DYNATECH CORPORATION

PHYSIO-CHEMICAL STUDY OF THE FLAMMABILITY OF FIRE-RESISTANT MATERIALS FOR AIRCRAFT CABINS

- TECHNICAL PROPOSAL -

PCH-190

Submitted to:

NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER
Atlantic City, New Jersey

In Response to:

Request for Proposal NAOO-9-12

June 25, 1969

Progress through Research

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PERSONS AUTHORIZED TO CONDUCT NEGOTIATIONS

Kenneth D. Roberts, Vice President and Treasurer

John B. Eliot, Controller

F. Robert Johnson, Manager, Government Marketing Department

Section 1
INTRODUCTION

An important field of aircraft safety engineering is the development and utilization of fire resistant and low smoke producing materials of construction. Interior materials of aircraft such as seats, cushions, curtains, paneling, and carpeting have received increasing attention because of a series of crash survivable accidents in late 1965 and early 1966 that revealed the contribution of such materials to loss of life through fire, smoke, and gases. In recent years fire-control engineers concerned with both the construction and transportation fields have learned that smoke from smoldering or burning materials poses as great a threat to life as flames or heat generated in a fire (References 1 and 2). During the past 2 years articles appearing in British and American fire journals suggested that, except for clothing fires, more than half the deaths due to fire are caused by smoke rather than by heat or flames. Accordingly, the National Aviation Facilities Experimental Center, Atlantic City, New Jersey, has issued Request for Proposal NAOO-9-12 outlining the need for a physio-chemical study of the factors affecting the emission of smoke during pyrolysis and the need for screening and developing high temperature stable polymers which emit minimum quantities of smoke.

Based on the experience of Dynatech engineers in plastic and polymer technology and in the development of flame retardant treatments a program in response to RFP NAOO-9-12 has been prepared. The following sections of this proposal outline a specific program:

1. for determining the physio-chemical nature of materials such as molecular structure, composition, inhibitor additives, degradation kinetics, etc., that cause emission of smoke when materials are thermally decomposed as in a typical fire.

2. for conducting a search to identify high-temperature stable polymers potentially useful as cabin replacement materials which inherently emit minimum quantities of smoke (i.e., D_s less than 16 for 90 seconds fire exposure).

3. for developing new additive polymer formulations of polyurethane foam, acrylonitrile-butadiene-styrene, acrylic resins, and vinyl resins, and testing these samples for flammability (by Test Method 5902), for critical optical density D_s 16 (by a modified NBS smoke chamber), and for toxicity (by colorimetrically monitoring CO, HCN, HCl, and HBr).

Dynatech R/D Company has the staff, the association with polymer and pyrolysis experts at the Massachusetts Institute of Technology, and the facilities for conducting a comprehensive investigation into the mechanisms of smoke emission and for formulating new flame and smoke retardant systems. The basic analytical facilities for a study of the molecular aspects of smoke generation, including thermal gravimetric analysis (TGA) and differential thermal anslysis (DTA) instruments, are maintained at Dynatech while gas chromatographic, mass spectrometric, and atomic absorption instruments are available in the immediate vicinity. The staff of the Chemical Engineering Department has had a combined total of over 80 years of experience in formulating polymer systems for specialty and exacting applications. Of particular pertinence is a flameproof coating for flammable polymers that was recently developed by the Chemical Engineering Department for NASA-MSC under contract NAS-9-8179. This coating is notable not only because it enables certain polymers to pass the extremely severe silicone igniter test (conducted in pure oxygen at 6.2 psig), but also because it is formulated from an exceptional class of flame retardants that have proved to produce very little smoke when combustion does occur. The experience and techniques developed in meeting the technical requirements for a flameproofing coating are directly applicable to the objectives of the program requested by the National Aviation Facilities Experimental Center.

In addition to the required technical background and facilities necessary for the conduct of the program, Dynatech can point to a record of substantial accomplishment in research and development project management and financial and accounting capability. Dynatech R/D Company has completed more than a thousand projects for both industrial and government clients, establishing an organization skilled in efficient and effective financial and technical management.

Section 2
TECHNICAL DISCUSSION

A. Background

Many polymers have been developed that have exhibited a functionality, ease of fabrication, and low cost that made them highly desirable in applications such as structural components, adhesives, flexible sealants, foams, paneling, and fibers. However, serious fires involving these materials have created much concern over the possible role plastics may have played in these conflagrations. Consequently, more attention is being given to the amount of smoke and toxic fumes as well as the flames that are evolved during combustion of polymers.

Investigations have led to the general agreement that smokes from smoldering or burning materials present three kinds of hazards:

1. They are irritating to the eyes and respiratory system.
2. If dense, they will impede the escape from burning locations and make difficult the entrance of fire-fighters and rescue teams.
3. They are toxic, either directly--by virtue of the components they contain--or indirectly by reducing the quantity of oxygen in the environment.

B. Determination of Smoke Evolution Mechanisms

In the burning process heat causes a material to decompose to solid fragments, liquid distillate, and a gaseous fraction. These decomposition products are then carried out tc the flame front where they undergo further oxidation and cracking until they are emitted and cooled.

Thus, smokes are basically a two phase system--a dispersed phase consisting of minute light-scattering particles and a continuous vapor phase. The particles consist of both solid fragments and liquid drops formed by the condensation of the gaseous products of thermal decomposition. The constituents of the vapor phase vary depending upon the material undergoing decomposition, but the predominating constituents are usually H_2O, CO_2, and CO.

To determine the mechanism or mechanisms by which smoke is evolved, therefore, it is necessary to study both the polymer phase from which the initial products are generated and the smoke phase that contains the oxidized and cracked products of the further reactions undergone by the initial decomposition species. The mechanism of thermal degradation of organic polymers, of which smoke evolution is a part, may be described as a function of the following three parameters:

1) The change of molecular weight of the polymer as a function of temperature and extent of degradation.
2) The qualitative and quantitative composition of the volatile and non-volatile pyrolysis products.
3) The rates and activation energies of the degradation process.

The techniques used to monitor these parameters are:

1) For molecular weight--The measurement of the rate of change of polymer viscosity as a function of conversion by evaluating the viscosity of the polymer residue in the molten state.

