Applications of Aerospace Technology in Industry

A TECHNOLOGY TRANSFER PROFILE

FIRE SAFETY

ACKNOWLEDGEMENTS

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Much of the information was gathered with the assistance of NASA in-house and contractor personnel who participated in the development and application of the technology discussed.

APPLICATIONS OF AEROSPACE TECHNOLOGY IN INDUSTRY

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FIRE SAFETY

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PROFILE HIGHLIGHTS

NASA interest in fire safety, particularly with respect to manufacturing, handling, and storing hazardous materials, required the discovery and use of new fire safety techniques -- techniques valuable not only to the space program but also to other sectors of the American economy. NASA-funded work in the treatment, processing, and formulation of such nonflammable and fire retardant materials as Beta fiber, fluorinated elastomers, and polyurethane foams is making it possible for firemen, airline safety officers, and other fire protection specialists to make substantial improvements in traditional methods of preventing, extinguishing and controlling fires. Such transfers of NASA-developed fire safety technologies to other organizations provide graphic evidence that technical advances in the space program benefit the rest of society in important ways.

INTRODUCTION

During the early part of May 1970, a national conference on fire safety was held in Houston, Texas. Approximately 500 industrial representatives and NASA personnel met at the Manned Spacecraft Center to discuss recent progress in the field of fire safety, particularly in the area of noncombustible materials and the combustion characteristics of flammable materials. The substantial impact of the conference suggested the subject of this presentation: NASA contributions to the field of fire safety.

The Apollo 204 fire at Cape Kennedy in 1967 stimulated concentrated research into the prevention and extinguishment of a specific type of fire; however, NASA already had compiled an impressive safety record throughout its brief history, particularly with respect to the manufacture, handling, and storage of hazardous materials. The routine use of vast quantities of propellant materials, including liquid oxygen and hydrogen, fluorine, nitrogen tetroxide, and hydrazine, is enough to suggest the scope of the space agency's program for evaluating, processing and handling such materials.

In this presentation the fire safety field is divided into three parts: an industry, a technology base and a user base. The industry provides equipment and materials for fire extinguishment together with materials and techniques for combustion prevention. The technology provides continuing redefinition of approaches that can be taken for both extinguishment and prevention. The user base consists of local and Federal, professional, and volunteer groups which purchase and operate fire protection equipment.

Section I of this presentation provides an overview of the field including a perspective on the magnitude of the national fire safety problem. Selected NASA contributions to the technology of fire safety are considered in Section II. Section III reviews the communication mechanisms, particularly conferences and publications, used by NASA to alert the community to new developments in the fire safety field. Several examples of nonaerospace applications of NASA-generated fire safety technology are presented in Section IV. The presentation concludes by focusing on certain issues associated with attempts to transfer this technology from the space program to other sectors of the American economy.

SECTION I. AN OVERVIEW OF THE FIRE SAFETY FIELD

Approximately 12,000 persons perished in fires throughout the United States in 1970. Add to this statistic the fact that there were in excess of 2.3 million fires during the year causing an estimated $2.5 billion in damage, and it is quickly apparent why Federal agencies, industry, and private organizations wage a continuing and costly war against this national menace (McClennan, 1970; Orey, 1970).

Fire losses, measured in deaths and dollars, tell only part of the story. Injuries sustained by firefighters, for example, are estimated at 500,000 yearly (Kimball, 1970, p. 14). Another factor not usually measured is the massive funding required by all levels of government for fire safety education, establishment and maintenance of standards, and the purchase of firefighting apparatus.

The degree of social and industrial concern over the fire problem can be understood, in part, by considering the number of organizations devoted to prevention and safety practices associated with fire. Some 30 in number, these organizations range in size from the 120,000-member International Association of Firefighters to the nine-member Mill Mutual Fire Prevention Bureau. The influential 22,000-member National Fire Protection Association (NFPA) is noted for its function as a clearinghouse for information on fires. Through its 130 committees, it develops and publishes advisory standards on virtually every aspect of fire protection and prevention. Maintaining a library of 800 volumes of fire protection and prevention data, the NFPA also publishes 10 publications and numerous reference works, folders and handbooks. Including the NFPA, the numbers of associations, organizations, and professional groups linked to the prevention of fire exceeds numbers of similar interest groups in such major industries as plastics, furniture or appliances.

While it is not possible to put a dollar figure on the total amount involved in losses and expenditures connected with fires in the United States, it is readily evident that the cost of this problem to the national economy reaches staggering proportions. In 1960, Americans spent an estimated $1.9 billion in insurance protection against fire; in 1970, $3.2 billion was involved (Parker, 1971). Not even taking into account the increase in expenditures in the last decade, the fact that so many dollars have been spent on fire protection shows the scale of the problem in the United States.

Unfortunately, there has not been much headway made in reducing fire losses in the past five years. According to NFPA, total fire loss in 1966 was $1.8 billion; in 1967 it jumped to $2.07 billion; in 1968 it reached $2.18 billion; in 1969, $2.4 billion; in 1970, estimates are that it surpassed the $2.5 billion mark (Orey, 1970, p. 49). An increase in large fires (losses of $250,000 or more) also is reported by NFPA. For example, a 21 percent jump in major fires occurred in 1969 alone. These statistics would be discouraging were it not for the substantial fire safety research effort being conducted in the United States. The Federal government supports broad programs through the Agriculture Research Service, the Forest Service, Department of Health, Education and Welfare, DOD, Bureau of Mines, and NASA, each reflecting major problem areas. The Directory of Fire Research in the United States, 1967-1969 (National Research Council, 1970) reports that some 1,000 fire research programs sponsored by government, universities, associations, and private industry were conducted during the three year period surveyed.

Government concern in the area of fire safety is twofold: keeping pace with rapid change in industry and protecting the interest of consumers. Such key industries as building and packaging are progressing so quickly in the development of fireproof products that government regulatory agencies have been hard pressed to keep pace. The fact that the National Bureau of Standards has undertaken a new research program on the flammability of wearing apparel, and has proposed the need for a flammability standard for all types of blankets, underscores the specific concern for public fire protection active in government thinking (Washington Science Trends, June 1970, p. 11).

The substantial growth of synthetic fibers and plastic applications make these industries primary targets for new governmental fire standards and regulations. Flammability control of fabrics is one major area with vast implications for synthetic textile producers. Literally millions of dollars are being spent to research methods of rendering nonflammable such synthetics as nylon, acrylic and polyester. Plastics raw materials producers are also setting a fast pace of fire-retardant-additive development in the face of tightening government regulations that affect plastics use in automotive, upholstery and home furnishings. C. T. Davis, writing for the 1970-1971 Modern Plastics Encyclopedia (p. 372), reports that fire retardants consumed in plastics were only 85 million pounds in 1968, but consumption was growing at 13 percent yearly. As a result of the Flammability Fabrics

Act and other recent Federal regulations, the overall growth rate will be 25 to 50 percent over the next three years. As plastics growth continues, moving into new applications at a very rapid rate, new regulations will have to be established, and the industry will have to meet these challenges with many new formulations. The DuPont development of Fairperene, which won the I·R 100 award in 1970, is one example of new fire retardant formulations.

By considering the problem of fire control in the context of a society growing larger and more complex daily, it is apparent that present fire control methods as well as the materials used in product, structure, and systems design must be improved. Society's need for fabrics that will not burn, for housing that will not burn, and for vehicles of all types that will not burn may not be realized in the immediate future, but there is little question that fire safety work accomplished in the space program will play a part in meeting the nation's needs.

For example, major NASA developments in the treatment, processing, and formulation of plastics that render these materials nonflammable, and in the development of fabrics and apparel that will not burn in a 100 percent oxygen atmosphere have become important to the issue of future fire safety in society. New methods of fire prevention and extinguishment, particularly through the development of new materials, are among the NASA contributions to improved fire safety detailed in Section II of this presentation.

SECTION II. REPRESENTATIVE NASA CONTRIBUTIONS TO THE FIRE SAFETY FIELD

NASA has been directly responsible for generating many important developments in the field of fire safety. The space agency, for example, has made significant advances in dealing with the problems of handling flammable materials and in developing numerous new instruments and techniques for flammability testing. The focus of this section, however, will be on a third area of contribution--the development and utilization of fire resistant materials in structures and systems. This area was chosen because the use of materials that will not burn in the form of structural components, apparel, and coatings strikes at the heart of the fire safety problem. If materials will not burn, obviously the need for extinguishment and prevention is markedly lessened, even in the presence of hazardous fuels and other highly flammable substances.

Perhaps the most significant factor in NASA's key role as a developer of fire resistant materials is the extremely stringent requirements imposed by the space agency on materials specified for use in the interior of manned spacecraft: they must neither support combustion nor emit toxic gases when heated in a pure oxygen atmosphere. Successfully meeting this standard, NASA produced totally new and substantially improved materials. In reviewing the prolific development of fire resistant materials during the past decade--in which more new materials were developed than in any other decade--NASA's accomplishments certainly deserve special consideration.

Three key NASA contributions dealing with materials for improved fire safety are discussed in this section: NASA's uses of Beta fiber to fireproof the Apollo spacecraft cabin; the development and subsequent utilization of noncombustible elastomers; and the development of a group of polymeric foams that show great promise as fire resistant materials. These developments, chosen from many, reflect the fundamental nature as well as the breadth of NASA contributions to this area of technology. They are examined in somewhat more detail in Attachment II. The purpose here is to illustrate, with a number of select examples of new fire safety materials, the nature of NASA contributions in this area and the important role this agency is playing in the generation of useful technology.

Beta Fiber

The utilization of nonmetallic materials that will not undergo combustion in high oxygen environments is one area in which developments have arisen almost solely in response to NASA's needs. In most instances, existing materials have been modified and adapted, rather than completely new polymer systems developed, in order to meet these objectives. As a result, not only have the combustion characteristics of the materials been improved, but the variety of applications for the original materials has been extended. A good example of this type of development work includes the ways in which NASA has utilized Beta fiber as a fireproof material in the Apollo spacecraft.

Beta fiber is a glass fiber of extremely fine diameter that is commercially available from the Owens Corning Fiberglas Corporation. Because the fiber is so fine, textiles woven from it, while still remaining nonflammable, are unusually flexible, pliable and soft.

NASA selected Beta fiber as the material to replace organic textiles for most applications in the interior of the Apollo spacecraft. Adaptation of this material to meet all of NASA's needs involved a number of modifications. Teflon coatings for both the fabric and the individual yarns were developed to improve abrasion resistance. Special weaves were devised for different types of applications. Composites of Teflon-coated Beta fabric, aluminum foil, and asbestos fiber were developed to provide excellent thermal insulation for susceptible items such as medicine kits.

Adaptation of Beta fiber to meet NASA's varied requirements, while a major technical achievement in its own right, has increased the utility of this material for nonaerospace applications. Teflon-coated fabrics, for example, offer improved abrasion resistance in clothing applications, such as firefighting garments, where the cloth is now being used. A further refinement, in which individual yarns are coated with Teflon and then woven into a fabric (such a material is used for the outer layer of the astronauts' space suit) provides even greater durability and tear strength. With improvements such as these, Beta fiber can now be considered for additional uses in applications such as protective work clothing, flameproof bedding for hospitals, and upholstery for public transportation.

Fluorinated Elastomers

The development of a class of fireproof synthetic rubber is another result of NASA's requirement that all materials used in the construction of the spacecraft cabin be noncombustible in oxygen. Fluorocarbon-based polymers somewhat similar in structure to Teflon, but elastomers rather than plastics, were modified with fire retardant inorganic compounds to give products that are still rubbery but will not burn. Such materials have found many applications in the Apollo spacecraft. One important use has been as potting compounds and coatings to protect electrical components such as diodes, capacitors, and printed circuit boards from shock, humidity and corrosion. In the cabin they have been used in such diverse ways as the materials for oxygen umbilical cords and the boot soles and heels of the astronauts' space suits. Their largest single application has been the fireproofing of the interior of the mobile quarantine facility in which the Apollo 11 and 12 astronauts stayed following their return from the moon.

