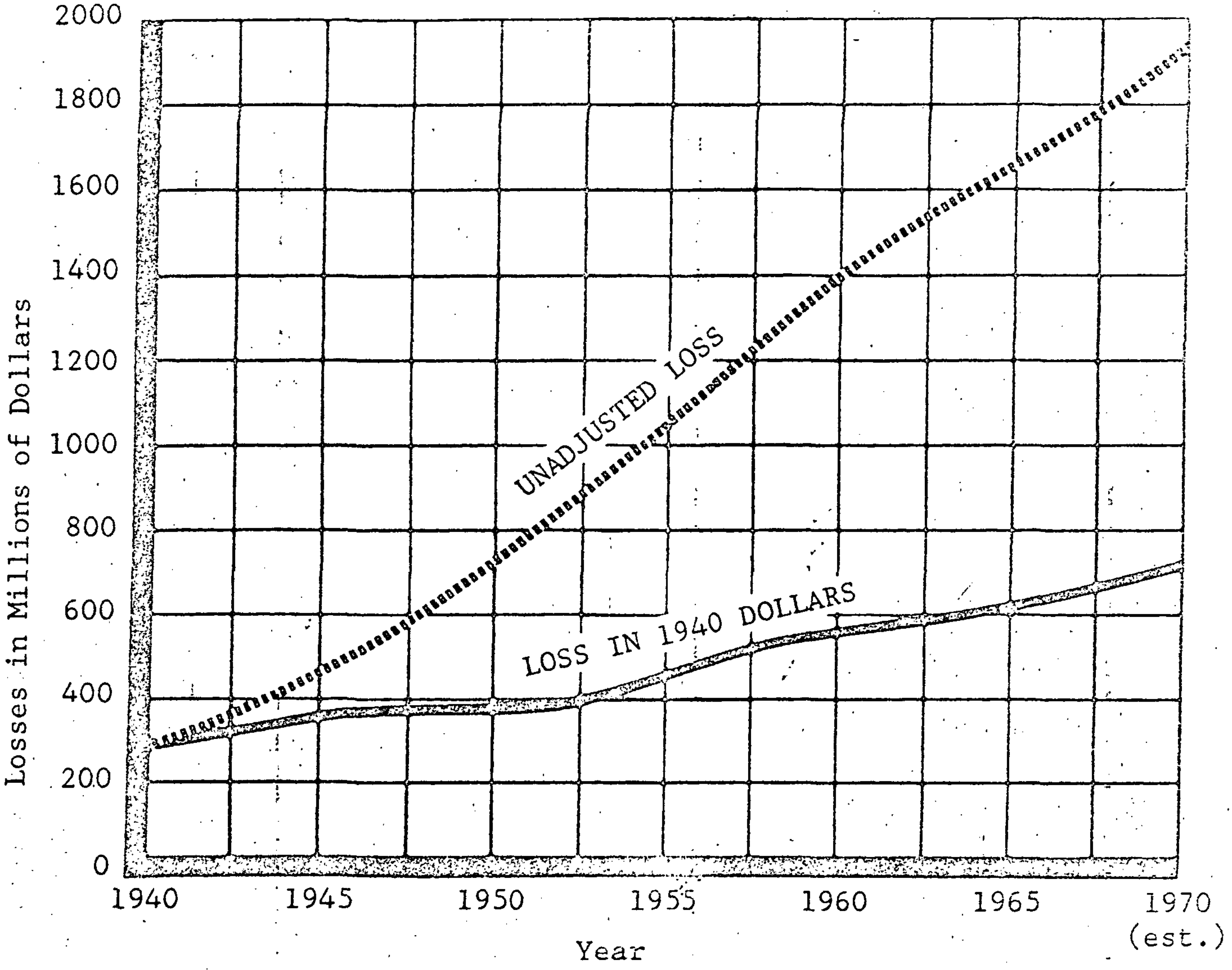
FIRE RETARDANCY AND HEAT TRANSMISSION CONTROL USING APPLIED MATERIALS

Introduction

Ever since man moved out of his fireproof cave he has had fire problems. Unharnessed fires have been violently destructive. The burning of Rome and the Great Fires of London and Chicago are but three examples of devastation wrought by the raging monster.

Progress has been made slowly in man's efforts to protect his property from the ravages of fire. Eliminating all timber and using heavy masonry walls, Catullus constructed a "fireproof" repository in 78 B.C. But fireproof constructions scarcely advanced beyond that point during the next two thousand years. It is only in comparatively recent times that the practice of fire protection began to develop into a science. Present methods and experience make hit-or-miss or arbitrary fire protection procedures totally unnecessary. Their deployment, however, is tangled up in the labyrinths of archaic regulations and building codes.

The need for more effective fire protection is brought sharply into focus by the gruesome statistics published by the National Fire Protection Association. In 1970 the property damage due to fire is estimated to exceed $2 billion,



FIRE LOSSES, SHOWING EFFECT OF INFLATION
(EXCLUSIVE OF FOREST FIRES)

with another half billion dollars lost in forest fires, aircraft fires, motor vehicle fires, and other non-building losses. Every two seconds a fire breaks out in the United States; every two minutes someone's home goes up in flames; and every forty minutes someone dies in a fire. Fire injuries are substantially more frequent than deaths.

The three worst residential loss-of-life fires in 1970 occurred in hotels, killing a total of 67 people and injuring many more. At the Ozark Hotel in Seattle, 20 people died on March 20; in the Tonet Square Hotel in Los Angeles, 19 people died on September 13; and in the Pioneer Hotel in Tucson, 28 people died on December 20. All three fires had two things in common: all were believed to be of incendiary origin and none employed fire retardant materials where they should have.

Only a few days ago, on Friday, May 14, a fire occurred at the Ambassador Hotel and Residence in St. Louis. Before rescue could be effected, four people were dead and many more injured. The fire, which was of incendiary origin, started in a third story room. The room employed wood paneling. The fire quickly spread along its surface to that of the walls down the corridors, causing heavy damage and making rescue of those trapped in their rooms extremely difficult if not impossible.

But this is 1971--and such tragedies are no longer inevitable. Science is no longer devoted to alchemy or the search for the philosopher's stone to turn lead into gold. Space age technology has landed us on the moon . . . and taught us to combat the inferno-like heating of re-entry conditions. The knowledge of heat control utilized in aerospace applications has resulted in the development of highly efficient fire retardant and heat transmission control materials. Some of these are highly competitive in price--costing no more than ordinary good quality paint.