2a) For qualitative-quantitative composition of the volatile products--flash pyrolysis, hot-wire pyrolysis, or programmed decomposition followed by an effluent gas analysis by one or more of the following techniques:
    1) Vapor-phase Chromotography (VPC)
    2) Mass Spectrometry
    3) Infrared Spectrophotometry
    4) Electron Spin Resonance

Often a combination of techniques has proved valuable. For example, particularly fine measurements may be made by utilizing a 500 ft. capillary column (0.02 in) coated with SF 96 (50) (Applied Science Laboratories, State College, Penn.) in VPC and coupling the output from the chromatograph to a time-of-flight mass spectrometer (Ref. 3).

In programmed decompositions, the temperature is increased at a predetermined rate and the products analyzed as they are evolved. Such analysis studies can be conducted simultaneously with differential thermal of thermogravimetric analysis.

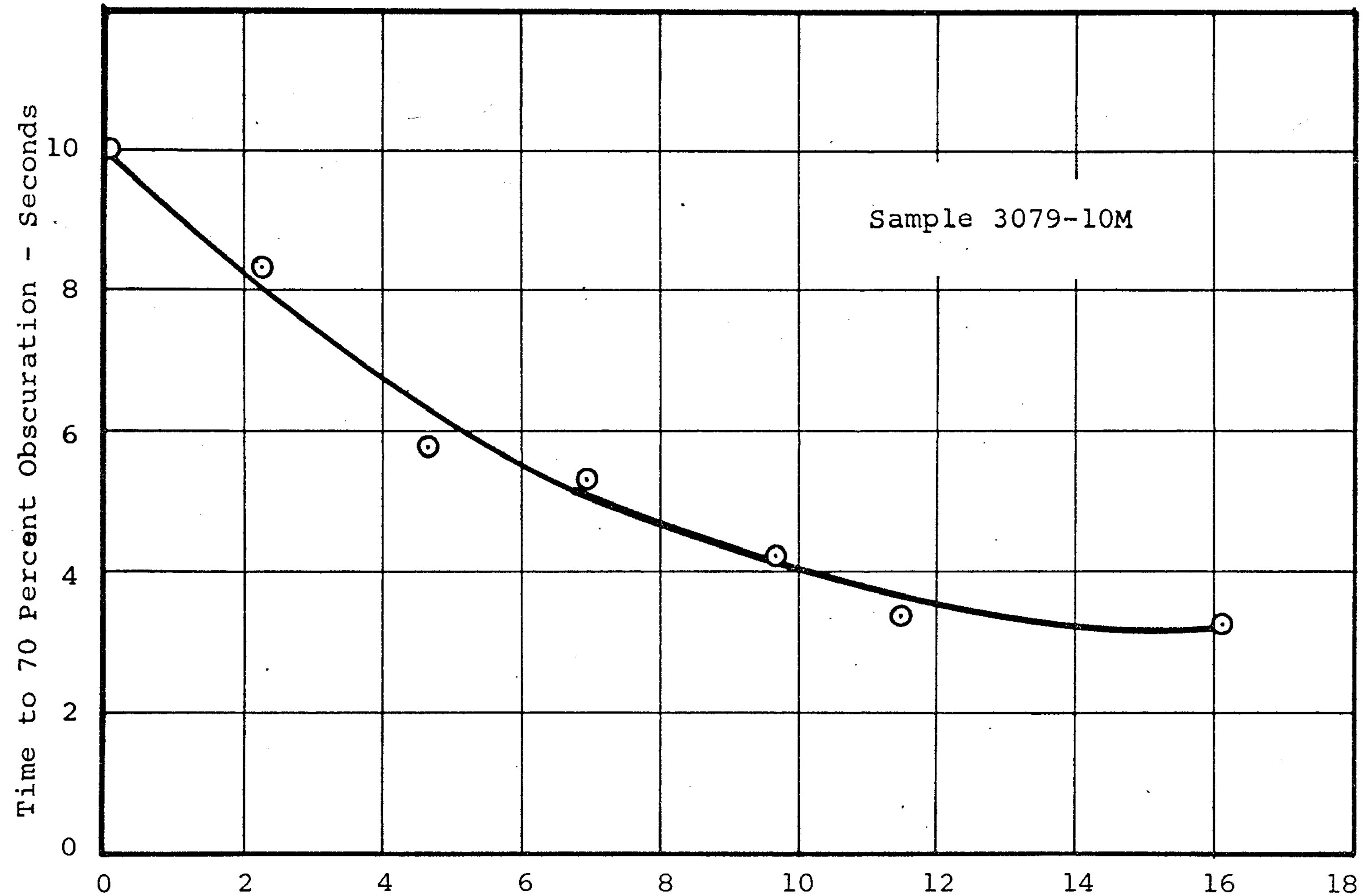
2b) For qualitative and quantitative description of nonvolatile products--a method detailed by Hoffman (Ref. 4) for conducting a controlled pyrolysis or combustion of the polymer surface and then successively scraping off thin layers of the surface for analysis. In this manner the decomposition history of the polymer surface may be determined.

Thus, by utilizing the techniques discussed in 2a and b a complete picture of both the solid and gas phase products may be obtained.

3) For rates and activation energies--DTA (measures the heat-energy change occurring in a substance as a function of temperature. Typical phenomena that will relate to thermally induced processes include melting, vaporization, polymerization, cross-linking, oxidation, and thermal decomposition) and TGA (monitors the weight loss of a sample as a function of temperature or isothermally as a function of time).

By synthesizing the data on the amount and types of decomposition products formed, the decomposition history of the polymer, the rates of the reactions, and the heat associated with reactions; a description of the thermal decomposition mechanisms may be evolved. From a comparison of the decomposition mechanisms with the smoke generating behavior of flame-retardant and non-flame-retardant polymers, those mechanism associated with smoke emission may be determined.

Most of the fundamental work concerning smokes has been performed on wood and tobacco (Refs. 5, 6, 7) and this work has resulted in the development of some of the analytical tools described above. In the area of polymers Mickelson and Einhorn (Ref. 8) have attempted to correlate the amount of smoke evolved during combustion with the activation energy governing the kinetics of thermal decomposition. They point out that the amount of fire retardant incorporated into a polymer system not only affects the flammability characteristics of the material, but also the dependency of the material to smoke. For example, Figure 1 from their paper shows how increasing the amount of a retardant in the formulation affects the smoking tendency of a urethane. This same behavior has been observed by Gaskill (Ref. 9) for phenolics, polycarbonates, and acrylics. However, no satisfactory smoke emission mechanisms were advanced.