A significant result of these fluoro-elastomer developments is that nonflammable rubbers, not just plastics and fibers, are now available. As materials, rubbers possess a number of unique properties. Because of their molecular structure they are far more flexible than other types of polymers, and so can be used in dynamic situations without cracking or fracturing. Equally important is the fact that when they are cross-linked, or vulcanized, they resist permanent deformation. They can be physically distorted by a load, but when the load is removed they assume their original shape. Such is not the case with plastics, which do not have the "memory" of rubber; plastics, once they are distorted, tend to remain distorted. It is for these reasons that fireproof rubbers were needed for oxygen lines, window gaskets, and coatings where flexibility and elasticity were required.

The significance of NASA's activities in adapting materials for use in the Apollo spacecraft extends beyond the fact that there are now available materials with improved fire resistant properties. The agency has demonstrated that it is not only theoretically possible, but technically feasible to construct living quarters which are fireproof under the worst conditions imaginable--in a relatively cramped, completely closed environment containing pure oxygen where weight is at a premium. The Apollo cabin provides a benchmark by which subsequent developments can be evaluated; it can be used in the design and manufacture of living quarters with similar problems and requirements, such as aircraft, nuclear submarines and undersea experimental stations.

New Lightweight Foams as Fire Safety Materials

The two developments that have just been discussed are both based on the underlying principle that fire can be prevented if all the materials present in a given environment are noncombustible. A wayward spark or an overheated wire cannot start a fire because there is nothing that will burn. This has been the approach taken by NASA in the construction of its manned spacecraft. As was pointed out, they have demonstrated that such a philosophy is feasible even under the extremely severe constraints of having to use pure oxygen and operating in a completely closed environment.

Another whole area of fire safety deals with extinguishing or containing a fire that already is burning and minimizing the damage that it causes. In most situations this is the approach that must be used, since some combustible materials are always present. Developments of the type discussed so far are, of course, helpful in containing a fire and reducing damage since their use reduces the amount of combustible material that is available. However, in many cases other means must be used as well. Materials that will extinguish the flame and lower the temperature are used most commonly (for example, water from a fireman's hose). If extinguishing materials are not immediately available, containment of the fire and reduction of damage then requires confining the heat generated during combustion to a localized area so that the flames themselves will not spread. One of the best ways to do this is by using an insulating material that will conduct heat only very slowly. The fire will burn itself out before neighboring areas will become hot enough to ignite spontaneously, or before a material encased in the insulator becomes hot enough to be damaged.

NASA scientists at Ames Research Center have developed noncombustible foams which function dynamically as fire safety materials through a number of mechanisms. When heated they release gases which inhibit ignition and convective transfer; they are extraordinarily effective thermal insulators; and they form a surface char which can reach a high temperature and reradiate a large fraction of the incident heat. Produced from relatively inexpensive starting materials, these foams not only represent a very significant advance in the state-of-the-art, but offer the possibility of providing protection in situations where formerly it was virtually impossible.

An exciting potential application of these fire retardant foams is as insulating materials for aircraft. In a great many of the fatalities associated with commercial aviation, people are burned to death. Aircraft fuel ignites on contact with almost any part of an operating jet engine and burns with an extremely hot flame. In little more than a minute cabin temperatures can soar hundreds of degrees, reducing to virtually nil the possibility of passenger survival (see Figure 2-1). The foams developed at Ames appear to be a very significant breakthrough in the air transportation industry's attempts to deal with this tragic situation. In a test conducted by scientists from Ames and the Avco Corporation during the summer of 1970, a C-47 aircraft fuselage was separated into two sections by steel bulkheads, and the sections were insulated--one with the Ames foam and the other (the control section) with a two-inch blanketof fiber glass batting, the standard insulation used in today's aircraft. The sections were equipped with movie cameras and instruments to measure temperatures and toxic gas concentrations. The fuselage was surrounded with a pool of several thousand gallons of jet fuel and the entire assembly ignited.

This initial test produced startling results. Within two minutes of ignition the air temperature in the control section was above 500°F; in the protected section it was slightly above 100°F. After five minutes the temperature had not yet reached 150°F, and after ten minutes it was still well below the human tolerance limit of 275°F to 300°F. After five minutes there were still no detectable quantities of toxic gases (carbon monoxide, hydrogen chloride and hydrogen cyanide) present in the protected cabin. At the completion of the test when the intact foam section was entered (the rest of the fuselage was destroyed) some smoke was present in the cabin, but it was not considered to be excessive. Ways in which these foams can be used to insulate commercial and military aircraft are now being actively pursued by the air transportation industry.

Only a small portion of NASA's research efforts result in developments of such a spectacular nature. Yet it is organizations like NASA which, because of their own requirements for materials, techniques, and designs that must go far beyond those which are demanded by industry as a whole, often supply the radical solutions or really novel developments. In some cases the contributions do not have immediate and far ranging consequences simply because industry is not yet dealing with the problems to which these developments have provided solutions. In other cases, however, such as the development of improved fire resistant materials, NASA contributions may be readily utilized by a society also greatly concerned with the prevention and control of fire.

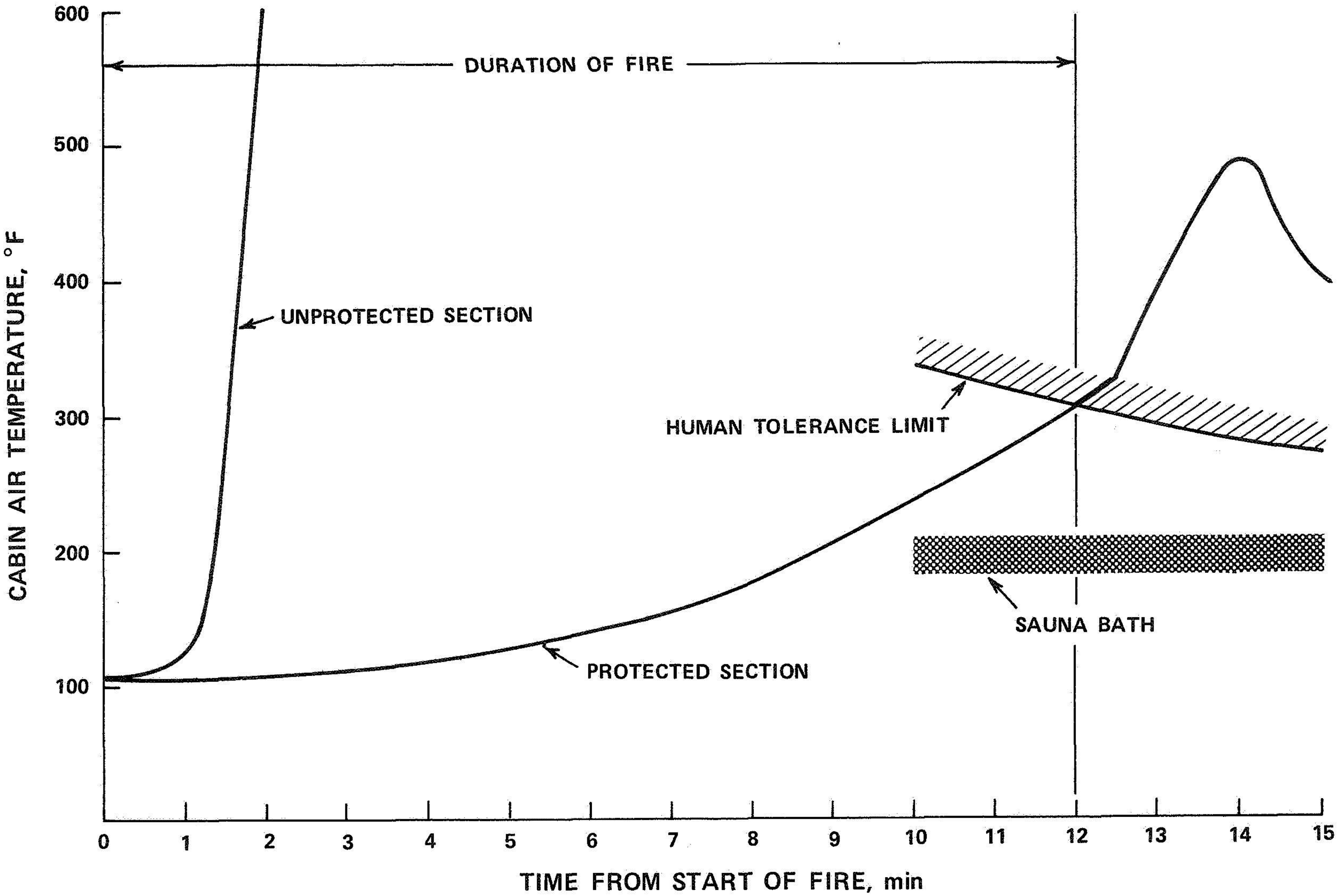

Figure 2-1. Cabin Air Temperature During Firing. (Source: Interim Report, Fire Protective Materials Application Program--Crash Fire Test; Avco Corporation, December 1970.)

SECTION III. COMMUNICATIONS OF NASA CONTRIBUTIONS

Recognizing that maximum benefit can be obtained from space research only when discoveries are widely shared, NASA has attempted in several ways to familiarize potential users with the results of its work in fire safety. This section focuses on two mechanisms which have been particularly useful in communicating NASA contributions, conferences and publications. Attachment III describes related, but less well documented, informal ways that space program contributions have been disseminated to fire safety specialists throughout the world.

Conferences

During the past three years, NASA has sponsored two national-level conferences specifically designed to acquaint American fire safety specialists with technical developments having nonspace application potential. The first of these two conferences was held at Ames Research Center in Moffett Field, California on February 27-28, 1970. The conference was entitled, "Preliminary Data From Studies of Fire Retardant Materials." Members of the Chemical Research Projects Office at Ames described the results of their research that led to the development of polyurethane foams and intumescent coatings. (Descriptions of these developments are presented in Section II and Attachment II.)

Approximately 100 fire safety specialists from industrial and governmental organizations participated in the Ames conference. Participants learned about the chemical mechanisms associated with producing polyurethane foam and paranitroanaline based coatings, as well as how these materials should be configured and applied.

NASA recently organized and conducted a much larger national-level meeting, one which presented a broader range of NASA-generated fire safety materials and techniques than the one held at Ames. The "NASA Conference on Materials for Improved Fire Safety" was convened at the Manned Spacecraft Center in Houston, Texas on May 6-7, 1970. Approximately 500 persons from industrial firms, government agencies (including NASA), research institutes, and universities participated in the conference. They heard 25 presentations dealing with a broad spectrum of NASA contributions to fire safety: nonflammable materials, fire extinguishment methods, flammability testing methods and data, material selection criteria, and materials configuration control. The presentations focused partly on why NASA had developed and used the technologies and partly on actual or potential applications outside the space program. A considerable amount of information concerning subsequent attempts by participants to use the technologies reported in the conference has been collected and will be presented in Section IV.

The main point to be emphasized here is that the conferences NASA has used to communicate the results of its fire safety research have succeeded in making hundreds of potential users aware of significant technical accomplishments--significant in the sense of their demonstrated relevance to the development of solutions to many of society's unresolved fire safety problems.

Formal Publications

In addition to its major conference activities, NASA has developed an extensive formal publication program which fire safety specialists both within and outside of the space program have found useful in their work. Table 3-1 shows the number of titles related to fire safety technology in specific NASA-funded publication categories from 1963 through 1970.

TABLE 3-1 NASA PUBLICATIONS PRESENTING AMERICAN SPACE PROGRAM CONTRIBUTIONS TO THE FIRE SAFETY FIELD: 1963-1970

	TYPE OF PUBLICATION				
YEAR OF PUBLICATION	Tech Briefs*	Technical Reports	Contractor Reports	Other Publications	TOTALS
1963	0	7	0	2	9
1964	0	3	0	2	5
1965	2	3	1	3	9
1966	5	3	1	0	9
1967	2	2	1	1	6
1968	7	9	3	3	22
1969	8	0	6	0	14
1970	9	0	3	3	15
TOTALS	33	27	15	14	89

* Tech Brief titles related to fire safety technology are presented in Attachment III.

These NASA-funded publications collectively report the broad range of space program contributions to the fire safety field. It is useful to note that Tech Briefs, as a single publication category, report the largest number of fire safety innovations resulting from NASA research. Sometimes, too, Tech Briefs are used to announce the availability of publications in the other categories. Understanding the scope of fire safety technology reported in Tech Briefs, therefore, serves as one approach for grasping the wide range of NASA contributions to this field.