Fire

What, then, is a fire? A fire may be defined as "rapid oxidation with the evolution of light and heat." Combustion in the broadest sense includes not only the chemical combination of fuel with oxygen, but also in combination with other oxidizing agents such as chlorine. Hence combustion may occur not only in the atmosphere of oxygen, but elsewhere.

Ignition of a combustible material will occur only where there is a sufficiently high temperature and a sufficient quantity of heat and oxygen to initiate self-sustaining combustion. Fire will not propagate from point of ignition if heat is carried away faster than it is produced, as the temperature will be decreased and the fire will go out. Heat may be carried away from a point of ignition by radiation, conduction, and convection. In the case of a log touched by a match, conduction may start at the point where the match flame touches the wood. The flame of the match may produce a temperature of 2000°F or higher, but it does not produce enough heat to start sustained burning of the wood. Heat will be conducted and absorbed by the body of the log and incendiary heat will be lost by radiation and convection.

The same match, when dropped on a material of better insulative qualities and lower mass (such as cardboard boxes), will after a short time initiate combustion, which will rapidly spread. In the case of a single log, even if sufficient temperature is attained to initiate local combustion, the fire may go out because of rapid loss of heat by radiation and convection. If two or three logs are placed together, however, the radiation and convection from one to the other will tend to keep the wood hot and fire will readily continue.

The same principles apply in the case of a fire, particularly one contained in close quarters. Consider, for example, the case of a fire in a corridor or typical room. Assuming that there is adequate air supply to sustain combustion, fire in such a space--with combustible surfaces on several sides, each side reradiating heat to the other--produces a much more severe fire than a similar area of combustible surface in the open. Protecting these surfaces with a fire retardant will, of course, greatly minimize if not completely eliminate the potential of fire spread.

When a combustible material is still more finely divided, in the form of dust flying in the air, ignition can occur from a minute heat source. The same is more pronounced in the case of flammable gases and vapors, where the combustible material is divided into individual molecules. This explains why a fine cloud of combustible dust, gases or vapors can be ignited by a very small source of heat, such as a spark.

With some fires where the air supply is restricted, a considerable quantity of carbon monoxide may be produced. The carbon monoxide may subsequently come in contact with additional oxygen and ignite to form carbon dioxide and further spread the flame; hence the necessity to restrict the size of open spaces susceptible to fire by means of fire walls and openings protected by fire doors.

Building Codes

"In a general sense building codes are designed to provide rules for public safety in the construction of buildings to the extent which can be applied as law under the broad authority of the police power," states the NFPA. They thus comprise minimum standards consistent with reasonable public safety. They do not necessarily provide complete safety or ideal conditions. By their very nature they may adequately cover structures of common types only, with less applicability to large manufacturing buildings and major structures of unusual design.

Building code requirements vary widely in different parts of the United States and Canada. In many areas there are no building codes as such, or there are only incomplete or absolute requirements. The following five principal codes are in circulation in the United States and Canada:

National Building Code (1st Edition 1905)
Uniform Building Code (1st Edition 1927)
Southern Standard Building Code (1st Edition 1935)
Basic Building Code (1st Edition 1950)
National Building Code, Canada.

These are in addition to a number of state codes. All are markedly informal in arrangement, and most features are prepared in such different manners as to make comparisons difficult. All are revised and re-issued periodically.

The general practice is to specify minimum requirements for the protection of structural members, partitions, etc., in terms of specific materials or combinations of materials. These requirements are then expressed in terms of time of ultimate fire resistance, or, in other words, the time period during which the construction member should stand up to a fire of given intensity before specific damage occurs as determined by applicable standards.

In the past it has been standard building code procedure to place restrictions upon the use of combustible materials for the interior finish only in assembly occupancies and in buildings of fire resistant construction.

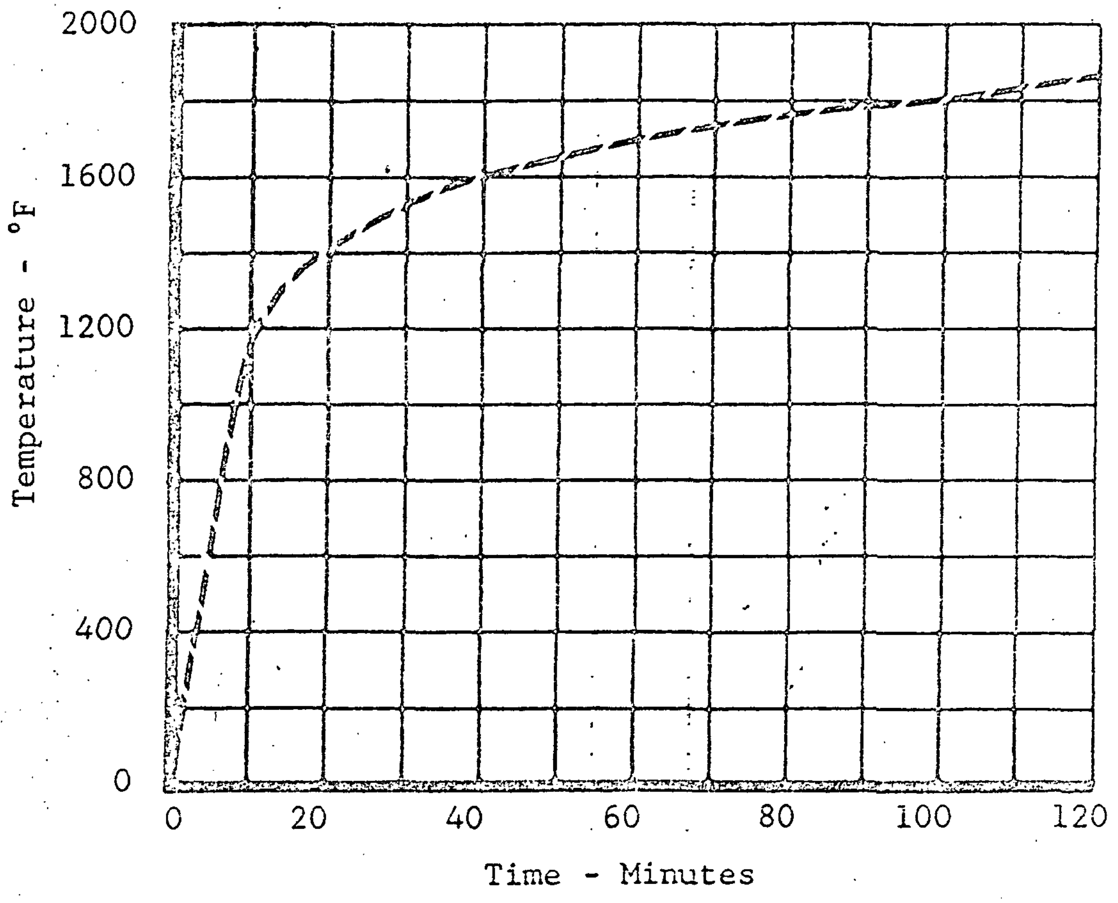
However, the situation has changed with the development of many new types of finish materials, some of which are highly combustible and already proven to be dangerous, creating a need for more careful regulation. Buildings which would appear to be fire safe can be rendered unsafe through the use of hazardous types of finish materials. Under present building codes, the use of combustible finishes, regardless of degree of hazard, considered too dangerous for use in fireproof or fire resistant buildings, are permitted in non-fire-resistant structures. Such procedure is obviously unsound in principle and very dangerous.