Weight Percent o, o DIETHYL-n, n′-BIS(2 HYDROXYETHYL) AMINOMETHYL PHOSPHONATE

Figure 1 THE EFFECT OF A REACTIVE FIRE RETARDANT ON SMOKE DEVELOPMENT

C. Screening of High Temperature Stable Polymers for Smoke Emission

The first standard method for determining smoke evolution was the Steiner Tunnel test (ASTM-E-84). This test was primarily designed for structural materials and so the requirement that test samples be 18" x 25 ' did not impose a severe requirement. However, for many materials the tunnel test was neither expedient nor applicable, and Rohm and Haas seeking a definitive smoke evolution test, developed the XP-2 smoke chamber. After evaluating the XP-2 chamber, the National Bureaü of Standards designed their own apparatus. The Lawrence Radiation Labs then took the NBS design and modified it to suit their own purposes. In Table I is a comparison of the smoke test systems.

Gaskill recently presented the results of his work at LRL in determining smoke density and toxic gas concentrations for various polymer formulations. In the standard nomenclature

$$D_s = \frac{V}{AL} \log_{10} \frac{100}{T} = \text{specific optical density}$$

T = percent light transmission at any time

$$D = 10 \log_{10} \frac{100}{T} = \text{optical density}$$

V = chamber volume

A = sample face area

L = light path length

D_m = maximum D_s obtained in a test

$D_s\,16$ = time for smoke to reach a critical (i.e., vision obscuring) density.

Some of his results are shown in Table 2.

As can be seen, only cellulose and polysulfone take longer than 90 sec. (1.5 min) to give a critical smoke obscuration value. Since polymers tested had no flame retardants, it can be expected that even shorter times would be necessary to reach critical obscuration with polymers flame retarded with chlorinated and phosphated organics. However, Gaskill does present evidence (see Fig. 2) that a good fire retardant does not have to be a high emitter of smoke. Under nonflaming conditions the inorganic

Table 1

Comparison of Smoke Test Systems for Measuring Smoke Obscuration

	Steiner Tunnel	XP2 Chamber	NBS Chamber	LRL Chamber
Sample size	36 ft^2	1 in^2	6.6 in^2	6.6 in^2
Test duration (min.)	10	4	≥ 30	≥ 30
Heat Source	flame	flame	Radiant & optional flame	Same as NBS
Smoke Production mode	Pyrolysis & Combustion	Combustion	Pyrolysis without flame Pyrolysis & Combustion with flame	Same as NBS
Smoke measurement method	Integrated rate	Integrated rate	Accumulation; maximum rate is increased as is obscuration time	Same as NBS
Provisions for smoke sampling and physico-chemical analysis	No	No	No	Yes

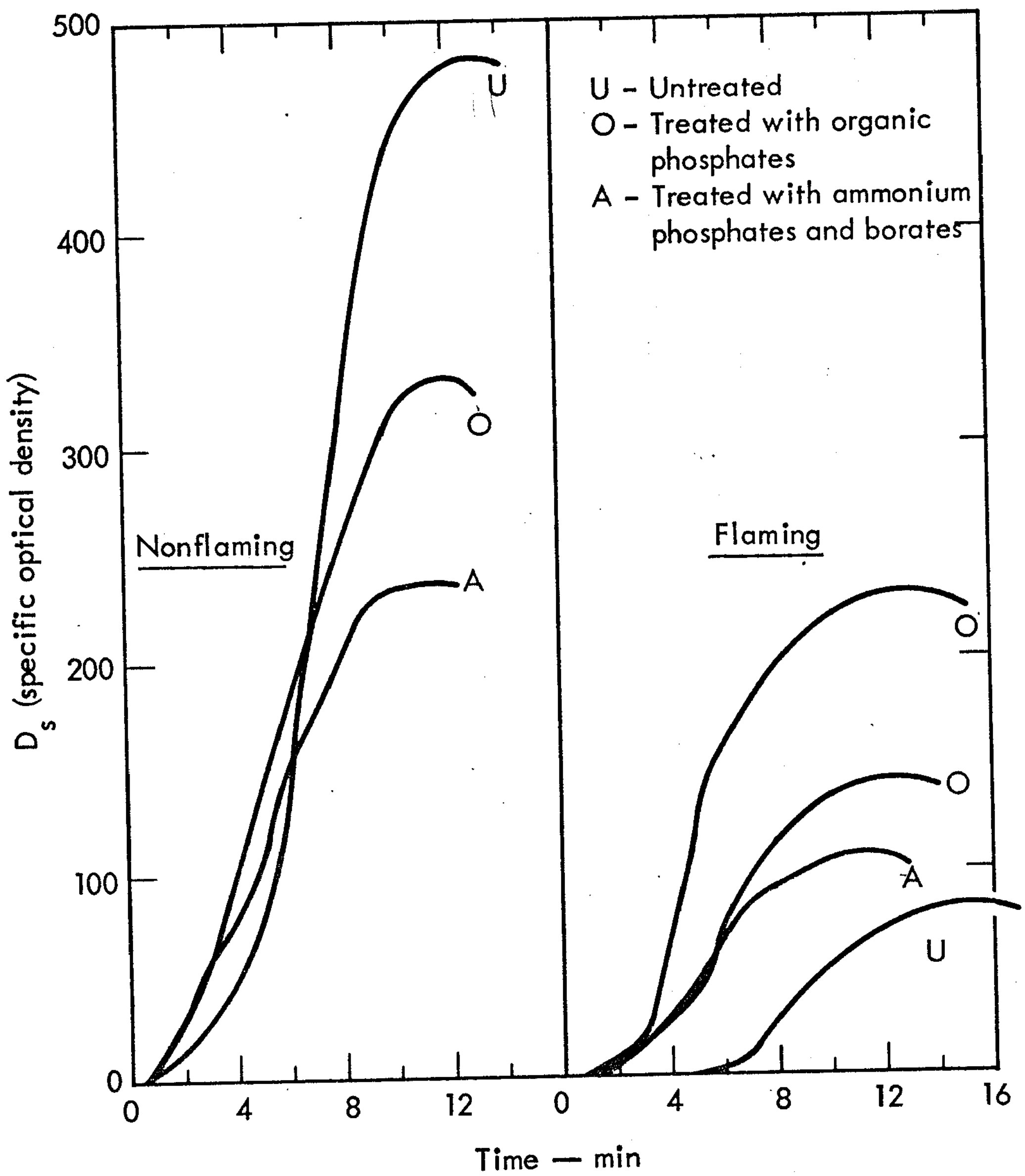

500
400
300
200
100
0
D_s (specific optical density)
Nonflaming
Flaming
U - Untreated
O - Treated with organic phosphates
A - Treated with ammonium phosphates and borates
U
O
A
0
4
8
12
16
Time — min