For analytical convenience, the 33 fire safety Tech Briefs and their associated Technical Support Packages (TSP's) may be divided into three technical categories: those describing fire prevention materials or techniques; those presenting fire detection, extinguishment and protection methods; and those reporting fire hazard testing techniques. Table 3-2 indicates that roughly four out of five (82 percent) of the Tech Briefs fall into the first two categories. These data also indicate that while fire safety research has been conducted system-wide in NASA, two field centers--Manned Spacecraft Center and Marshall Space Flight Center--generated a majority of the Tech Briefs.

TABLE 3-2. TECH BRIEF TECHNICAL CATEGORY BY ORIGINATING NASA FIELD CENTER

TYPE OF CONTRIBUTION	NASA CENTER			TOTALS
	Manned	Marshall	Other	
Prevention	7	5	4	16
Extinguishment-Protection	2	4	5	11
Testing	3	1	2	6
TOTALS	12	10	11	33

The relevance of technology reported in these Tech Briefs to fire safety problems outside of the space program is partially evident in the number of requests which have been made for related TSP's. During the last three years, persons interested in obtaining additional technical information made 1,011 specific requests to NASA for TSP's associated with the 33 Tech Briefs. Data in Figure 3-1 demonstrate that those TSP requesters wanted information in all three of the technical categories. The fact that two-thirds of the requests were for

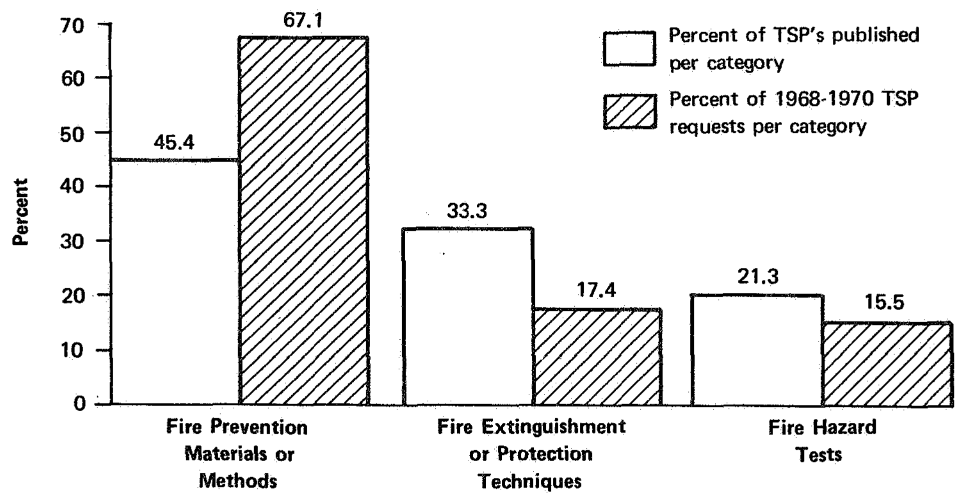

Figure 3-1. Total Production of Fire Safety TSP's Compared With 1968-1970 TSP Request Frequency for Three Technical Categories.

TSP's concerned with fire prevention can be explained partially by comparing TSP request frequency with the number of Tech Briefs produced in each category. It is clear that requests greatly exceeded production in the prevention category but fell far below production in the extinguishment and prevention category. The major reason for this was the tremendous interest shown in three support packages: 405 requests for the document describing fireproof inorganic paint (TSP 65-10156), 148 requests for the Hydrogen Safety Manual (TSP 68-10323), and 78 requests for the support package explaining a new low-expansion nonflammable printed circuit board (TSP 70-10154). One publication in the fire extinguishment category, "Fire Retardant Foams Developed To Suppress Fuel Fires" (TSP 68-10358), generated 105 requests. In the fire hazard testing category, 104 persons requested the document presenting a new burn-rate testing apparatus (TSP 69-10740).

Conclusion

The communication mechanisms described in this section have successfully linked the space agency with hundreds of potential industrial users of NASA-generated fire safety technology. Once those links were established, new cycles of technology transfer began. Section IV presents specific information concerning non-NASA application activities associated with the use of NASA documents or participation in NASA-sponsored conferences.

SECTION IV. A TRANSFER PROFILE

When fire safety specialists outside of the space program learn that NASA has developed a new method for preventing or extinguishing fire, they have in effect, taken the first step in applying the technology to situations that concern them. In some rare cases, they can begin using a new material or technique with little or no modification. In most cases, however, when engineers are able to continue transfer activities, they must modify a technology to meet a variety of technical and economic limitations. These conclusions were derived from the data on technology transfer developed for this section.

To determine how NASA-generated fire safety technology has been used by persons outside of the space program, several hundred engineers and scientists who indicated an interest in that technology were contacted in two different surveys. One survey was directed toward persons who participated in the "NASA Conference on Materials for Improved Fire Safety" at the Manned Spacecraft Center in Houston, Texas on May 6-7, 1970. The other survey involved persons requesting Technical Support Packages associated with Tech Briefs reporting new fire safety technology. Whereas the first survey focused primarily on uses made of new fire safety materials, the second survey dealt mostly with applications of new techniques for handling hazardous materials.

Three Dimensions of the Technology Transfer Process

Before describing the specific details of the application activities identified in the surveys, it will be useful to examine three dimensions of the transfer process: the types of fire safety technology involved, the transfer stages that occur, and the action status of application activities. Once these dimensions are understood, they can be used to place specific examples of technology transfer into a meaningful frame of reference.

Three types of NASA contributions to the fire safety field can be distinguished: those involving fire prevention materials or techniques; those concerned with fire detection, extinguishment or protection methods; and those dealing with techniques for testing fire hazards or the flammability of materials.

Transfer activities may be divided into four stages. Stage 1 transfers involve the recognition of opportunity and searches for additional information to determine the relevance of fire safety innovations to professional activities. Stage 2 transfers include laboratory verifications of fire safety materials or techniques. Transfer cases are classified in Stage 3 when organizations either are market testing prototypes or are using new fire safety techniques in their operational activities. Stage 4 transfers include those situations in which adopters are selling new nonflammable materials or fire extinguishment techniques developed originally either by or for NASA. Organizations active in the first three transfer stages are referred to as adapters; their primary goal is to adapt or transform a technology for new applications. Organizations active in the fourth transfer stage are referred to as adopters; they are marketing new applications of adapted technology.

The action status of transfer activities refers to the dynamic nature of the transfer process at the time contact is made with organizations. For convenience, two action statuses are distinguished: those which are continuing, and those which have terminated. As will be shown, interest in an innovation may progress through all four transfer stages; or it may continue indefinitely in one or another of the transfer stages; or, finally, interest may terminate in any of the transfer stages. Cases are classified as terminated when one or more of three conditions exist: no further adaptation or adoption activities are contemplated, a better technical alternative has been found, and/or continued transfer activity is not economically feasible.

The Surveys

Technology transfer processes are triggered and facilitated by several different communication mechanisms, including conferences, publications and personal contacts. For the purposes of this presentation, transfer activities associated with the use of Tech Briefs and participation in the 1970 Houston Fire Safety Conference were selected for special examination. The primary reason for selecting these communication mechanisms is that a substantial body of transfer activities associated with both mechanisms has been developed which makes it possible to draw some general conclusions about the nature of the transfer process.

Procedures. As noted in Section III, 33 Tech Briefs have been published since 1963 which report the development of new fire safety technology. With reference to the type of technology reported, 16 describe fire prevention materials or techniques, 11 present fire extinguishment and protection materials or methods, and six deal with fire testing techniques. During the past three years, persons outside the space program have made 1,011 specific requests for Technical Support Packages (TSP's) associated with the 33 Tech Briefs. Mail questionnaires were sent to 500 of the TSP requesters six months after they had requested the documents. This time delay was considered sufficiently long to permit TSP users to reach tentative conclusions concerning applications of the technologies presented. Approximately three-fifths (59.8 percent) of the TSP requesters contacted returned questionnaires. Several of those who indicated making substantial progress in attempts to adapt technologies subsequently were interviewed by telephone to substantiate and clarify the specific nature of their transfer activities.

A second survey was conducted to generate illustrations of transfer activities associated with the Houston Fire Safety Conference. In October 1970, questionnaires were mailed to 182 non-NASA engineers and scientists who attended the May conference. Again, the six month time lag was considered sufficient for participants to make initial decisions concerning their use of the technology presented. Sixty-two percent of the 182 conferees contacted returned their questionnaires. Telephone interviews subsequently were conducted with respondents indicating they were involved in more advanced transfer activities.

Results. Profiles showing the different transfer activities identified in the TSP and conference surveys are presented in Figures 4-1 and 4-2. Approximately four-fifths of the TSP users indicated they either had used the information to keep up-to-date with developments in the fire safety field or that they were still trying to determine the relevance of the technology to their organizational needs. By contrast, three-fifths of the conference participants indicated they were involved in Stage 1 transfer activities.

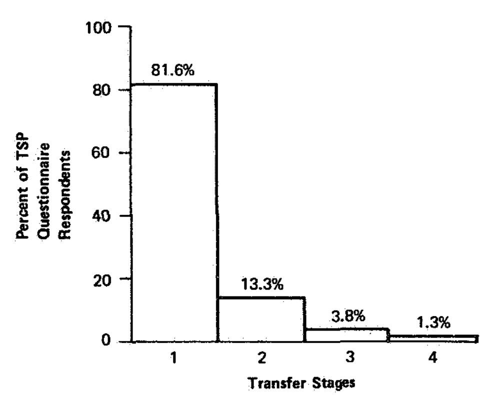

Figure 4-1. Transfer Profile of 299 Persons Using TSP's Related to the Fire Safety Field.

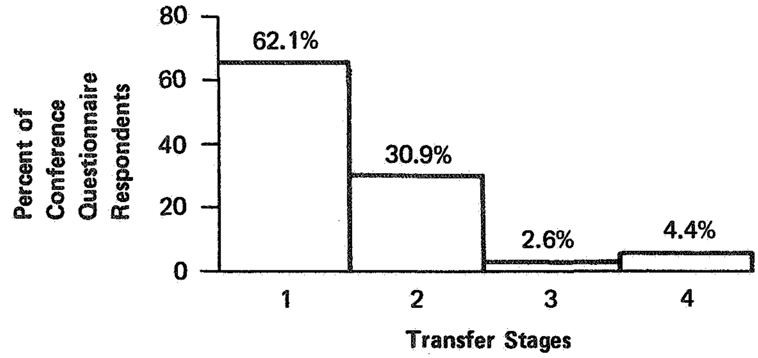

Figure 4-2. Transfer Profile of 113 Non-NASA Persons in the Houston Fire Safety Conference.

One example of technology transfer, drawn from the conference data, illustrates the type of adaptation activities characteristic of Stage 1. It involves DeSoto, Incorporated, a paint company in Des Plaines, Illinois. A DeSoto engineer who attended the conference said his firm is planning to use fiber additives when it undertakes the development of new nonflammable paints in the near future. (See "Houston Fire Safety Conference" Transfer Example File Summary in Attachment IV.)

Another Stage 1 transfer example, drawn from the TSP data, may be used to illustrate that transfer activities sometimes are suspended in this stage for economic rather than technical reasons. The Rubber Specialties Company in Minneapolis, Minnesota received the TSP describing fire retardant foams from another local firm to answer questions raised in a discussion of possible insulation materials for a project under consideration. Rubber Specialties was contemplating entry into the business of making prefabricated plastic panels for room dividers in modular homes. A company engineer said he was considering using the foam for fireproofing and soundproofing the dividers. Before experiments on these proposed applications were undertaken, however, economic and market considerations led to a decision not to enter the new field. While company engineers still were interested in the NASA document describing the foams at the time of the interview, they had not yet found other uses for the technology. (See "Fire Retardant Foams" Transfer Example File Summary in Attachment IV.)

NASA's announcement of the development of a fireproof and durable inorganic paint (Tech Brief 65-10156) has stimulated a great deal of interest among commercial paint manufacturers. One case, demonstrating Stage 2 transfer activities, involves the Lithoid Corporation in Lima, Pennsylvania. Lithoid is using information in the TSP in experiments to develop a base coat for "ceramic teflon" products which are exposed to extremely high temperatures. The "Inorganic Paint" Transfer Example File Summary in Attachment IV briefly describes eight other cases in which experiments are underway to find commercially acceptable fireproof inorganic paints.