Test and Approval Methods

The regulation of interior finish materials has been given considerable study by building code and fire authorities in the last several years. Performance standards have been developed to measure the relative hazard of these materials with respect to surface burning characteristics. One standard method of test for surface burning characteristics of building materials (ASTM E-84) has become widely recognized in modern building codes throughout the country. The ASTM test represents the conditions of a vigorous incipient fire and determines relative fire hazard of the material by evaluating the rate of flame spread along the surface of a 20-25 foot long test sample under a standard exposure fire. The test establishes relative hazard represented by the finish material according to numerical flame spread, the lower rating indicating less hazardous finishes (0 for asbestos cement and 100 for untreated Douglas fir).

Another procedure is followed by the Factory Mutual Corporation by the use of a calorimeter in which a precise measurement of heat contribution in addition to flame spread is evaluated and comprises a key standard in the rating of materials, particularly in the area of activities covered by Mutual Insurance Companies. The relative fire hazard of finish materials, as classified by the numerical flame spread and heat and smoke contributed ratings of the Underwriters' Laboratories and Factory Mutual, represents a national endeavor toward the creation of realistic test conditions.

It has become standard practice in building codes to specify the degree of fire protection that must be provided by the various structural parts of the building according to the hours of fire resistance which they are capable of developing under standardized conditions of fire exposure. ASTM E-119 procedure and adaptations thereof comprise the recognized standard by which the duration and intensity of fires are classified and on which recognized fire resistance ratings of materials of construction are based. For illustration, see the standard time-temperature curve depicted on the following page.



FIRE SIMULATOR TIME-TEMPERATURE CURVE
PER ASTM E-119

In order to establish the fire resistance rating of any building assembly of construction, a specimen of prescribed size must be exposed to a standard fire. The fire resistance rating of a construction assembly or material is determined by the length of time that it successfully performs during the fire exposure. The condition of performance or construction of a material during a fire test varies with expected function of the material and assembly. For instance, wall, floor and roof panels must also withstand exposure without allowing the passage of flame and without transmitting heat through the construction to raise the temperature of the un-exposed surface more than 250°F above its initial temperature. In order to qualify for fire ratings of one hour or more, walls and partitions must also withstand a prescribed exposure to a hose stream of specified pressure immediately after fire exposure, thereby establishing the integrity of the construction to the effect of cooling.

State of the Art Materials

Until very recently, when the accelerated rate of the transfer of aerospace developed technology to everyday fire protection needs occurred, commonly used materials of construction included gypsum, vermiculite, perlite, mineral fiber, concrete, masonry, metal lathe and plaster and many other combinations. Although the materials in themselves are relatively inexpensive, brute force techniques employed in their utilization and the common cumbersomeness associated with in situ installations makes the installed cost very high indeed, the cost of building in many cases prohibitive. This coupled with an increase in inflation, particularly in the area of labor, has resulted in serious slumps in the building industry by making many types of institutional and commercial buildings prohibitive for many uses.

During the last two decades, plastics have encroached into many traditional areas of building construction. They are essentially composed of organic material easily susceptible to combustion. The stress on fire protection has thus become even more apparent. State-of-the-art fire protection or fire retardance includes the use of externally applied coatings.

Replacing sometimes highly flammable finish materials with coatings or paints which inhibit rather than contribute to the spread of fire is both possible and practical. Using these coatings permits much greater flexibility in choice of building materials, allowing lightweight and low cost constructions otherwise impossible because of their extreme susceptibility to fire. For example, in addition to a number of plastics, cardboard has been introduced into building construction. A "paper" bridge is only one dramatic example of innovative and imaginative engineering utilizing cardboard as a structural material.

One noteworthy means of protection is offered by intumescence. In essence, intumescence is provided by coatings in various thicknesses which offer a measure of thermal protection to surfaces to which they are applied. Prior to the occurrence of fire, such coatings are indistinguishable from conventional products. Upon heating, however, they decompose, bubbling and foaming to form a thick, not easily combustible, multi-cellular insulative barrier. The materials are useful for short periods of time, measurable in minutes. However, for sustained protection of an hour or more, the required material thickness of one-half inch or more is prohibitive.

A major disadvantage of intumescent materials is the propensity of the active ingredient to leach out under exposure to humidity or rain. The coatings are thus rendered ineffective for protection from fire after extended periods of time.

In still other applications, emphasis has been placed on chemical equilibrium shifts of the material surface via high concentrations of halogens--notably fluorine. Such methods provide adequate short term protection from fire but greatly increase the toxicity hazard due to the introduction of inherently poisonous gases.

THERMO-LAG

A more advanced means of fire protection is offered by a family of paintlike materials utilizing the principle of sublimation for thermostatic temperature control. These materials, marketed under the trade name of THERMO-LAG, have proved effective in numerous aerospace applications over the past decade and more recently for protection from the ravages of fire.

A sublimate, by definition, is a material which undergoes a transition from a solid into a vapor at a fixed temperature. THERMO-LAG materials utilize a family of subliming agents to attain different levels of temperature control. The materials operate in the facsimile of a water jacket - as long as the THERMO-LAG is there, the temperature of sublimation cannot be exceeded. Some typical temperatures of sublimation are 220°F, 400°F, 550°F and 800°F.