Figure 2

Table 2

Smoke Density for Several Plastics
(Flaming Conditions)

Material	Dm	Ds 16 (min).
Cellulose	18-25	4 - 7.9
Polysulfone	42-100	1.6 - 2.3
Polycarbonate	78-127	0.6 - 1.2
PVC - ABS	309-391	0.33-0.5
Urethane rubber	230	1.5

phosphate and borate treated woods produce the least smoke and in flaming they produce only slightly more smoke than the untreated wood. The only problem with the inorganic salts is that they may be leached out of polymer matrices, but it is possible to minimize losses of the retardant. In fact, the flameproofing coating developed at Dynatech utilizes inorganic phosphates and, yet, can stand immersion in 5% sodium chloride solution for at least one-half hour and still perform its flameproofing function in 100% oxygen environments. It may also be possible to permanently radiation graft inorganic phosphates to polymer chains and, in this way, provide a durably fire-resistant, low smoke producing polymer.

D. Formulation of Low-Smoke-Producing and Fire-Resistant Polymer Systems

While a considerable effort has been expended by researchers in developing flame retardants for polymers (e.g., Delman (Ref.10) lists approximately 130 patents that have been awarded in this area in the last two years alone), very little work has been done in smoke suppression. Einhorn has shown that with urethanes a high degree of aromaticity can be associated with a high degree of smoke development and also that increasing cross-link density also increases smoke production (Ref. 11).

At this point it would be usual to include a discourse on the chemistry of urethanes, vinyls, ABS, etc., and the usual additive, reactive, and coadditive methods for incorporating fire retardants. However, this is singularly useless because all the commonly used fire-retardants for polymers enhance the emission of smoke in proportion to their effectiveness as fire retarding agents except, apparently, for the inorganic agents. With the addition to cellulose of as little as 5% of ammonium phosphate the tarry decomposition distillates are reduced from 55% to 5% of the weight of the original cotton (Ref. 12). On the other hand, treatments of the antimony oxide-chlorinated compound type, where sublemation of both constituents along with the tars takes place, an apparent tar value of 27% is obtained for the fabric. The higher tar value and the presence of the retardant in the vapor phase where it can inhibit oxidation reactions and promote cracking and polymerization of the hydrocarbons may be one of the reasons for increased emission, but this is at present just speculation. It is necessary to study the gas phase, the solid phase, the heats involved, and the kinetics of the reactions to arrive at a definitive answer.

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Section 3
PROPOSED PROGRAM

A program divided into three phases of activity has been adopted in preparing the program outline. The detailed breakdown of the project tasks is as follows:

	Project Task	Duration, Months From Project Initiation
Phase I	Study of the Mechanisms of Smoke Emission	
1)	Assemble polymer systems of interest. If representative formulations of potentially important retardants are not commercially available (e.g., radiation-grafted allyl phosphates, vanadium pentoxide, nickel plus ceramics containing NH_4I, iron carbonyls, and cyclopentadienyl manganese tricarbonyl), synthesize them.	0 - 3
2)	Gas phase analysis	
	• Develop flash pyrolysis and controlled decomposition techniques	0 - 1
	• Couple pyrolysis (combustion) devices to gas chromatograph-mass spectrometer and examine the representative polymers in N_2 and air.	1/2 - 5 1/2
	• Analyze results and duplicate important experiments	5 - 6
3)	Solid phase analysis	
	• Assemble surface pyrolyzer	0 - 1 1/2
	• Develop standardized techniques for pyrolysis and analysis	1 1/2 - 3
	• Test representative samples in N_2 and air.	3 - 6
	• Analyze results and duplicate important experiments	5 1/2 - 6 1/2

4) Heat and kinetics analysis

- Develop standardized techniques for TGA and DTA analysis — 0 - 1
- Test representative samples in N_2 and air. — 1 - 4
- Analyze results and duplicate important experiments — 4 - 5 1/5

5) Synthesize the results of the gas solid, heat, kinetic, and smoke chamber (see Phase II) analyses into a coherent view of the mechanisms of smoke emission. — 5 - 7

Phase II <u>Screening of Available High Temperature Stable Polymers</u>

1) Search, identify, and obtain high temperature stable polymers. — 0 - 3

2) Construct modified NBS smoke chamber with provision for toxic gas analysis and standardize chamber with that at NBS. — 0 - 3

3) Test polymers for flammability using Test Method 5902, for Ds16 under both smoldering and flaming conditions using smoke chamber, and for toxic gas concentration using colorimetric filters on exhaust from smoke chamber. — 3 - 6

4) Analyze results — 5 - 6

Phase III <u>Formulation of Low Smoke Producing and Fire Resistant Polymers</u>

1) Predict from the mechanistic study of Phase I, flame and smoke retardants able to meet the requirements of NAFEC. — 6 - 7

2) Assemble materials — 6 - 8

3) Synthesize prepolymers and retardants. if necessary. — 7 - 9

4) Formulate and synthesize representative flame and smoke retardant polyurethanes, vinyl resins, ABS plastics, acrylic resins, and other polymers that may be of interest. 7 - 11

5) Test formulations with analytical instruments used in Phase I, with Test Method 5902 and with smoke chamber to confirm the predicted flame and smoke retardant behavior. 8 - 12

6) Prepare rough draft of Final Report 11 - 12

The program plan has been carefully developed to include provisions for anticipated problems. For example, it is anticipated that modifications of the analytical equipment will be required to permit specialized experiments to be carried out--provisions for the time necessary to make these modifications has been included in Phase I. Also provisions for the duplication of critical experiments is included. The contingency that all the important combinations of polymer and retardants to be examined in Phase I may not be available commercially has been provided for by allocating sufficient staff and materials to formulate and synthesize the otherwise unavailable combinations to insure that a comprehensive survey of emission mechanisms will be obtained.