One case can be used to illustrate how new transfer activity may be stimulated when initial activity terminates in Stage 2. General Motors' engineers working in a Warren, Michigan laboratory recently conducted tests of a burn-rate testing apparatus described in TSP 69-10740. One of the engineers indicated that the testing apparatus was under consideration as a device for testing the flammability of cloth used in GM's polishing buffs for steel. They decided that the apparatus was too sophisticated in its present form for this type of test. Some of its features, however, may be incorporated in a simpler device which is in the conceptual stage at this time. This particular case highlights the fact that technologies sometimes do not transfer intact. In this case, adapters decided not to use the burn-rate testing apparatus as described in the TSP. Their decision to consider using certain of its elements, however, indicates the initiation of a new transfer cycle--one in which only selected elements of the original technology may finally be used. (See "Burn-Rate Testing Apparatus" Transfer Example File Summary in Attachment IV.)

Approximately three percent of the respondents in both surveys indicated their transfer activities had progressed into Stage 3. Two companies using the Hydrogen Safety Manual associated with Tech Brief 68-10323, for example, reported they established safety methods which are used in regular company operations. The Midland, Michigan division of the Dow Chemical Company uses data from the manual to provide adequate safety measures in handling hazardous materials. Engineers with Fenwal Electronics, Incorporated in Framingham, Massachusetts used the manual to develop safety methods connected with their operation of a hydrogen atmosphere chamber. Both the Dow and Fenwal experiences demonstrate the fact that transfer activities are sometimes stage-limited. In neither case do the companies involved plan to "market" the NASA-generated technologies they are using. (See "Hydrogen Safety" Transfer Example File Summary in Attachment IV.)

By contrast, another transfer example can be cited that shows how some companies are laying the groundwork for successful Stage 4 activities in Stage 3. It is a case that shows considerable promise for reducing the fire hazards confronting the air transportation industry. It involves the development of fire retardant foams by the Avco Corporation in Wilmington, Massachusetts. Under NASA contract, Avco recently completed investigations of processing methods, application techniques, and properties of the foam as they relate to aircraft fire safety. The company received a nonexclusive NASA license in 1970 to use the invention. Market studies related to its use in aircraft are underway. (See "Fire Retardant Foam" Transfer Example File Summary in Attachment IV.)

Both surveys revealed that a few companies, seven altogether, should be grouped in the fourth stage of technology transfer. They are commercially marketing technologies developed primarily for space program applications. Four of these Stage 4 cases involve the marketing of the inorganic paints (Tech Brief-TSP 65-10156) referred to above in the discussion of Stage 2 transfer activities. One firm, the Wisconsin Protective Coatings Company in Green Bay, holds a nonexclusive NASA license to produce and sell inorganic paints. A company spokesman recently estimated the firm's 1970 earnings from sales of the inorganic paints totaled $100,000.

In the area of nonflammable materials, three firms are involved in Stage 4 transfer activities: the 3M Company, Mosites Rubber Company, and Raybestos-Manhattan, Incorporated. All three firms were actively engaged in developing and supplying Fluorel materials to NASA before the Houston Conference was held. In fact, their primary customer for Fluorel up to that time was NASA. Since the conference, however, all three firms have experienced a substantial increase in the amount of interest firms not involved in the space program are showing in Fluorel. For example, several potential users have purchased small quantities of Fluorel from 3M for prototype testing commercial applications in the areas of air transportation, shipping, fire fighting and residential housing. The "Nonflammable Materials" Transfer Example File Summary in Attachment IV provides additional information on the commercialization of Fluorel.

Conclusion

Nine transfer examples have been cited to illustrate the wide range of activities in which persons outside of the space program have attempted to solve fire safety problems by using technology developed by or for NASA. More elaborate descriptions of these and 62 other cases, including the transfer activities of 19 companies not contacted in the original conference survey, are presented in Attachment IV.

The examples make three points very clear. One is that much of NASA's fire safety work is related directly to many of America's unresolved fire prevention and control problems. The second is that when NASA sets its communication mechanisms into motion, the initial step in the transfer process can be taken. Finally, regardless of the communication mechanism NASA uses, certain factors--financial, technical, marketing--facilitate or retard transfer activities. Depending on their mix in a given situation, high cost, technological lags, or unfavorable markets may retard transfer. Conversely, growing markets and advanced, well capitalized projects speed the transfer process.

SECTION V. A FOCUS ON ISSUES

This presentation has afforded the opportunity to contrast two very different mechanisms for the communication of technology--the Houston Fire Safety Conference and the Tech Brief program as it deals with fire safety technology.

The two profiles of aggregate transfer activity presented in Section IV are striking in that unfavorable markets, technological lags, or high costs are reflected in both as barriers to transfer. These similarities in the two profiles appear to be far more important than the proportionate numbers of people found in the various transfer stages. Although this was the first comparison of its kind between these two communication mechanisms, it is interesting that three-fifths of the conference participants were in the awareness stage as compared to four-fifths of the people using Technical Support Packages. The fact that the awareness stage dominates both profiles, however, is a strong confirmation of a basic concept in technology transfer. Once a technology generator like NASA forges a link of communication with a potential user, then the transfer process begins. How far it goes depends upon the industrial benefits and constraints influencing the user. NASA's challenge and its credit in this case, therefore, lies in the continuing refinement of the mechanisms used to achieve communication.

ATTACHMENT I

A Brief Chronology of the Fire Safety Field

ATTACHMENT I

A BRIEF CHRONOLOGY OF THE FIRE SAFETY FIELD

1678 Boston imports first hand pumped engine from England and employs 12 firemen and a chief.

1683 Most of the colonies and villages have rudimentary equipment and some organized response.

1718 The Mutual Fire Society, the first volunteer fire company in America, is formed in Boston.

1801 First water system with hydrants installed in Philadelphia.

1809 New York obtains first fireboat.

1841 First steam fire engine built in America.

1847 Automatic sprinklers introduced.

1852 First central fire alarm office and street box system is installed in Boston.

1870 First aerial ladder invented in San Francisco.

1871 Woven jacketed, rubber-lined, 1-1/2 inch hose first used in Boston.

1907 First gasoline-powered pumps and engines are used.

1931 Owens-Illinois and Corning Glass develop glass fiber.

1938 Teflon invented at DuPont Company.

1953 Congress passes the Flammable Fabrics Act which specifies a test standard for determining the fire danger of fabrics.

1953 First real breakthrough in flame retardant finishes for conventional fabrics. THPC, tetrakis (hydroxymethyl) phosphonium cloride, discovered at Southern Regional Research Laboratory.

1954 Intumescent coatings invented at Monsanto Company.

1957 Fluorinated elastomers developed at DuPont.

1958 Chicago fire commissioner, Robert J. Quinn, invents the snorkel (a truck mounted, hydraulic-operated extension platform).

1961 Polybenzimidazoles (PBI) first prepared for the Air Force.

1962 Patent on preparation of aromatic polyamide fibers (Nomex) by DuPont.

1963 American Viscose Division of FMC Corporation begins marketing flame retardant acetate yarns based on addition of brominated organic phosphate.

1965 Owens-Corning develops Beta cloth.

1967 Teflon-coated Beta cloth developed at Owens-Corning under NASA contract.

1967 FMC Corporation announces a permanent flame retardant rayon, Avisco PFR Rayon.

1968 Nonflammable fluorinated elastomers are developed at DuPont and 3M.

1968 High char forming intumescent coatings developed at Ames Research Center.

1968 Coatings and Resins Division of PPG Industries announces fire retardant paint, Spudhide Latex Fire Retardant Paint, which foams and then chars when exposed to flames.

1969 Inventors of Micatex, fireproof paint, apply for patent.

1969 Polyisocyanurate foams developed at Ames Research Center.

1970 Polyisocyanurate foams shown by NASA in C-47 test to provide greatly improved fire protection for aircraft.

ATTACHMENT II

NASA Development of Noncombustible Foams as Fire Extinguishing Materials

ATTACHMENT II

NASA DEVELOPMENT OF NONCOMBUSTIBLE FOAMS AS FIRE EXTINGUISHING MATERIALS

This attachment to Section II is devoted to the consideration of a key NASA contribution to the field of fire safety: the development of noncombustible foams which, through a number of different mechanisms, can be used to extinguish major fires. The emphasis on fire extinguishment in general, and on the foams in particular, is warranted for both technological and economic reasons. NASA research in developing these foams has produced what appears to be a major breakthrough in the control of extremely hazardous fires, fires whose cost in lives and dollars has been intolerably high.

Before the problems of fire extinguishment are examined, however, another point should be emphasized. NASA contributions to the fire safety field span all dimensions of that field: prevention, extinguishment and materials testing. Substantial documents have been or could be written which explore this wide range of contributions in considerable detail. NASA contributions to the development of nonflammable materials such as modified Beta fiber and fluorinated elastomers (described in Section II) are examined in papers by Naimer (1970), Supkis (1970) and Radnofsky (1970). As indicated, however, this Attachment will focus specifically on NASA's development of noncombustible foams that are highly effective in extinguishing fires.

Methods for Extinguishing Fires

In their publication Handling Hazardous Materials, Cloyd and Murphy (1965) presented the main approaches that can be taken to extinguish fires. Their discussion, which provides a useful frame of reference for discussing NASA's development of fire retardant foams, follows:

> Nature of extinguishment actions. The actions by which extinguishing agents put out fires may be classified as (1) physical actions, and (2) chemical actions. The physical actions include:
>
> 1. Cooling action which lowers the temperature of the combustible substance below its ignition temperature.
> 2. Blanketing action which prevents air from reaching the fire and results in a dilution of the oxygen content of the surroundings.

3. Mechanical action which results from directing the agent across the fire with sufficient force to cut the flame away from the combustible.

The chemical actions include (1) chain-breaking and (2) "preferential-oxidation."

The chemical actions are complex. A complete understanding of them ultimately depends upon a complete understanding of the combustion mechanisms. In the case of the hydrocarbon compounds the combustion processes are so intricate and complex that a rational scientific solution of them is impossible at present. It has been fairly well established that hydrocarbon combustions, like the hydrogen and carbon-monoxide combustions, proceed by branched-chain mechanisms, although it is not known with certainty what radicals function as the chain carriers. The inhibiting action that minute quantities of the halogens and other substances have on these reactions has been interpreted as one of combination with or deactivation of the chain carriers. This results in a breaking of the reaction chains and a subsequent partial or complete retardation of the reaction. The chain-breaking action is the more important of the two chemical actions of fire-extinguishing agents. The other chemical action, preferential oxidation, which is exhibited by some of the slightly inflammable extinguishing agents, is the reaction of the agent with the ambient oxygen and results in a smothering of the fire.

Relative importance of the different actions. Some, and possibly all, of the five actions of fire-extinguishing agents are operative during the extinguishing of a fire. Evaluation of their relative importance becomes very complex. The gaseous and liquid extinguishing agents will be considered first, then the metallic salts.

The mechanical action is primarily a function of the method of application. Since it is dependent on the manner in which the agent strikes across the flame, it is probably of major importance in extinguishing most aircraft fires. The blanketing action is mainly a function of the rate of application but also depends on the volatility and the density of the extinguishing agent. The FAA found that the rate of application is the most important factor affecting the ability of an agent to extinguish fires. From this fact, it would seem that the blanketing action of extinguishing agents is one of the most important actions.

Cooling action is a function of the physical properties of the agent (that is, heat capacity, thermal conductivity, and the heat of vaporization) and is of different magnitude for different agents. The differences in extinguishing effectiveness of the various inert gases (helium, argon, nitrogen, carbon dioxide, and water vapor), as measured in inflammable-limits studies, are adequately explained by differences in cooling action. The cooling action obviously is also a function of the amount of extinguishing agent employed. With most extinguishing agents, except water and highly compressed carbon dioxide, the amounts used are small and the cooling action is of only secondary importance.

The importance of the chemical actions are indicated by the greatly enhanced extinguishing effectiveness of the gaseous and liquid halogen-containing compounds, as determined in inflammable-limits studies. These compounds have larger specific heats than the inert gases and the cooling action should therefore be increased, but the increase is not large enough to account for the much greater effectiveness of many of the compounds investigated. Among the halogen compounds there is no relation between extinguishing effectiveness and specific heat. This effect therefore must be derived from strong chemical actions.