As the material sublimes, undergoing the transition from a solid into a vapor, it absorbs a considerable amount of heat at the same time. This process is similar to that of boiling water. It takes approximately 1 Btu/lb. to raise the temperature of water by one degree. It takes 980 Btu/lb. to boil water off, without elevation in temperature. In the case of THERMO-LAG, it takes approximately 750 Btu/lb. to vaporize it. At higher temperatures the THERMO-LAG vapors undergo additional decompositions; larger THERMO-LAG molecules break up into smaller ones. The result is the absorption of extremely high levels of heat energy, as high as 6000 Btu/lb. under some conditions. The heat energy absorbed by the THERMO-LAG vapors is no longer available to impinge upon the structure protected by the THERMO-LAG coating. The result is actual heat blockage: heat is prevented from penetrating to the surface of the material.

Decomposition has to take place within the coating itself; once it gets into the fire it is of little value. When a missile travels at extreme velocity through the air, it produces a boundary layer of air which sort of drags along with the missile. This layer of stagnant air in itself provides an effective means of insulation, protecting the re-entering missile to a considerable extent from the aerodynamic heating. When THERMO-LAG gases inject into this boundary they, too, absorb a considerable amount of heat energy. They further stretch the boundary layer by physical extension of its volume, improving its effectiveness as insulation.

In the case of a fire, where there is no high velocity speed, a boundary layer must be created. This is accomplished from the principle of intumescence. Because THERMO-LAG produces a rather voluminous amount of gaseous matter, it is also used as an intumescing agent. Upon exposure to heat, the initial thickness of THERMO-LAG is increased many times, performing an action comparable to that of intumescent coatings. However, the passage of the cooling gases produced by the sublimate do more than stretch the intumescent multi-cellular layer. They also block a considerable amount of heat by coming into contact with the foamed-up THERMO-LAG structure, using the heat from the fire for decomposition of the mass. This heat is thus rendered unavailable to penetrate the un-vaporized material.

It is a well-known fact that an important component of a fire is radiation. However, ordinary commercial fire retardant materials or heat transmission materials, such as used on steel, have not utilized this technology. The important criterion here is to absorb the minimum and reflect the maximum amount of heat energy by radiation. In aerospace jargon, this means producing a low alpha over epsilon ratio. This has been accomplished by THERMO-LAG materials, comprising a significant advance in the state-of-the-art for fireproofing and fire retardant materials.

In simplest form, THERMO-LAG is used for commercial applications in coatings applied approximately 0.005 inches thick. This is comparable to two coats of paint. In this thickness, THERMO-LAG can be used to protect materials such as cardboard, wood, plastics and other combustibles from burning. Two THERMO-LAG formulations have been selected for commercial use: THERMO-LAG 220 and THERMO-LAG 330, subliming at 220°F and 400°F respectively.

THERMO-LAG 220 is a water-based material; THERMO-LAG 330 is solvent based. Both are quick drying; both have been evaluated by the Underwriters' Laboratories. In addition, THERMO-LAG 220 is one of the few materials ever approved for protection of combustibles by Factory Mutual Research Corporation in Boston.

THERMO-LAG 220 has a flame spread of 0, a fuel contributed rating of 0, and a smoke developed rating of 0, as determined by the Underwriters' Laboratories in ASTM E-84 tunnel tests. THERMO-LAG 330 has a UL rating of 5 flame spread, 0 smoke developed and 0 fuel contributed. (The ratings are determined on a comparison basis, with asbestos board the standard for 0 and untreated Douglas fir being given a rating of 100.)

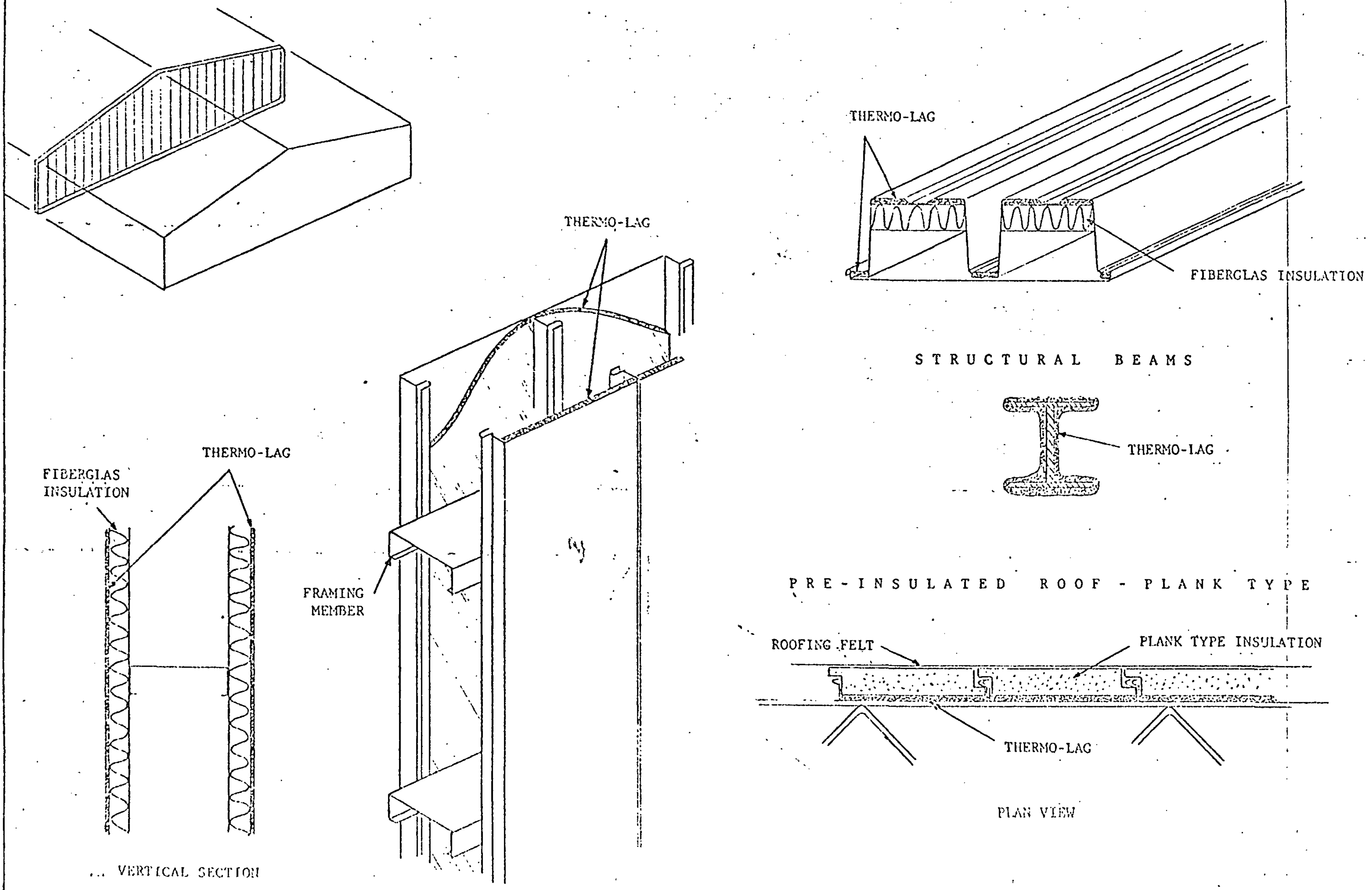
The application of THERMO-LAG, particularly on materials such as cardboard, is indeed dramatic. When a coating of 0.005 inches is applied to the cardboard, the exposure to a typical flame will not cause the cardboard to combust, regardless of the duration of exposure. After some time (in the standard two-coat thickness of 0.005 inches, from twelve to seventeen minutes), dehydration will cause the cardboard to become brittle and crumble, but it will not combust.