In Phase II an anticipated problem was that the smoke measurements obtained using the tunnel test and the XP-2 chamber were for particluar types of combustion and not necessarily representative of the flame exposure occurring in aircraft. Consequently, a chamber that had provisions to produce both smoldering combustion and flaming combustion, the National Bureau of Standards test chamber, was selected for use. The advantage of this chamber is that smoke production values that bracket all possible combustion conditions can be obtained. In addition, by using the Lawrence Radiation Laboratory's modification of the test chamber, toxic gas concentrations can be obtained colorimetrically under the conditions of the smoking experiments.

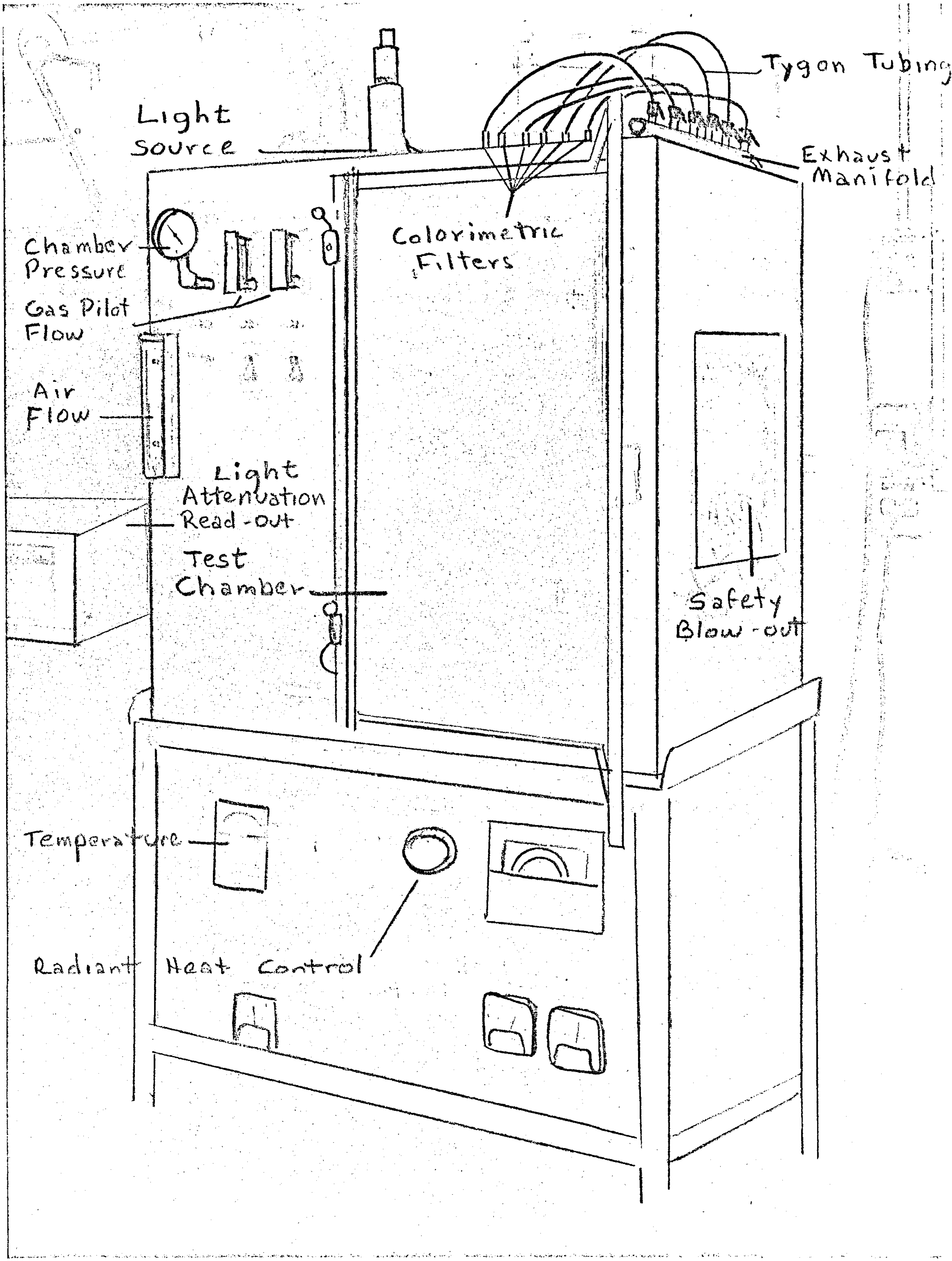

Figure 3 Smoke Chamber

In Phase III the problem that the optimum fire and smoke retardant predicted from the mechanistic study may not be commercially available is anticipated by providing for the actual synthesis of the retardants. Also anticipated is that conventional methods of incorporating retardants into polymers, i.e., additive and reactive methods, may not be the best to provide low smoke emission; and so the provision for an examination of radiation grafting of organic and inorganic groups to the polymers is brought to the program through the inclusion of Prof. Allan S. Hoffman, a polymer and radiation expert, as a consultant to our staff.

Also anticipated in Phase III is that the research & development effort may easily become diffused and ineffective if the approach that every slightly promising lead be fully investigated is taken. Consequently, the major effort in developing low smoke producing and fire-resistant materials will be concentrated on polyurethanes, vinyl resins, ABS, and acrylic resins because these materials have already proved themselves in terms of functionality in aircraft cabins. Of course, other polymer systems that prove promising in the screening experiments of Phase II will also be examined in Phase III if their projected production costs and functionality compare favorably with those of equivalent replacement materials.

Monthly detailed Progress Reports and Financial Management Reports (DD Form 1097) will be submitted for the duration of the contract.