Although the chemical actions appear much more important than the cooling action, it is difficult to appraise their importance relative to the blanketing and mechanical actions. Such an appraisal could be made from a quantitative correlation between results obtained from inflammable-limits studies, which measure chemical actions (and cooling action), and those obtained by direct-application methods.

For metal salts, the main action appears to be chemical in nature. This is self-evident for water solutions because the addition of the salt can hardly produce any marked change in the cooling and blanketing properties of the water. For dusts and powders, there is little blanketing action; it has been shown that the extinguishing effect arises primarily from the undecomposed salt.

Although the chemical actions appear to be important in fire extinguishing, their importance must not be overemphasized.

At present, it is impossible to give a quantitative evaluation of the significance of the chemical actions relative to the blanketing and mechanical actions because no reproducible quantitative data on the relative efficiencies of different agents have been obtained by direct-application methods.

Thus, two general approaches may be taken to extinguishing unwanted fires. The first approach is for an outside agent--human and/or mechanical--to apply gaseous, liquid or metallic salt extinguishing agents. The second approach, one taken by NASA in the development of its fire retardant foams, involves the use of structural materials which can act dynamically as fire extinguishing substances. This second approach is based on the principle that a coating of structural material, when exposed to heat, will generate compounds which will tend to extinguish flames and limit the spread of fire. Such an approach is quite new and one in which a great deal of research still needs to be carried out. Used by NASA, it has led to the development of foams which represent a significant advance in the state-of-the-art of fire safety.

Thermally Protective Foams

In September 1967, a team was established at the NASA Ames Research Center to develop new techniques and materials for fire protection utilizing the principles that had been employed to protect space vehicles during reentry. Certain ground rules were established that were designed to avoid the normal long leadtimes between the generation of an idea and the production of a final, useful product. First, specialists from a number of segments at Ames Research Center were organized 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.

A variety of principles or mechanisms were integrated in this group's overall approach. One involved the fundamental realization that thermal protection can be achieved as long as there is a high resistance to heat flow between the heat source and the structure being protected. Low density foams with a low thermal conductivity are extremely efficient thermal insulators, hence they were chosen as the basic fire protection material.

Another important mechanism, often overlooked in fire protection systems but widely used in spacecraft, is that thermal protection can be achieved through the release of gases from the thermal-protective material when it is subjected to a 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. Another mechanism that affords protection against fires is a production of char by the action of heat on the materials. If char with low thermal conductivity and high oxidation resistance can be formed, it will not only allow 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.

Employing these principles, the group at Ames developed a number of foams which are exceptionally good thermal insulators. One class uses polyurethane as the base composition. Several different kinds of materials were then incorporated into this basic polymer system. Polyvinyl chloride was added to increase the amount of char that was formed. When pyrolyzed, this halogenated polymer released hydrogen chloride gas, which is an effective free radical flame scavenger. Potassium fluoborate was added to the foam system. This inorganic salt is thermally decomposed to give fire quenching or suppressing species; in addition, the decomposition products of the salt potentially can react with the degradation products of the urethane foam, giving a char with improved dimensional stability. Short glass or quartz fibers could be added to give foams with improved mechanical or insulating properties; however, this procedure resulted in foams in which the density was roughly tripled. In Figure II-1 it can be seen that these foams as insulators are superior to commercial isocyanurates, one of the best insulating foams on the market.

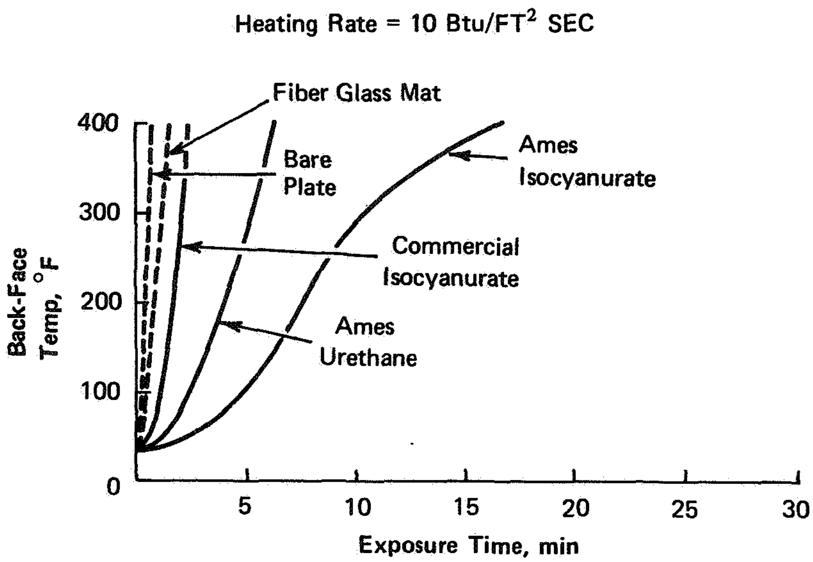

Figure II-1. Performance of Various Fire Retardant Foams in JP-4 Fuel Fire.

A conclusion drawn from early work by the Ames group was that the effectiveness of a foam as an insulating material is directly related to the percent of the original foam that is converted to a char. Hence materials were sought which would have high char yields upon pyrolysis. Studies showed that char yield could be correlated with the number of multiple bonded, aromatic linkages per unit weight of material. This relationship is depicted in Figure II-2. Ames 51 is the polyurethane foam that was just discussed. It can be seen that polymers possessing a high degree of aromatic structure, such as polybenzimidazoles and polyphenylenes, have exceptionally high char yields. Although both of these materials are very expensive, they are currently being investigated for use as fire retardant foams, and have shown considerable promise.

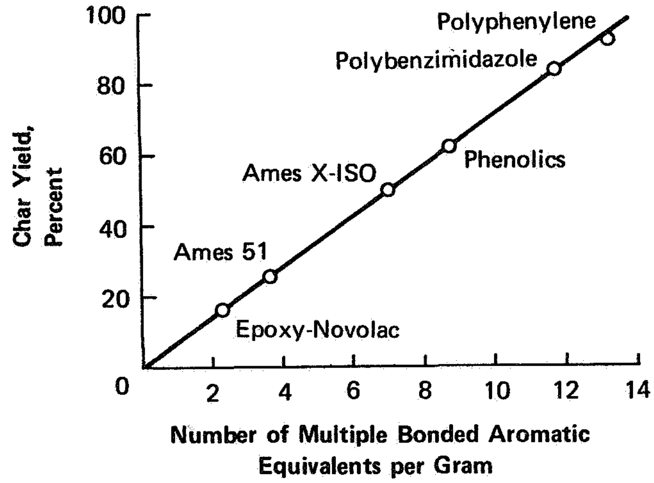

Figure II-2. Correlation of Primary Thermochemical Char Yield with Molecular Structure.

Materials that are not expensive, but give substantially more char than polyurethanes, are polyisocyanurates. An isocyanurate group is a ring structure formed by the cyclization of three isocyanate groups. (Figure II-3) This multi-ring network results in char yields of about 50 percent, roughly double that of isocyanates.

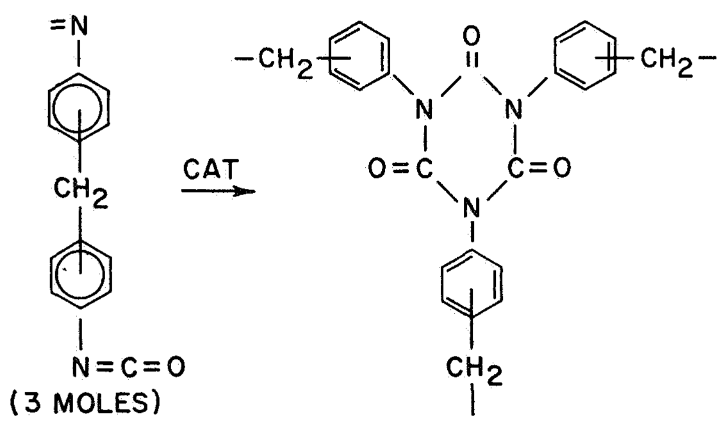

Figure II-3. Isocyanurate Structure

Polyisocyanurate foams have been commercially available for some time, but have found limited use because they are so brittle. The brittleness appears to be due to the cyclic structure of the isocyanurate monomer, which greatly restricts motion in the polymer chains. By ingeniously altering the molecular structure of the polyisocyanurate network, the group at Ames increased the flexibility of the foam without affecting other properties.

It was decided that flexibility could most readily be improved by using a small amount of polyol monomer to introduce a limited number of urethane linkages into the polyisocyanurate structure. The potential disadvantage of this approach was that introduction of less stable urethane linkages could lead to flammable gaseous species during pyrolysis. Hence a number of criteria were established for the polyol that could be used. The monomer itself had to form a char independent of the urethane linkage. The reaction to form this thermally stable structure had to occur before degradation of the urethane linkage in order to minimize formation of volatile fragments. The polyol had to have a low hydroxyl number in order to convert as few as possible of the isocyanate groups to urethane linkages in the polymer system. The polyol itself had to have chain length long enough for it to be flexible in order to impart flexibility into the entire system.

On the basis of these criteria, a liquid polyoxypropylene material to which acrylonitrile groups had been grafted was selected as the polyol to be used. This material introduced considerable flexibility into the isocyanurate foam. When exposed to heat, the acrylonitrile groups cyclized to give heterocyclic structures which tended to aromatize on further heating. The polyol itself was thus a car forming material.

Isocyanurate foams modified in this manner are exceptionally good fire resistant materials. When heated, they yield a high amount of char, maintain excellent dimensional stability, and are far better insulators than foams that are commercially available (see Figure II-1).

Ames Isocyanurate Foams as Fire Protective Materials

A study was conducted during the summer of 1970 by the Avco Systems Division of the Avco Corporation, under the sponsorship of NASA's Ames Research Center, to determine the effectiveness of the Ames polyisocyanurate foam as a fire protective material in a simulated aircraft crash fire. This experiment was so significant it is described in detail below.

A C-47 aircraft fuselage obtained by Avco was divided into two sections, each physically and thermally separated by steel bulkheads and thermal insulation. The two individual sections of the aircraft were prepared as follows:

> Foam Protected Section: This section was protected with the Ames polyisocyanurate foam sprayed onto the walls, ceiling, and floor to a thickness of 2-1/2 inches and a density of 3.75 pounds/cubic foot. On the inside face of the foam was attached a fiber glass epoxy laminate, representing the interior decorative skin of a passenger aircraft.
>
> Reference Section: This section included the fiber glass laminate interior skin; but in place of the foam, an insulation blanket was installed, typical of present day aircraft design. The blanket consisted of a 2-inch thickness of fiber glass batting, at a density of .60 pounds/cubic foot, supplied by Johns Manville and known as Microlite AA.

The test vehicle was instrumented so as to ascertain the thermal environment to which the aircraft was subjected and the response within the fuselage cabin to that environment. At both ends of the vehicle, instrumentation probes were installed to monitor the smoke and gas environment of the interior. This was accomplished by movie cameras and the "drawing off" of gas samples for later analysis. Instrumentation and recording equipment consisted of one tape recorder, four pen recorders, three external motion picture cameras, one outside still camera, three internal motion picture cameras, and an internal gas sampling device.

The fuselage was situated between two pits of JP4 aircraft fuel. Each pit was 27 feet wide and 48 feet long, extending beyond the aircraft by approximately 11 feet at each end. The fuel was floated on top of 3 to 4 inches of water with the top of the fuel being level with the ground and the bottom surface of the fuselage. The fuel depth of 2.9 inches was calculated to last for a ten minute burn at maximum heat flux, with approximately two to three minutes to self-extinguish. A fire was then initiated with pyrotechnic squibs at two positions in each pit with "systems turn on" at intervals from T -60 seconds. Within 30 seconds of T -zero, the complete test vehicle was engulfed in flames which lasted for a total of 12 minutes. The fire finally was extinguished at 13 minutes when only small flames were present at the edge of the pit.

Visual observation of the reference section during the fire was difficult due to the volume of flame and smoke, however, inspection of the movies showed that the interior was filled with smoke within one minute and flames penetrated at two minutes. Aluminum pieces were observed to be "flying off" at approximately T +2 minutes. In contrast to this, the foam protected section survived the fire with only minor penetration at the floor-to-fuselage connection, which occurred at approximately T +7 minutes.