Present applications of THERMO-LAG extend from warehouse complex containers and shelves through other industrial and institutional use where a low flame spread is vital. Many items are being introduced on the market which have been rendered non-combustible by the application of THERMO-LAG.

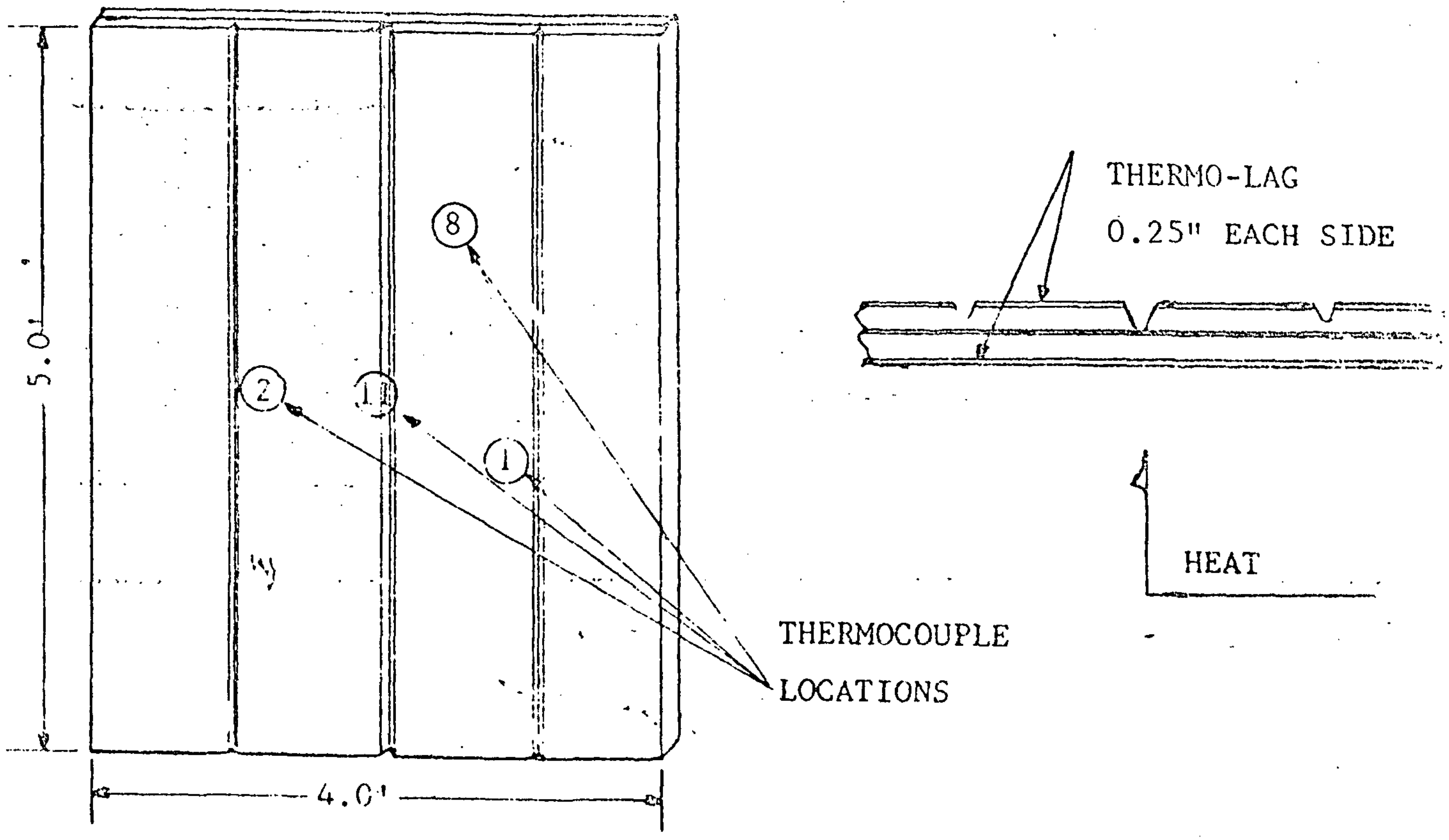
In the case of structural steel applications, the particular utility of THERMO-LAG is its economy of application. It can be applied during production, minimizing the requirement for less reliable and more costly field application. A fire wall is a typical example of factory-applied fire protection. THERMO-LAG can be sprayed or otherwise dispensed in small thicknesses to the interior of the structure. The resultant product is lightweight, efficient and economical. For example, one-half inch of THERMO-LAG dispensed in one application performs the same function as four layers of one-half inch gypsum board. The applied cost is considerably lower, as continuing process equipment can replace the less efficient in situ installation, where considerable cutting, drilling, fitting in place, etc., is required.

A schematic depicting some typical metal constructions employing THERMO-LAG as well as a figure showing a typical temperature response are included on the following pages. Please note the asymptotic temperature behavior of THERMO-LAG to the 220°F level. In addition to fire protection, THERMO-LAG also offers significant sound deadening, stiffening of low guage partitions, stability, and flexibility in design.