Section 4
PROJECT ORGANIZATION AND MANAGEMENT

4.1 The Project in the Dynatech Organization

The proposed project will be assigned to the Chemical Engineering Department at Dynatech Corporation. This department is one of the five technical operating departments within the Dynatech organization. The relationship of the project to the corporate organizational structure is shown in the accompanying figure.

Within the Chemical Engineering Department at Dynatech R/D Company are two closely cooperating groups. These groups are referred to as the Applied Chemistry Group and the Process Engineering Group.

4.2 Project Management and Contract Administration

Authority for technical and cost control on a project is assigned to the Project Manager, who will be William H. Crandell. Mr. Crandell will maintain direct liaison with the technical manager at National Aviation Facilities Experimental Center. The Project Manager fully controls all project activities, including project personnel activities, experimental direction, and report preparation.

Formal contract liaison with National Aviation Facilities Experimental Center will be maintained by Dynatech's Financial and Administrative Department. This department also monitors project costs and schedules. The accounting and contract administration systems used by Dynatech are specifically designed for research programs and provide for excellent cost control. Direct labor and material costs are forecast on a weekly, monthly, and yearly basis, and actual costs are reported to the Project Manager by the accounting group within two days after the weekly reporting period. This report of status of expenditures for labor and materials on the project is furnished on a weekly control sheet prepared for the Project Manager by the Treasurer from information supplied by the Project Manager. Further fiscal control is exercised through regular monthly meetings of the Project Manager and Treasurer to forecast labor and material budgets.

It is the Project Technical Manager's responsibility to establish procedures for the systematic filing and organization of research and engineering records,

DYNATECH R/D COMPANY

A DIVISION OF DYNATECH CORPORATION

organization chart

April 3, 1969

- DYNATECH CORPORATION BOARD of DIRECTORS — W. M. Rohsenow, Chairman
  - DYNATECH CORPORATION — J. P. Barger, President
    - DYNATECH CORPORATION — K. D. Roberts, Treasurer and Vice President
    - DYNATECH R/D COMPANY — A Division of Dynatech Corp. — J.R. Turner, President (Vice Pres. DYNATECH CORP.)
      - LIBRARY — Marie Canfield, Tech. Librarian
      - PERSONNEL DEPT. — D. G. Cooley, Mgr.
      - MARKETING DEPT. — D. W. Harvie, Vice Pres., Mktg.
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          - CHICAGO — F. M. Kenney
      - CHEMICAL ENGRG. DEPT. — R. L. Wentworth, Mgr.
        - APPLIED CHEMISTRY GROUP — W. H. Crandell, Mgr.
        - PROCESS ENGRG. GROUP — A. R. Reti, Tech. Director
        - BACON LABORATORIES — W. H. Crandell, Mgr.
      - ADVANCED SYSTEMS DEPT. — M. Hurwitz, Mgr.
        - INDUSTRIAL SYSTEMS GROUP — C. J. Oberhauser, Mgr.
        - PROCESS SYSTEMS GROUP — S. E. Sadek, Mgr.
      - ENGRG. MECHANICS DEPT. — J. H. Putukian, Mgr.
        - PRESSURE VESSEL DESIGN GROUP — N. A. Goldstein, Mgr.
        - APPLIED MECHANICS GROUP — J. H. Putukian, Mgr.
      - FLUID & THERMAL ENGRG. DEPT. — D. A. East, Mgr.
        - THERMAL ENGRG. GROUP — J. G. Bourne, Mgr.
        - FLUID MECHANICS GROUP — K. E. Hickman, Mgr.
      - THERMATEST DEPT. — K. G. Coumou, Mgr.
        - MEASUREMENTS LAB — R. P. Tye, Mgr.
        - INSTRUMENTS GROUP — K. G. Coumou, Mgr.
    - DYNATECH PRODUCTS CO. — A Division of Dynatech Corp. — Burlington, Mass.
    - BACON INDUSTRIES, INC. — A Subsidiary of Dynatech Corp. — Watertown, Mass.
    - COOKE ENGINEERING COMPANY — A Subsidiary of Dynatech Corp. — Alexandria, Virginia
    - GIER DUNKLE INSTRUMENTS, INC. — A Subsidiary of Dynatech Corp. — Santa Monica, California

communications, reports, and literature sources. The preparation of status and final reports to the National Aviation Facilities Experimental Center is the responsibility of the Project Technical Manager. The technical personnel of the project furnish the drafts of these reports and final drafts are prepared by the Project Technical Director.

4.3 Technical and Management Personnel

The program proposed to be carried out in the Chemical Engineering Department at Dynatech R/D Company will be under the direction of William H. Crandell, Manager of the Applied Chemistry Group. He is well versed in the techniques of research and development contract management, having participated in or supervised a large number of Dynatech's projects as well as those at Bacon Laboratories prior to that organization's merger with Dynatech. Included in projects managed by Mr. Crandell have been many involving polymer and resin technology closely allied with the kind which will be utilized in the proposed program. Mr. Crandell's technical experience includes many assignments in materials development and process engineering, including projects to develop flame resistant adhesives, encapsulating compounds, and coating systems for metals and plastics as well as reinforced epoxy and polyester resin systems. Under his direction a host of epoxy resin coatings have been developed, tested, and marketed.

Assisting Mr. Crandell will be Dr. P. L. T. Brian, Technical Director of the Chemical Engineering Department, and Mr. John B. Gregory. Dr. Brian is a noted expert in the field of simultaneous heat and mass transfer with chemical reaction. His incisive analyses have been of telling value on many of Dynatech's projects. John B. Gregory, a specialist in polymer synthesis and formulation, has had extensive experience in formulating urethanes, acrylic resins, and vinyl resins.

Staff engineers on the project will be Glenn K. Armstrong, Kenneth R. Sidman, and Keith J. Sims. Mr. Armstrong and Mr. Sidman have been active in developing unique flame retardant systems that have been utilized by NASA-MSC for protective coatings for flammable polymers. They have had extensive experience in formulating retardant systems to meet exacting physical property requirements. Mr. Sims is a materials specialist who has concentrated on physical properties measurement. He has had two years of experience working with acrylonitrile-butadiene-styrene polymers.

Also available to assist in the formulation phase of the program is Stewart C. Spinney. Mr. Spinney has concentrated on the preparation of polymers for specialty applications.