The interior of the foamed section was inspected immediately upon termination. Although some smoke was present, it was not considered to be an excessive amount. The walls of the section (i.e., the fiber glass epoxy laminate interior skin) were charred in many places where the inner skin was attached to the full depth frame, and other areas where the foam had fissured. There was, however, no physical penetration of the fiber glass laminate other than as mentioned previously at the fuselage-to-floor connection. On inspection and removal of foam samples, it became evident that the foam had formed a very strong char, requiring considerable force of knife and hand to be removed; in addition, the interior fiber glass laminate provided a shell which would certainly have protected passengers from structural failure.

Figure 2-1 in Section II shows the air temperatures recorded by thermocouples positioned within the fuselage. The temperature in the reference section climbed dramatically after one minute and was off the scale at two minutes, confirming the visual and movie observations that the section was on fire and collapsing at approximately T +2 minutes. In contrast, the temperature in the foam-protected section remained reasonably constant for two minutes and then increased at a steady rate of approximately 17°F per minute.

Preliminary examination of IR Spectra of gas samples taken from the foam-protected section showed no detectable quantities of toxic gases (CO, HCl, HCN) or freon at T +4 minutes, and no detectable quantities of toxic gases (CO, HCl, HCN) but significant freon peaks at T +5 minutes.

Avco (1970), in its interim report on this study, drew the following conclusions:

> As of the date of this report, only the data from the direct reading instrumentation and preliminary gas analysis is available, requiring further data reduction and analysis to obtain

results from the tape recorder and gas samples. Nevertheless, from physical observations of the test results, photographic coverage, available temperature data, and gas analysis, it is obvious that the installation of the foam provided habitable protection for a minimum of five minutes beyond that provided by the conventional fuselage cabin design. Therefore, it is concluded that a successful result was achieved and that the installation of the foam to passenger aircraft will dramatically increase the time for rescue and survivability.

The significance of this work is obvious in the context of aircraft fire safety. In other applications, however, the demonstration that material properties can be altered to achieve thermal isolation and flame retardant action will have a lasting influence on new designs for fire safety.

ATTACHMENT III

Technical Information Dissemination Activities

ATTACHMENT III

TECHNICAL INFORMATION DISSEMINATION ACTIVITIES

The major contention of Section III was that NASA in-house and contractor personnel have been quite effective in disseminating the results of their fire safety work through conferences and publications sponsored by the space program. By using those mechanisms, NASA has made it possible for hundreds of fire safety specialists throughout the world to become quite familiar with new fire prevention and extinguishment materials and methods.

Not discussed in Section III, however, were the other communication mechanisms used to disseminate NASA contributions to the fire safety field. Some of the other mechanisms employed, such as development contracts with commercial firms and literature searches by regional technical information centers, constitute formally organized and systematic attempts to stimulate technology transfer. Other mechanisms, such as consulting with industrial design engineers and working with industrial magazine editors, have triggered technology transfer in unplanned ways. To date, no systematic attempts have been made to trace the frequency or magnitude of transfer activities intiated by these mechanisms. The absence of such quantitative data does not mean, however, that worthwhile adaptations and applications of NASA fire safety technology have not been undertaken through the operation of these mechanisms.

This attachment presents examples of the ways certain mechanisms other than conferences or NASA-funded publications have stimulated technology transfer activities in the area of fire safety. The instances cited are meant simply to substantiate that other mechanisms are also operating. The examples chosen should not be considered wholly representative. How frequently such activities occur and what technical and economic impacts they produce are questions which have not been answered. By identifying such instances, however, their importance as communication mechanisms can be clarified.

The attachment concludes with an exhibit that lists NASA Tech Briefs related to fire safety technology.

Contract Activities

An important mechanism in transferring fire safety technology involves the commercial utilization of technical know-how that NASA contractors develop during the course of their work for the space agency. Four examples can be cited to illustrate this mechanism in action. These illustrations do not emphasize the details of the specific technology involved; such information is presented in the Transfer Example File Summary reports in Attachment IV.

Two examples involve attempts to find additional applications for the fire retardant foams described in Attachment II of this presentation. The Avco Corporation in Wilmington, Massachusetts was awarded a NASA contract in 1969 to investigate processing methods, application techniques, and properties of the foam as they relate to aircraft fire safety. The company received a nonexclusive NASA license in 1970 to use the invention and is currently concluding market studies related to commercial aircraft applications of the foam.

Abt Associates, Incorporated in Cambridge, Massachusetts is working under NASA sponsorship with the United States Department of Housing and Urban Development to find applications for the fire retardant foams in the area of urban construction. Their joint efforts to date have led to prototype testing of the foam by the National Association of Home Builders and the New York Urban Development Corporation. (See the "Fire Retardant Foams" Transfer Example File Summary in Attachment IV.)

The third and fourth examples of the ways in which contract mechanisms facilitate technology transfer involve the nonflammable material Fluorel produced by the 3M Company. Subsequent to 3M's independent development of nonflammable Fluorel, NASA contracted with two companies--Raybestos-Manhattan, Incorporated in Charleston, South Carolina and Mosites Rubber Company in Fort Worth, Texas--to manufacture a variety of finished products for use in the space program. Until recently, NASA was the primary customer for the finished nonflammable products. During the past few months, however, both firms have undertaken vigorous programs to broaden the market for these products. (See the "Nonflammable Materials" Transfer Example File Summary in Attachment IV.)

In all four of the examples cited, the main point is that each contracting firm has been able to transfer technologies to situations extending beyond original mission requirements. Dialogue between NASA and contracting organizations served to clarify problem areas requiring new fire safety technology; subsequently, the firms involved have sought quite actively to broaden the user base for the developed technology.

Industrial Magazine Coverage

Fire safety specialists, like all other specialists, are continually faced with the necessity of learning about new developments which might make their work more effective and more efficient. They call this "keeping up" or "keeping abreast." To do this, they rely heavily on several mechanisms--especially industrial magazines. Some industrial magazines, such as Fire Engineering, Fire Journal, and Fire Chief, periodically provide news of important technical advances through editorial items and advertisements.

Information concerning NASA work in the fire safety field is regularly reported to specialists through such publications. In the October 1970 issue of Fire Engineering, for example, Joseph E. Keller described some initial results of the NASA Conference on Materials for Improved Fire Safety:

> Examples of fire safety materials discussed and demonstrated include fabrics that will not burn, paints that will protect the surface beneath them, nonflammable electrical switches, circuit breakers and wiring, spray coatings that prevent combustion on the protected surfaces, noncombustible plastic foams used for insulation, and nonflammable paper products.
>
> Applications of these new nonflammable materials are not limited to just one industry or one area of society. Commercial, household, and military applications of these new materials were all discussed. Specific items include clothing, bedding, carpeting, upholstery, and automobile and aircraft furnishings and accessories.
>
> Reactions from those in attendance were unanimous in praise for the conference. Sample reactions include the statement by an airline official that the sessions "have accomplished more in a few years than has been done over many years in the past." He pointed out that the information gained from the conference will assist his airline in the search for nonflammable substitutes or processes for aircraft interior materials and will instruct airline personnel in the application of nonflammable coatings to aircraft interiors. . . .
>
> The International Association of Fire Fighters has asked for help in developing protective clothing for firemen. NASA

has already done much in this area and has developed an improved protective garment for the fire department at the Manned Spacecraft Center in Houston, Texas. Relative to this, NASA has stopped procurement of Nomex flight coveralls for pilot and astronaut personnel in favor of coveralls made of Durette, which is reported to have improved fire-resistant qualities.

Such articles in trade publications serve, in a sense, to alert fire safety specialists to the fact that important technical advances--which will affect them soon--are occurring. As a part of the process in which the widespread adoption of these new, space program developed materials is encouraged, the educational role of such publications is obvious.

The publications identified above are directed primarily to people responsible for controlling and extinguishing unwanted fires. Phrased differently, the people receiving such magazines are paid to cope with poorly designed or inadequately controlled flammable systems. Another group of magazines--a group much larger than the type addressed to firefighters--provides design engineers with information they can use in planning less flammable and nonflammable systems. NASA contributions to the fire safety field also have been received in these magazines, usually in more technical detail. Thus, for example, NASA work in developing improved intumescent paints was described in a news item reported in the November 1970 issue of Materials Engineering. The May 1970 issue of The Modern Hospital presented a feature article describing the ways hospitals may benefit from new fire safety materials developed for the space program.

Two points--one quantitative, the other qualitative--must be emphasized in this brief description of industrial magazine coverage of NASA fire safety work. The direct impact of such feature articles and news items is unknown in terms of the extent to which the technology has been applied. Qualitatively, however, their indirect value is indicated by the decision to publish. Technical editors continually screen information for relevance to their readership. Since editors have a unique knowledge of what information is relevant to their readers, the announcement of NASA-generated technology through their publications has an important implication. The fact that thousands of readers--ranging from firefighters to structural designers--have been alerted to specific advances in the field represents the necessary first step in the transfer of technology.

Tech Brief Exhibit

Section III presented an overview of the different types of documents that NASA in-house and contractor personnel have used to report the results of their work in the fire safety field. Among other things, that description of NASA-funded publications emphasized that the technologies presented in Tech Briefs are broadly representative of the entire scope of technologies described in other NASA documents. The following exhibit presents a detailed list of the 31 Tech Briefs related to fire safety. Their titles are divided into three groups: those announcing new or improved fire prevention methods or techniques; those dealing with fire detection, extinguishment and protection methods; and those reporting on fire hazard testing or evaluation techniques.

TECH BRIEF EXHIBIT

Technical Category	Tech Brief Number	Tech Brief Title
Fire Prevention Materials or Techniques	65-10156	Inorganic Paint is Durable, Fireproof, Easy to Apply
	66-10514	In-Tank Shutoff Valve is Provided with Maximum Blast Protection
	66-10646	Process Produces Chlorinated Aromatic Isocyanate in High Yield
	67-10098	Toroidal Ring Prevents Gas Ignition at Vent Stack Outlet
	68-10177	Saran Film is Fire-Retardant in Oxygen Atmosphere
	68-10323	Hydrogen Safety Manual
	68-10404	Design Concept for Nonarcing Electrical Connector
	68-10520	Ambient Temperature Catalyst for Hydrogen Ignition
	69-10495	Heat-Shrinkable Jacket Holds Fluid in Contact with Tensile Test Specimen
	69-10552	Technique for Ultrasonic Cleaning with Volatile Solvents Eliminates Need for Hoods or Condensers

TECH BRIEF EXHIBIT (Continued)

Technical Category	Tech Brief Number	Tech Brief Title
	69-10629	Glass Fabric Fire Barrier for Silicone Rubber Parts
	70-10154	A New Low-Expansion Nonflammable Printed Circuit Board
	70-10490	Flame-Resistant Thin Panels of Glass Fabric-Polyimide Resin Laminate
	70-10540	Chemical Treatment Makes Aromatic Polyamide Fabric Fireproof in Oxygen Atmosphere
	70-10546	New Type of Nonflammable Paper
	70-10644	Nonflammable Organic Adhesives Effective over Wide Temperature Range
Fire Detection, Extinguishment and Protection Methods	65-10108	Magnetic Field Controls Carbon Arc Tail Flame
	66-10363	Infrared Television Used to Detect Hydrogen Fires
	66-10368	Hydrogen Fire Detection System Features Sharp Discrimination
	66-10634	Emergency Escape System Protects Personnel from Explosion and Fire
	67-10622	Fire Extinguisher Control System Provides Reliable Cold Weather Operation
	68-10277	Thermal Protective Visor for Entering High Temperature Areas
	68-10358	Fire Retardant Foams Developed to Suppress Fuel Fires
	69-10354	An Infrared Television System for Hydrogen Flame Detection
	69-10450	Improved Fire Resistant Radio Frequency Anechoic Materials
	70-10450	Intumescent Coatings as Fire Retardants

TECH BRIEF EXHIBIT (Concluded)