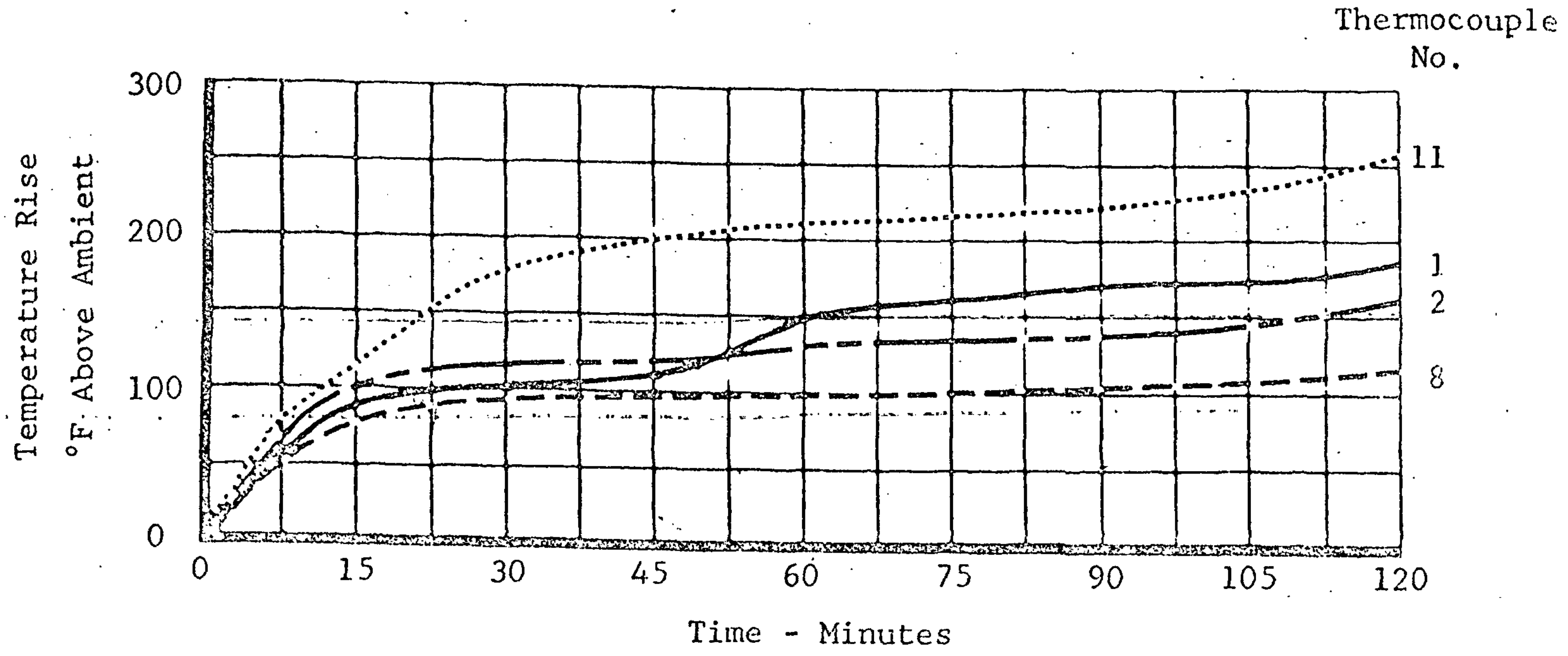
A considerable amount of testing has also been done in the area of roof tops and structural beams and columns. THERMO-LAG in a thickness of approximately 0.150 inches will



TYPICAL THERMO-LAG APPLICATIONS
FOR METAL STRUCTURES



SKETCH OF TEST SPECIMEN



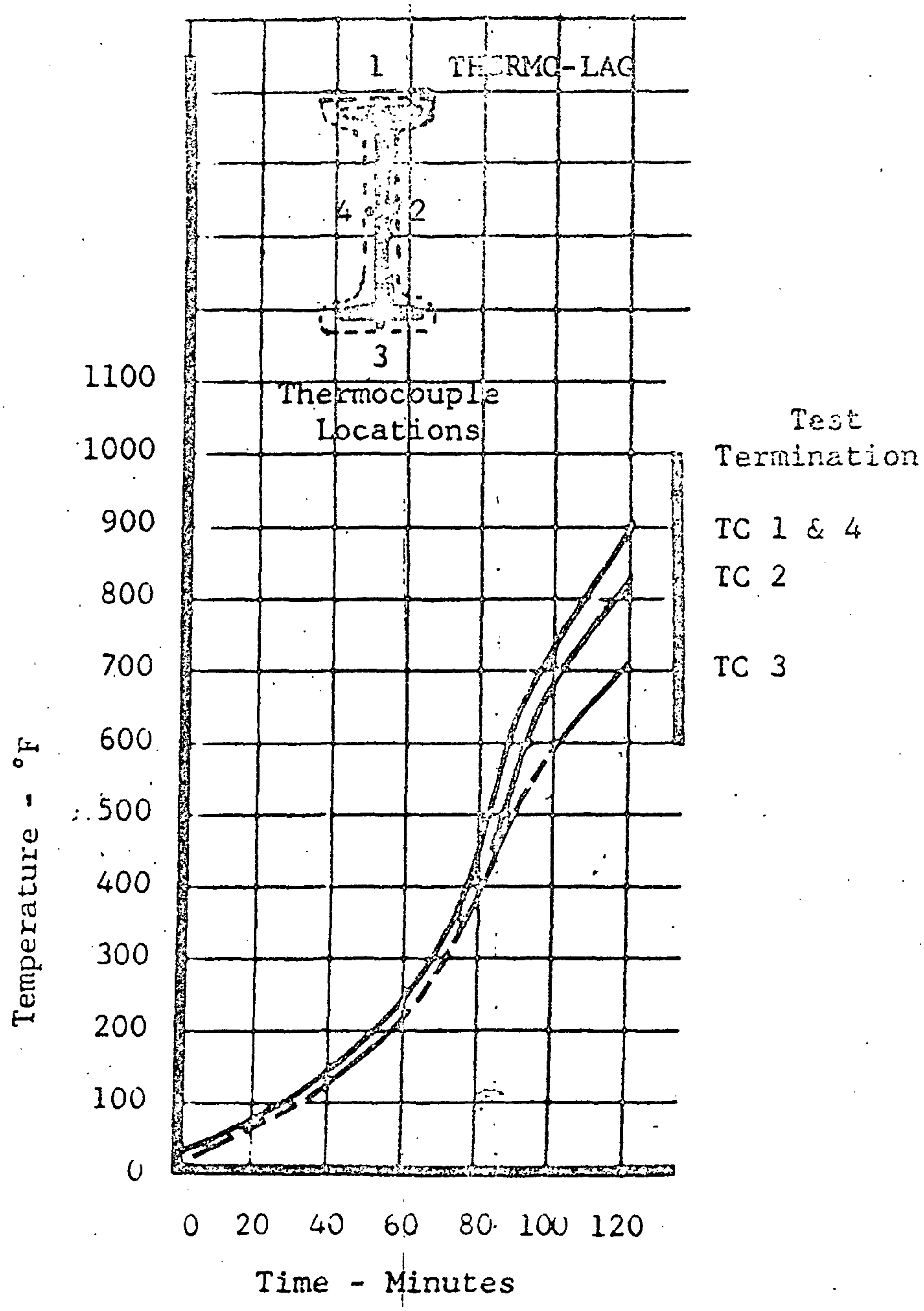
THERMAL RESPONSE OF STEEL WALL

give two hours' fire protection, comparable to that provided by four inches of concrete and 0.500 inches of a state-of-the-art intumescent coating. The total applied cost of THERMO-LAG is thus appreciably lower.