Skilled chemical technicians will support the engineering activities.

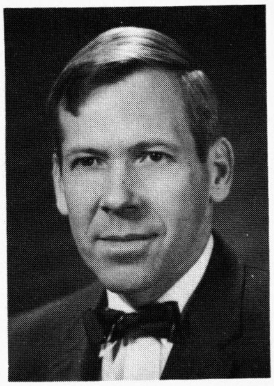
Consultants for the mechanistic study will be Prof. Allan S. Hoffman and Prof. Phillip Issenberg. Prof. Hoffman is a polymer materials specialist (synthesis, structure and properties, and flammability mechanisms). Of particular relevence to the proposed program is his work on thermal stability and flammability mechanisms of polymers, and his background in radiation processing technology. Prof. Issenberg has been concerned with the investigation of the composition of wood smoke. He and his associates have been responsible for developing particularly fine analytical tools for qualitatively and quantitatively analyzing the pyrolysis products of this complex system.

The Treasurer and Controller of Dynatech Corporation, Kenneth D. Roberts, will work with the Project Manager in the fiscal control of the project. Mr. Roberts organized the reporting system utilized at Dynatech for efficiently providing prompt reports of financial status. This system is unusual in providing such information on a weekly basis rather than the commonly-used monthly basis.

4.4 Resumes of Key Personnel

William H. Crandell
John B. Gregory
Glenn K. Armstrong
Kenneth R. Sidman
Keith J. Sims
Stewart C. Spinney
Allan S. Hoffman
Phillip Issenberg
P. L. T. Brian

WILLIAM H. CRANDELL



Dynatech R/D Company

EDUCATION: B.S., Chemical Engineering, Northeastern University.

BACKGROUND: President and Director of Plastics Research, Frederick S. Bacon Laboratories.
President of Bacon Industries, Inc.
Member: Society of Plastics Engineers,
American Chemical Society,
Tau Beta Pi.
Massachusetts Professional Engineer.

EXPERIENCE: Mr. Crandell specializes in the technical and financial management of research and development projects. His technical skills have been devoted especially to materials engineering through the application of polymer technology.

Among the many projects directed by Mr. Crandell are the development of low coefficient of expansion, dimensionally stable epoxy resin potting compounds and adhesives; development of heat seal patches for nylon airmail bags and modification of equipment to apply the patches; and investigation of glass bonded inorganics for materials of construction. These latter materials can be molded to shape at relatively low temperatures and then fired at elevated temperature to develop maximum high temperature properties. Under his direction a family of specialty potting compounds and adhesives was developed and is being marketed successfully by Bacon Industries, Inc. Among these materials are compounds tailored especially for use in the manufacture of precision gyroscopes for inertial guidance systems. A method for manufacturing intricate impregnated coils for electronic devices utilizing a unique soluble coil arbor has been developed under Mr. Crandell's direction. After winding and impregnation of the coil the arbor is dissolved away leaving a self-supporting coil.

Mr. Crandell has broad experience in developing adhesives for unusual surfaces; a recent example being a composition suitable for bonding to beryllium oxide surfaces. He has developed a unique method for preparing thin, but reliably uniform, epoxy resin coatings on metal parts of complex shapes. Under his direction hot melt adhesives have been developed which effectively bond cellulose acetate butyrate to steel in the presence of aliphatic hydrocarbons. The utilization of this particular adhesive required the development of unique application methods.

The evaluation and modification of elastomers have been Mr. Crandell's responsibility in a number of programs. Under his direction a technique for preparing shell molds for casting metal parts which contain undercuts was developed. Essential to this development were selecting the proper silicone elastomer and bonding this elastomer to the aluminum master mold pattern. Mr. Crandell has experimentally manufactured polytetrafluoroethylene and polymonochlorotrifluoroethylene coated elastomer parts for use in extremely corrosive chemical environments.

Mr. Crandell has been instrumental in scaling-up the production of an ultrapure grease for precision instrument use. Several of his projects have been directed toward advanced coating procedures where curtain coating, plasma spray, flame spray and electrostatic application techniques are required. He is actively working in the field of transfer molding of thermosetting polymers, including mold design and compound development. He has formulated unusual porous plastic compositions and methods for their manufacture.

Of particular interest to Mr. Crandell is the solution of polymer quality control problems through the application of new test techniques as well as the old "tried and true" methods.

PUBLICATIONS:

1. "Evaluation of Silicone Rubber Modified with Teflon," Rubber World, November 1955.

2. "Development of a Potting Compound and Mold for Precision Pottings," Technical Papers, 12th Annual National Technical Conference, Society of Plastics Engineers.

3. "Potting with Epoxy Resin," Electronic Design, December, 1956.

4. "Low-Cost Gel Time Meter," Adhesive Age 3 (8) 43 (1960).

5. "A Method for Molding Intricate Passageways in Cast Epoxy Parts," Insulation, December 1964.

P. L. THIBAUT BRIAN

Dynatech Corporation
Professor of Chemical Engineering,
Massachusetts Institute of Technology.

EDUCATION: Sc. D., Massachusetts Institute of Technology.
B. S., Louisiana State University.

BACKGROUND: Teacher of Engineering Subjects.
Consultant to Industry.
Director, Bangor Station of the MIT School of Chemical Engineering Practice.
Member: AIChE, ACS, Tau Beta Pi, Sigma Xi, Phi Lambda Upsilon, Phi Kappa Phi, Pi Mu Upsilon.
Massachusetts Professional Engineer.

EXPERIENCE: Applied mathematics in the analysis of chemical processes is Dr. Brian's specialty. The analysis of chemical reaction kinetics and of the rates of heat and mass transfer in chemically reacting systems has been a focal point of his research and his consulting work. In addition, he has made substantial contributions in the field of numerical methods for chemical reactor simulation.

As a consultant to the chemical and aerospace industries, Dr. Brian has contributed to numerous research, development, and engineering design projects in petrochemical processing, cryogenic processing, and high temperature gas-solids reactions. Problems involving the interaction of diffusion fields with chemical kinetics have been a special interest in Dr. Brian's consulting work. These have included gas absorption and liquid-liquid extraction separation processes with simultaneous chemical reactions, heat transfer in reacting systems, and diffusion controlled catalytic reactions.