Technical Category	Tech Brief Number	Tech Brief Title
	70-10680	Astronaut Rescue Air Pack (ARAP) and Emergency Egress Air Pack (EEAP)
Fire Hazard Testing or Evaluation Techniques	68-10167	Evaluation of Ignition Mechanisms in Selected Nonmetallic Materials
	69-10287	Technique for Assessing Potential Fire Hazards
	69-10531	Testing the Flammability of Materials Exposed to Arcs
	69-10740	Burn-Rate Testing Apparatus
	70-10285	Investigation of the Reactivity of Organic Materials in Liquid Oxygen
	70-10404	Detonation Hazards with "Safe" Industrial Solvents

ATTACHMENT IV

Summary of Technology Transfer Reports
Involving NASA-Generated Fire Safety Technology

ATTACHMENT IV

SUMMARY OF TECHNOLOGY TRANSFER REPORTS INVOLVING NASA-GENERATED FIRE SAFETY TECHNOLOGY

TRANSFER EXAMPLE FILE TITLE	TRANSFER STAGES 1		2		3		4	
	Cont.*	Term.	Cont.	Term.	Cont.	Term.	Cont.	Term.
BURN-RATE TESTING APPARATUS	39644** 41186			40610***				
FIRE RETARDANT FOAMS	26468		20015 46622		42935 46621			
HOUSTON FIRE SAFETY CONFERENCE	46617		46611 46613 46620 46625 46655					
HYDROGEN SAFETY					22064 28946			
INORGANIC PAINT	750		476 654 656 669 672 694 709 782 8610	734 757 761	2425		763 2433 4535 47957	
NONFLAMMABLE MATERIALS			46607 46609 46610 46612 46614 46615 46618 46619 46623 46627 46628 46652 46653 46854				43001 43002 46608	
POLYURETHANE FILTER FOR BURN TREATMENT					38611			

* The action status, continuing or terminated, of transfer cases at the time DRI-PATT contacted users. Cases are classed as terminated when (a) no further adaptation or adoption is contemplated, (b) a better technical alternative has been found, or (c) continued transfer activity is not economically feasible.

** Numbers in columns refer to PATT case numbers.

*** New transfer cycle initiated.

BURN-RATE TESTING APPARATUS

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

An important part of NASA's fire safety research is testing the flammability of materials. Tests and testing apparatus have been designed by NASA scientists to simulate combustion conditions which exist in spacecraft. The test data have been indispensable for material selection and flammability specifications for material. The data did not exist prior to NASA tests because no similar specifications had been required previously.

The burn-rate testing apparatus invented at Manned Spacecraft Center is capable of testing a variety of combustion parameters. By using the apparatus, engineers are able to control atmospheric conditions, fuel/oxygen mixtures, the igniting flame mechanisms, and test sample orientation. A thin rectangular piece of material is used for the test sample. The apparatus incorporates several sensors including a calibration thermocouple for the igniting flame temperature and three photocells to detect flame at three different points: where flame is applied to the sample, at a point exactly opposite to where the flame is applied, and at a given distance from this point on the same side as the second photocell. Data from the first and second photocells indicate the burn-rate through the sample. Data from the second and third photocells indicate the burn-rate along the sample surface.

Ferro Corporation in Los Angeles, California (39644) has reviewed and filed the Technical Support Package describing the apparatus. The company ordered the NASA literature after a potential customer referred to the apparatus. A company spokesman said he expects new flammability specifications will be required by 1974, and the apparatus will probably be used then for testing the company's fiber glass products.

Simulation tests of the apparatus were conducted at General Motors Corporation in Warren, Michigan (40610). It was being considered for flammability testing of the cloth used in the company's polishing buffs for steel. The apparatus is considered too sophisticated in its present form for this type of test. Some of its features, however, may be included in a simpler device which is in the conceptual stage at this time.

U.S. Industrial Chemicals Company in Tuscola, Illinois (41186) plans to install a similar apparatus for testing its polyethylene products. A company spokesman said this will be done when an anticipated new ASTM flammability test is published and customers start requesting the new flammability specifications.

Control Numbers

Tech Brief Number: 69-10740
NASA Center: Manned Spacecraft Center
PATT Case Numbers: 39644, 40610, 41186
TEF Number: 348
Date of Latest Information Used: January 4, 1971

FIRE RETARDANT FOAMS

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

NASA research in the chemistry of ablation for protection of spacecraft during atmospheric reentry led to the development of fire retardant foams at the Ames Research Center. As described in a 1968 Tech Brief (68-10358), the material is a semirigid or rigid polyurethane foam having uniformly dispersed in it a halogenated polymer capable of splitting off hydrogen halide upon heating and charring of the polyurethane. The char layer and released gases help quench the flame. The density of the foam can be varied from two to fifty pounds per cubic foot, enhancing the versatility of the material for fire protection in aircraft, spacecraft, homes, autos, boats, trains, and in industries such as petrochemicals, paint and chemical processing and laboratories.

Approximately 100 inquiries have been received concerning the foam. Avco Corporation in Wilmington, Massachusetts (42935) was awarded a NASA contract in 1969 to investigate processing methods, application techniques, and properties of the foam as they relate to fire safety in aircraft. The company received a nonexclusive NASA license in 1970 to use the invention and is ready to produce the foam commercially. Market studies related to aircraft application are underway.

Abt Associates, Incorporated in Cambridge, Massachusetts (46622) is working under NASA sponsorship with the Department of Housing and Urban Development to transfer some of the technology described at the NASA Fire Safety Conference to the area of urban construction. Their efforts have led to prototype testing of fire retardant foams by the National Association of Home Builders and the New York Urban Development Corporation. The tests are scheduled for completion in February 1971. At that time, an economic evaluation will be initiated. The National Bureau of Standards also plans to conduct fire tests of the foam for housing applications.

Rubber Specialties Company in Minneapolis, Minnesota (26468) received the TSP from another local firm to answer questions raised in a discussion of possible insulation materials for a project under consideration. Rubber Specialties was contemplating entry into the business of making prefabricated plastic panels for room dividers in modular-constructed buildings. The foam was considered for soundproofing and fire retardant insulation. The company decided against entering the new field, however, and has not yet found other uses for the technology.

Dow Chemical Company in Golden, Colorado (46621) is using fire retardant urethane foam to fireproof and insulate radioactive waste containers. A company spokesman said that, prior to the NASA Fire Safety Conference, Dow had not applied fire safety techniques in its uses of the containers. Finally, Coastal States Gas Producing Company in Corpus Christi, Texas (20015) is considering the technology for potential fire suppression applications in gas processing plants.

Control Numbers

Tech Brief Number: 68-10358
NASA Center: Ames Research Center
PATT Case Numbers: 20015, 26468, 42935, 46621, 46622
TEF Number: 17
Date of Latest Information Used: January 11, 1971

HOUSTON FIRE SAFETY CONFERENCE

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Some of NASA's most significant work in recent years has been directly concerned with the control or elimination of fire hazards. Recognizing that maximum benefit can be obtained from space research only when its discoveries are widely shared, the space agency sponsored the "NASA Conference on Materials for Improved Fire Safety" at the Manned Spacecraft Center on May 6-7, 1970. The wide variety of NASA-generated technology on fire safety was presented to approximately 500 persons from industrial firms, government agencies including NASA, research institutes and universities. Twenty-five presentations were made which focused on the technology, its use in the space program, and its potential applications on earth.

Questionnaires were mailed to 182 non-NASA conferees in October 1970 to determine how they had been able to use or planned to use the information presented at the conference. To date, 113 (62 percent) of the conferees have returned the questionnaires. Twenty-two persons who returned the questionnaires subsequently were interviewed by telephone, primarily because they had indicated substantial progress in attempts to apply fire safety technologies presented at the conference.

Several nonflammable materials were described which conferees found particularly interesting. Two of these, and the transfer activities related to them, are described in the "Fire Retardant Foams" and "Nonflammable Materials" Technology Transfer Example Summaries presented elsewhere in this attachment.

Other materials which were of interest included nonflammable potting compounds and nonflammable fibers (e.g., Beta fiber, Polybenzimidazole (PBI), Durette, Frypo and Nomex). Each of the application activities described below was initiated by a company representative who attended the conference.

Desoto, Incorporated, a paint company in Des Plaines, Illinois (46617), will use fiber additives to develop nonflammable paints. The company plans to utilize some of the NASA flammability tests in its research.

Martin-Marietta Corporation in Denver, Colorado (46620) has used suggestions made at the conference to include new applications of PBI in a contract proposal. The company also is using one of the new flammability tests described in Houston.

General Dynamics in Fort Worth, Texas (46613) is conducting laboratory tests on nonflammable polyimides and potting compounds. These materials have been included in two recent contract proposals made by the company.

Battelle Northwest, a private research institute in Richland, Washington (46611), has received a contract to develop protective clothing for persons handling liquid sodium. The proposed clothing materials were selected on the basis of NASA research described at the conference.

The chief coal mine inspector for United States Steel Corporation in Pittsburgh, Pennsylvania (46655) established personal contact with Ames Research Center scientists at the conference. The contact has evolved into a cooperative effort to develop improved flame safety lamps and suitable fire resistant coatings for mine timbers.

Travelers Insurance Company in Dallas, Texas (46625) is using information obtained at the conference to recommend improved fire safety procedures to its industrial fire policy holders. The information also is used as part of the basis for determining hazards and premiums for industrial fire policies.

In addition to the transfer cases identified above through the questionnaire survey, the following additional transfer activities have been identified. Durette and Nomex are being investigated for application in fire fighting clothing by the Federal Aviation Administration, Airline Pilots Association, National Fire Protection Association, International Association of Fire Fighters, National Bureau of Standards, Glove Fire Suits Company, the Houston Fire Department and Humble Oil Company. Scientists from Kennedy Space Center and Manned Spacecraft Center are cooperating in this research. Prototype tests of Durette, Nomex, and fluorocarbons in aircraft applications are being conducted by Laminate Division of Tri-Wall Container Corporation, Cannon Electrical Company, Sargent Industries, United Airlines, Oklahoma City Downtown Airpark and the U.S. Air Force. Manned Spacecraft Center is cooperating in these investigations. Tests of intumescent paints and fire retardant foams in aircraft applications are being conducted by Avco Corporation, Cannon Electrical Company, General Electric, and the U.S. Navy in cooperation with Ames Research Center. The University of Texas, the University of Pennsylvania and

General Electric Company have contracted with Welson and Company to manufacture fabrics from Durette for underwater and decompression chambers.

Control Numbers

Tech Brief Number: None
NASA Center: Manned Spacecraft Center
PATT Case Numbers: 46611, 46613, 46617, 46620, 46625, 46655
TEF Number: 347
Date of Latest Information Used: December 17, 1970

HYDROGEN SAFETY

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

Hydrogen is an indispensable component of rocket fuel and spacecraft energy cells. The presence of hydrogen, however, constitutes the greatest single fire hazard in the space program. The hazard is caused by the fact that this odorless gas is ten times more flammable than gasoline; in addition, hydrogen fires are colorless. NASA engineers have developed extensive safety procedures for storing, handling and using hydrogen. The Advisory Panel on Experimental Fluids and Gases at Lewis Research Center has written the Hydrogen Safety Manual (NASA TM X-52454) which presents a unified statement of these procedures. The manual describes the characteristics and nature of hydrogen, design principles for hydrogen systems, protection of personnel and equipment, and operating and emergency procedures. It is an operating manual which sets forth acceptable standards and practices for minimum safety requirements at the Lewis Research Center. Because of its relevance to increasingly common nonaerospace scientific and industrial uses, NASA issued Tech Brief 68-10323 in August 1968 to announce publication of the manual.

Dow Chemical Company in Midland, Michigan and Fenwal Electronics, Incorporated in Framingham, Massachusetts reviewed the Tech Brief and ordered the manual. Dow (22064) has used data from the manual in conducting a study of gas cloud explosions and is still using the manual as a reference for designing equipment and facilities. Fenwal (28946) has used the manual to establish safety methods and procedures for a hydrogen atmosphere chamber included in the company's manufacturing process. The company president estimated that, to date, tangible savings of $2,000 have resulted from Fenwal's use of the manual.