Structural segments have been subjected to simulated fire tests in accord with ASTM E-119 procedures, with the results as depicted on the following page. Please note that none of the thermocouples exceed a temperature rise of 1000°F in the prescribed time limit.

Still another revolutionary development in THERMO-LAG materials is "instant fireproofing" via flexible, pressure sensitive tapes. The tapes are a three-part system consisting of a given thickness of THERMO-LAG, a contact adhesive for easy application and a vapor barrier which provides a protective and decorative finish. This system will prove effective for the protection of electrical circuitry and small diameter items requiring low cost but effective fire protection.

THERMO-LAG has also undergone a considerable amount of environmental testing. Weatherometer for accelerated life; humidity; salt spray; impact; abrasion--these are but a few of the exposure tests that have been performed. A complete report on tests performed in accord with Federal Test Standard 141a is available upon request.



TRANSIENT RESPONSE - 16" STEEL BEAM
PROTECTED WITH 0.150" THERMO-LAG

Conclusion

In summation, THERMO-LAG represents an example of advanced technology transfer yet to come in many other areas. Aerospace developed technology for protection from intense heat is effectively utilized in commercial THERMO-LAG fire retardant materials. Properties range from rigid to a pliable tape, with thermostatic temperature control capabilities as low as 200°F upward to 1000°F.

THERMO-LAG not only provides a unique method of fire retardancy and heat transmission control but also one that is more economical, efficient and reliable than conventional materials. THERMO-LAG is adaptable in use, permitting factory as well as field installation, resulting in broader use via wider availability and in appreciably reduced costs.

"FIRE RETARDANCY WITH STRUCTURAL MATERIALS"

Speaker: Richard E. Gardner
Technical Representative
Koppers Co., Inc.
Pittsburgh, Pennsylvania

Richard E. Gardner
Technical Representative
Koppers, Inc.

Mr. Gardner has worked in research and development in Koppers Chemical and Forest Products Divisions in Pennsylvania and Ohio and is currently the technical representative for the Western District, Forest Products Division of Koppers.

He attended Waynesburg College, the University of Pittsburgh, and was a graduate Wood Technologist from Penn State University.

PRESSURE TREATED FIRE RETARDANT WOOD

Impregnating wood with chemicals to reduce or prevent combustion is not an idea developed last year or even in the last decade. Historical documents of the United States Navy show that fire retardant treated wood was specified as early as 1895, and it was written into the New York City building codes by 1898.

The market for fire retardant treated wood remained small and processing was confined to one or two treating plants prior to World War II. During the war, and periods following, some potentially disastrous fires were held to relatively minor dollar losses because of treated wood in the structures. These experiences resulted in the first real recognition of FRTW as a fire-safe material of construction. Ultimately, acceptance into the building codes resulted and by 1963 all of the model codes had approved FRTW for various uses. In 1964 over 32 million board feet of lumber was treated. In 1969 this had increased to 45 million board feet. In addition, nearly 10 million square feet of plywood and 3 million square feet of other miscellaneous wood products were also treated. In 1969 there were 46 plants processing fire retardant lumber.

Commercially there are two basic types of fire retardants available - an interior type and an exterior type. These names refer to the usage of the treated material; i.e., on the interior of a structure, or the exterior. The interior type is considerably older. It was the fire retardant available when the Navy wrote it into their specifications in 1895.

Interior fire retardants for pressure treated wood all are formulated with water soluble inorganic salts. These salts are dissolved in water at concentrates of 10 to 15 percent depending on the formulation. The salts commonly used are compounds of borates, sulfates, phosphates, chlorides, etc. Some manufacturers add as many as five different salts in one formulation; each added to control certain properties (cost, hygroscopicity, smoke, etc.).

All Underwriters' approved fire retardants carry a Class I fire hazard rating. This means that treated wood has a flame spread of 25 or less when tested in the 25-foot tunnel by ASTM Method E-84. The better fire retardants will have an actual flame spread of about 15 which compares to 0 for asbestos cement board and 100 for untreated red oak. Fuel contributed and smoke developed during the tunnel test are also in the range of 25 or less.

Interior fire retardants do an excellent job of protecting wood from combustion. They are accepted by all model and local building codes. They provide permanent, lifelong protection, except when exposed to the weather or prolonged conditions of high humidity. The salts, being water soluble, will leach from treated wood when exposed to the action of running water. Unless well protected by paints or other impervious finishes, interior FR should be limited to interior uses. The salts are also hygroscopic, meaning that they have an affinity for moisture in the air, and when exposed to high humidity conditions, can absorb sufficient moisture to leach salts. (See Figure 1).

Exterior fire retardants are of recent discovery. Initial research originated following the massive Bel Air fire in 1961. The investigation of this fire disclosed that burning wood shakes and shingles blew from roof to roof contributing immensely to the loss of more than 500 homes in the Bel Air area. This fire prompted Koppers Company to initiate planned research for an exterior type fire retardant. Underwriters' Laboratories provided immeasurable assistance by establishing parameters for what they would consider to be a permanent treatment for wood shakes and shingles when exposed to any weather conditions. Underwriters' criterion for an exterior type fire retardant is detailed in UL790, Test Methods for Fire Resistance of Roof Covering Materials. This is available from Underwriters, Chicago, Illinois, or Santa Clara, California.

In late 1966 Underwriters' approved an exterior type fire retardant and gave Koppers the authority to apply a Class "C" roof covering label to red cedar shakes and shingles. The structure of this fire retardant is a complete new concept from the interior types. Where the interior fire retardants are simply inorganic salts dissolved in water, this exterior type is a water soluble monomer that polimerizes under heat to form an insoluble polymer. Phenolic resins, such as the common plywood adhesives, are in this category. The monomer is manufactured by reacting exact proportions of selected proprietary chemicals in water to form a low solids resin solution. Once the resin is properly cured it is no longer water soluble, nor is it hygroscopic.