Control Numbers

Tech Brief Number: 68-10323
NASA Center: Lewis Research Center
PATT Case Numbers: 22064, 28946
TEF Number: 258
Date of Latest Information Used: December 31, 1969

INORGANIC PAINT

TECHNOLOGY TRANSFER EXAMPLE SUMMARY

The environment in space imposes great burdens on external coatings for space vehicles. The most important function of a coating in space is to assist in maintaining spacecraft temperatures within specified limits. While the temperatures are somewhat affected by conditions internal to a spacecraft (e.g., heat generated by systems operation, body heat of astronauts), the more significant temperature effects are causedby direct solar radiation, solar radiation reflected from the earth, and infrared emissions from the earth. The thermal absorption and emmitance properties of a coating thus assume crucial importance, since the temperature of the spacecraft is determined by the ability of its external surface to exchange heat with the space environment. A coating also must remain stable over long periods in a hostile environment, maintaining adhesion under various mechanical stresses and temperature extremes.

Chemical coatings are widely used on spacecraft because of their low cost and ease of application, and because so much is known about them from their historically common usage. Knowledge is probably most extensive concerning organic-constituent coatings, but they are not generally suitable for space uses because the constituents outgas in space and leave harmful deposits on optical surfaces. Inorganic constituents do not have the outgassing property, and are preferable to organic coatings on this ground. The inorganic coatings used in space commonly consist of silicone and silicate binders and zinc oxide pigments, which form a highly stable system in the vacuum of space.

Building upon a large amount of NASA research on inorganic coatings, Dr. John Schutt of Goddard Space Flight Center formulated a number of inorganic coatings with attributes of nonflammability, durability and ease of application. In 1965, NASA used Tech Brief 65-10156 to announce the discovery of the formulations and prepared a Technical Support Package which provided details concerning ingredients, mixing, curing and other data.

To date, more than 400 potential industrial users of the inorganic paint have requested copies of the TSP. A few examples of application activities associated with the technology demonstrate the specific nature of nonaerospace uses to which the inorganic paint can be put.

Several TSP users stated they are attempting to develop inorganic paints with the fireproof and high temperature characteristics of the NASA formulations. The Lithoid Corporation in Lima, Pennsylvania (672), for example, is experimenting to develop a base coat for "ceramic teflon" products which are subjected to extremely high temperatures. The Bradley-Van Holm Chemical Corporation in Brattleboro, Vermont (750) will soon resume its efforts to develop a fireproof paint for hotels and motels. J. W. Mortell Company in Kankakee, Illinois (2425) was reported in 1969 to have developed a line of fireproof coatings for sale to builders, contractors and industrial buyers. By 1971, a Mortell spokesman reported that the paint was not being sold, but that efforts to diversify product lines into fire retardant coatings would stimulate new interest in the NASA paints. The Sperex Corporation in Los Angeles, California (4535) used the TSP to perfect its own formulations for heat resistant paints for racing cars. The firm's second year sales of the paint reportedly were 40 percent above the initial year's sales, with customers using the product for truck exhaust systems, oven liners, fire walls, brake drums, engine manifolds, mufflers, furnaces and electrical applications.

Several organizations reported using the TSP to develop coatings for outdoor structural and building applications for which fireproof characteristics are important. The General Services Administration (669) is evaluating the TSP for the purpose of drawing up Federal procurement specifications. Five small paint manufacturers (656, 694, 709, 782, 8610) are working on exterior coatings, and three firms (734, 761, 757) terminated experimental evaluations of the TSP without developing an exterior paint.

Ten firms mentioned durability and anti-corrosion properties as the most important goal of their development efforts. Wisconsin Protective Coatings in Green Bay, Wisconsin (47957), for example, earned $100,000 in 1970 from sales of its inorganic paint for lining railroad tank cars carrying ethylene oxide. The company is now developing a solvent base inorganic paint for kilns and smokestacks. Another firm, the Advanced Research Corporation in Altanta, Georgia (2433) uses its inorganic paint to coat containers for lithium compounds.

The inorganic paints are apparently quite useful for marine applications. An Eastern firm (763) sells its product for exterior coating of tanker steam lines, in which the inside temperature is 275°F and the sea water washing over the lines may be 40°F. Deck plates and super-structures coated with the paint are quite resistant to salt water corrosion, and the firm sells the paint for off-shore oil rigs, as well. The Kiesel Machinery Company in Jennings, Louisiana (654) is also developing an inorganic paint for off-shore rigs, and a small company in Pennsylvania (476) is working with the TSP to make an exterior paint for seashore locales.

Finally, nine other persons using the TSP reported conducting research on "specialty" coatings, not specifying the nature of intended application. Some of these doubtlessly will be sold for their fireproof properties when development is completed.

Most of the respondents still experimenting with the paint have reported experiencing difficulties with poor adherence and durability. The principal reason for this appears to have been the omission of an ingredient from the formulation given in the TSP. The final paint described in the patent contains 18 percent latex paint and 82 percent inorganic paint. The TSP neglected to mention the latex which provides the adherence and durability mentioned in the Tech Brief. Respondents cited above as having developed commercial inorganic paint products indicated they are using latex/inorganic mixtures based on either their own discovery or a copy of the NASA patent.

Control Numbers

Tech Brief Number:	65-10156
NASA Center:	Goddard Space Flight Center
PATT Case Numbers:	476, 654, 656, 669, 672, 694 709, 734, 750, 757, 761, 763 782, 2425, 2433, 4535, 8610, 47957
TEF Number:	34

Date of Latest Information Used: January 4, 1971

NONFLAMMABLE MATERIALS
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

After the tragic Apollo 204 fire at Cape Kennedy in January 1967, NASA fire safety research was greatly accelerated. The silicone elastomers which had been used extensively in spacecraft were found to be quite flammable in pure oxygen atmospheres. Research efforts to develop nonflammable silicone elastomers have yielded few results. Carboxy nitroso rubber was investigated as a nonflammable substitute for silicone, but its high cost and rapid decomposition when heated to 500°F have prevented widespread use of the material. A successful program was initiated to develop nonflammable elastomers from copolymers of vinylidene fluoride and hexafluoropropene which have been available for many years under the trade names Viton (Du Pont) and Fluorel (3M Company). As normally produced, both elastomers are flammable in oxygen. The two companies conducted independent research programs which resulted in nonflammable versions of the fluorocarbon elastomers with a wide range of physical properties. Manned Spacecraft Center scientists cooperated with company researchers since the research was prompted by NASA fire safety requirements.

The new fluorocarbon elastomers have replaced silicone and other materials in many spacecraft components and their importance to the space program was described at the NASA Conference on Materials for Improved Fire Safety in May 1970. NASA has used these elastomers in a variety of forms: elastomeric foams have been used for shoulder pads and spacers; they have been molded into boot soles and headrests; extruded stock has been used for oxygen and smoke-mask hoses, and sheet stock for gaskets; and coating compounds have been employed to protect flammable substrates. The fluoroelastomeric coatings are of special interest in that they provide adequate protection for flammable substrates in minimal applied thicknesses.

A spokesman for 3M Company in Chambles, Georgia (46608) reported that most of the Fluorel produced at 3M is sold as raw material to companies which fabricate spacecraft components and coating compounds for NASA from it. As a result of the conference, 3M has received numerous inquiries concerning Fluorel and several potential users have purchased quantities for prototype testing of commercial applications in shipping, air transportation, fire fighting garments and residential housing.

Mosites Rubber Company in Fort Worth, Texas (43001) has manufactured a variety of finished products, mainly for NASA, from Fluorel produced by 3M. A company spokesman reported that sales of Fluorel products have increased and a broader market has developed since the NASA conference.

Raybestos-Manhattan, Incorporated in Charleston, South Carolina (43002) is another manufacturer of finished products from 3M's Fluorel. The company uses the brand name Refset for its coating compound. To date, NASA has been the primary customer for these products; however, Raybestos is now conducting a vigorous sales campaign to broaden its market. Aircraft, submarines, and other oxygen-rich environments are promising new application areas where safety considerations outweigh cost factors.

The nonflammable fluorocarbon elastomers are being investigated for application in wire insulation (46612, 46619, 46627), fabrics and clothing (46607, 46614, 46653, 46854), commercial aircraft interiors (46610, 46623, 46628), housing (46615) and ships (46609, 46618, 46652).

All of the investigations resulted from the NASA Fire Safety Conference and personal contacts with NASA scientists.

Control Numbers

Tech Brief Number:	None
NASA Center:	Manned Spacecraft Center
PATT Case Numbers:	43001, 43002, 46607, 46608, 46609, 46610, 46612, 46614, 46615, 46618, 46619, 46623, 46627, 46628, 46652, 46653, 46854
TEF Number:	324

Date of Latest Information Used: December 18, 1970

POLYURETHANE FILTER FOR BURN TREATMENT
TECHNOLOGY TRANSFER EXAMPLE SUMMARY

NASA's program to land an unmanned craft on Mars included a project in which balloons were sent 100,000 feet above the earth to test for microbiological contamination. The testing device included a special polyurethane filter. Edward Rich, Jr., a NASA employee for nine years, conceived the idea of adapting the filter to medical uses, specifically for burn treatment.

After taking a job with the National Institutes of Health (NIH), Rich performed additional research to develop a new burn bandage known as Burn Aid (38611). Burn Aid is inexpensive and can be used at home as well as in a hospital. A portable unit provides a supply of air or specific gases, which flow through the filter to the burn. The filter itself is sandwiched between two sheets of vinyl that are sealed on all edges. The bottom sheet is coated with an adhesive and covered with paper. The physician cuts a hole in the bottom sheet, large enough to avoid contact between the bandage and the injured area, then peels off the remaining paper to expose the adhesive for application to unburned skin around the injury. The flow of gas is then started through the filter. Only the filtered air contacts the wound, preventing infection and hastening the healing process. NIH has filed a patent application for the medical use of the filter.

Control Numbers

Tech Brief Number: None
NASA Center: Goddard Space Flight Center
PATT Case Number: 38611
TEF Number: 84
Date of Latest Information Used: April 24, 1970

REFERENCES

REFERENCES

Avco Corporation, Avco Systems Division. "Interim Report for Task I: Fire Protective Materials Application Program - Crash Fire Test." Avco Corporation, [1970]. (Mimeograph)

Cloyd, D.R. and W.J. Murphy. Handling Hazardous Materials. NASA SP-5032. Washington, D.C.: Technology Utilization Division, Office of Technology Utilization, National Aeronautics and Space Administration, September 1965.

Davis, C.T. "Flame Retardants," Modern Plastics Encyclopedia, 1970-1971, p. 370, 372.

"Flammable Fabrics: Bureaucracy or Technology?" Washington Science Trends, XXIV (June 29, 1970), pp. 65-68.

Keller, Joseph E. "Washington Report: NASA Presents Materials to Improve Fire Safety," Fire Engineering, CXXIII (October 1970), p. 45.

Kimball, Warren Y. "Fire Fighting Casualties," Firemen, XXXVII (April 1970), pp. 14-15.

"Look for Improved Intumescent Paints," Materials Engineering, November 1970.

"Looking for Ways to Make the 'Fire Load' Lighter," The Modern Hospital, May 1970, pp. 97-99.

McClennan, Howard. "Fire Fighters Look to the Next Decade," Firemen, XXXVII (January 1970), pp. 26-28.

Naimer, Jack. "Apollo Applications of Beta Fiber Glass," in Proceedings of the NASA Conference on Materials for Improved Fire Safety. [Washington, D.C]: National Aeronautics and Space Administration, 1970. Pp. 16-1 - 16-8.

National Research Council, Division of Engineering, Committee on Fire Research. Directory of Fire Research in the United States, 1967-1969. Fifth Edition. Washington, D.C.: National Academy of Sciences, 1970.

Orey, Walter J. "Industrial Fire Safety: Losses Show Nation Needs Fire Prevention Education," Fire Engineering, CXXIII (September 1970), p. 49.

Parker, K. H., General Manager, Fire Insurance Research and Actuarial Association, New York, New York. Telephone interview on February 2, 1971.

Radnofsky, Matthew I. "New Materials for Manned Spacecraft, Aircraft, and Other Applications," in Proceedings of the NASA Conference on Materials for Improved Fire Safety. [Washington, D.C.]: National Aeronautics and Space Administration, 1970. Pp. 10-1 - 10-15.

Supkis, Daniel E. "Development and Applications of Fluorel," in Proceedings of the NASA Conference on Materials for Improved Fire Safety. [Washington, D. C.]: National Aeronautics and Space Administration, 1970. Pp. 7-1 - 7-20.