In addition to the Class "C" approval on shakes and shingles, further research has resulted in a Class "B" roof system. The Class "B" systems incorporate the Class "C" shakes or shingles on a plywood roof deck covered with a durable polyethelene coated steel foil. Lumber and plywood treated with this exterior fire retardant have been approved by Underwriters' for permanent exterior exposure. Lumber and plywood carry a Class I flame spread, as do the interior type fire retardants, but are not limited to indoor use.

Wood can be processed with this exterior fire retardant in the same facilities as used for interior fire retardants. Wood treated with exterior fire retardants are kiln dried at higher temperatures than interior. This is necessary in order to properly cure the monomer and assure its permanence in the wood.

Underwriters' Laboratories and the Building Codes recognize only pressure treated fire retardant wood. By pressure treating, control is maintained over penetration and retention of fire retardant chemicals. This is necessary in order to meet Underwriters' listing requirements. Underwriters' "Follow-up Service" assures the quality of treatment, and if for no other reason, where life safety is involved only Underwriters' listed products should be used.

Exterior fire retardants are generally easier to bond, machine, and finish than the interior types. Exterior fire retardants provide a good degree of decay and termite resistance. (See Figure 2). Exterior fire retardant treated wood products are more expensive because of the greater sophistication required in processing and more costly chemicals.

This paper could expound on the auxiliary properties of fire retardant treated in great length. The purpose, however, is to inform those unfamiliar with fire retardants that fire retardants do exist for both interior and exterior construction. They are approved by the codes and receive preferential insurance rates. For availability, ease of application, fire safety, economics, and architectural appearance, fire retardant treated wood is unequalled as a material of construction.

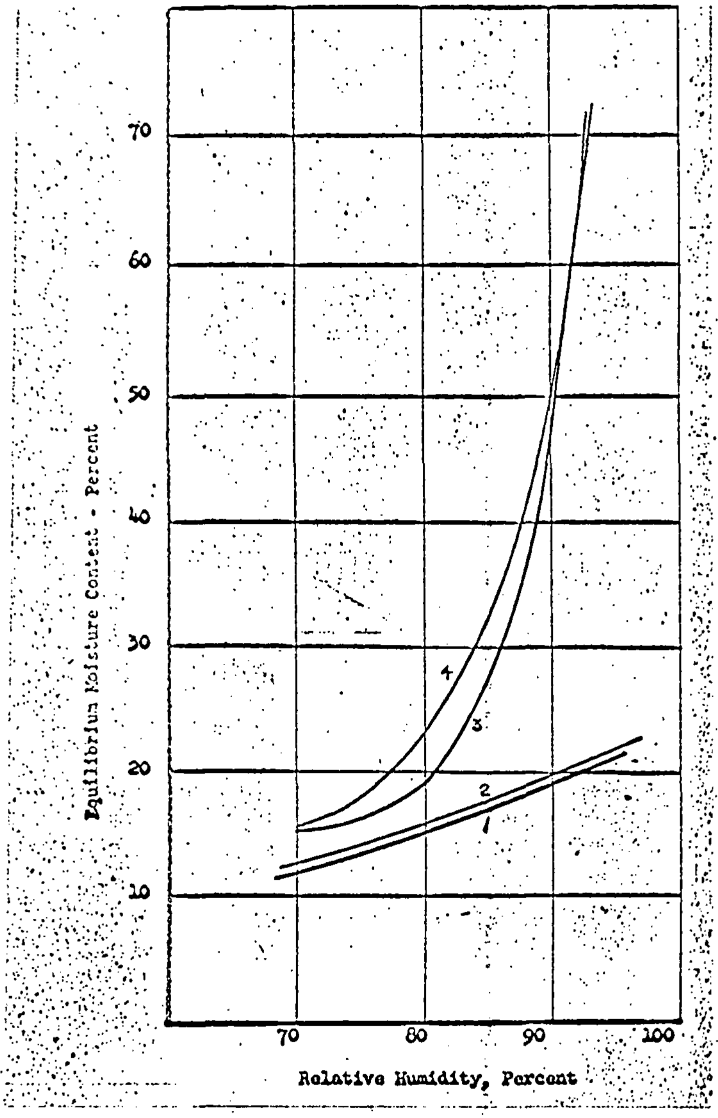


Figure 1. - Comparative hygroscopicity of interior and exterior type fire retardant treated wood.

Curve 1. Exterior fire retardant
Curve 2. Untreated wood
Curve 3. Interior fire retardant
Curve 4. Interior fire retardant (another formulation)

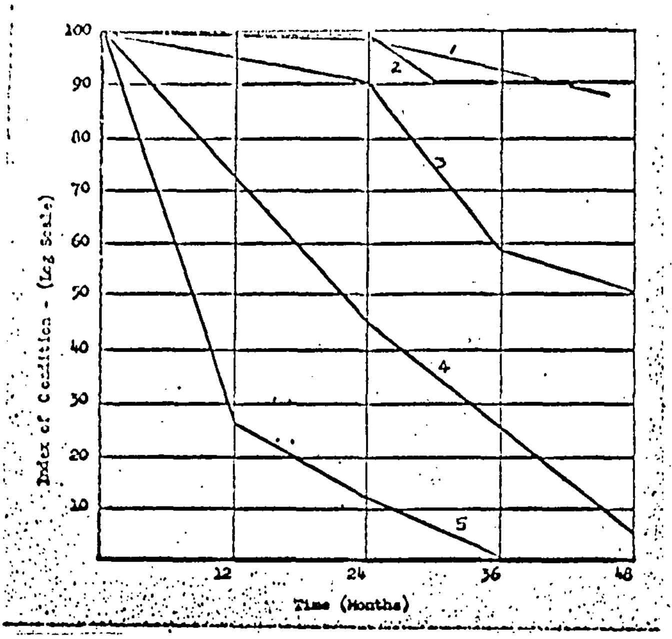


Figure 2. - Comparative resistance of exterior fire retardant treated wood to decay and termite attack. Tested in accordance with ASTM Method D1758.

Curve 1. Non-Com Exterior (R) fire retardant
Curve 2. Wolman Salts (FCAP) 0.4 pcf retention (preservative for above ground use)
Curve 3. Untreated foundation grade redwood
Curve 4. Untreated heart Western red cedar
Curve 5. Untreated sap Southern pine