Dr. Brian has had broad experience in the dielectric heating of polymers, in plastic molding processes, and in the development of special-purpose plastics. His background includes responsibility for projects in the fields of pulp and paper manufacture, glass manufacture, petrochemical processing, and inorganic chemical processing technology.

Dr. Brian has taught most of the undergraduate subjects and many of the graduate subjects offered by the MIT Chemical Engineering Department. For the past six years, he has been in charge of the Chemical Engineering Department's graduate course in distallation. Dr. Brian has organized and presented two new courses in the MIT Chemical Engineering Department: the first, a senior course, dynamics and control of chemical engineering processes; the second and advanced graduate seminar in the numerical solution of diffusive and convective transport problems, including the analysis of stability and convergence of finite-difference approximations to partial differential equations.

As Director of the Bangor Station of the MIT School of Chemical Engineering Practice, Dr. Brian directed graduate students in a variety of plant operating problems as well as research and development problems in pulp and paper manufacture.

Dr. Brian's research and publications have contributed substantially to an understanding of the interaction of thermal and mass diffusion fields with chemical kinetic rates. He has also made important contributions to knowledge in the fields of heat and mass transfer, chemical reactor simulation, numerical mathematics, crystallization, and water desalination.

PUBLICATIONS:

Mass and Heat Transfer

A. General

1. "The Influence of Gravitational Force on Gas Absorption in a Packed Column," with J. E. Vivian and V. J. Krukonis, AIChE Journal, 11, 1088 (1965).

2. "Gas Absorption in Packed Columns: Liquid Phase Resistance in the Loading Region," with J. E. Vivian and V. J. Krukonis, AIChE Journal, 13, 174 (1967).

3. "A Criterion for Supersaturation in Simultaneous Gas Absorption and Desorption," with J. E. Vivian and D. C. Matiatos, Chem. Eng. Science, 22, 7 (1967).

B. With Simultaneous Chemical Reaction

1. "Gas Absorption Accompanied by a Liquid Phase Chemical Reaction," with E. R. Gilliland and R. F. Baddour, AIChE Journal, 4, 223 (1958). Presented at the AIChE Meeting in Baltimore, September 18, 1957.

2. "Penetration Theory for Gas Absorption Accompanied by a Second Order Chemical Reaction," with J. F. Hurley and E. H. Hasseltine, AIChE Journal, 7, 226 (1961).

3. "The Effect of the Hydrolysis Reaction Upon the Rate of Absorption of Chlorine into Water," with J. E. Vivian and A. G. Habib, AIChE Journal, 8, 205 (1962). Presented at the AIChE Meeting in New York, December 5, 1961.

4. "Heat Transfer with Simultaneous Chemical Reaction: Film Theory for a Finite Reaction Rate," with R. C. Reid, AIChE Journal, 8, 322 (1962).

5. "Turbulent Pipe Flow Heat Transfer with a Simultaneous Chemical Reaction of Finite Rate," AIChE Journal, 9, 831 (1963). Presented at AIChE-ASME Heat Transfer Conference in Boston, August 14, 1963.

6. "Gas Absorption Accompanied by an Irreversible Reaction of General Order," AIChE Journal, 10, 5 (1964). Presented at AIChE Meeting in San Juan, October 1, 1963.

7. "An Ionic Penetration Theory for Mass Transfer with Chemical Reaction," with R. F. Baddour and D. C. Matiatos, AIChE Journal, 10, 727 (1964).

8. "Effect of Temperature Driving Force on Heat Transfer to a Nonequilibrium Chemically Reacting Gas," with S. W. Bodman, Ind. Eng. Chem. Fundamentals, 3, 339 (1964).

9. "Gas Absorption Accompanied by a Two-Step Chemical Reaction," with M. C. Beaverstock, Chem. Eng. Science, 20, 47 (1965).

10. "Heat Transfer to Decomposing Nitrogen Dioxide in a Turbulent Boundary Layer," with R. C. Reid and S. W. Bodman, AIChE Journal, 11, 809 (1965). Presented at AIChE Meeting in Boston, December, 1964.

11. "The Effect of Temperature on the Rate of Absorption of Chlorine into Water," with J. E. Vivian and Carlo Piazza, Chem. Eng. Science, 21, 551 (1966).

12. "Interfacial Turbulence During the Absorption of CO_2 into Monoethanolamine," with J. E. Vivian and D. C. Matiatos, AIChE Journal, 13, 28 (1967).

13. "Turbulent Heat Transfer to a Nonequilibrium Chemically Reacting Gas," with S. W. Bodman, Ind. Eng. Chem. Fundamentals, 6, 89 (1967).

C. With Frost Formation

1. "Heat Transfer and Frost Formation Inside a Liquid Nitrogen-Cooled Tube," with R. C. Reid and M. E. Weber, AIChE Journal, 12, 1190 (1966).

Finite-Difference Mathematics

1. "A Finite-Difference Method of High-Order Accuracy for the Solution of Three-Dimensional Transient Heat Conduction Problems," AIChE Journal, 7, 367 (1961). Presented at the AIChE Meeting in Cleveland, May 8, 1961.

2. "Numerical Solution of Convective Transport Problems," with H. L. Stone, AIChE Journal, 9, 681 (1963). Meeting in Buffalo, May, 1963.

Crystal Growth Kinetics

1. "Cinemicrographic Studies of Single Crystal Growth: Effects of Surface Active Agents of Adipic Acid Crystals Grown from Aqueous Solution," with A. S. Michaels and W. F. Beck, Paper No. B/V.27, Proceedings of the Fourth International Congress on Surface Activity (C. I. D.), September 7-12, 1964, Brussells, Belgium.

2. "Impurity Effects on the Basal Plane Solidification Kinetics of Supercooled Water," with A. S. Michaels and P. R. Sperry, J. of Applied Physics, 37, 4649 (1966).

Water Desalination

1. "Salt Concentration at Phase Boundaries in Desalination by Reverse Osmosis," with T. K. Sherwood, R. E. Fisher and L. Dresner, Ind. Eng. Chem. Fundamentals, 4, 113 (1965).

2. "Influence of Concentration Polarization on Reverse Osmosis System Design," Proceedings of the First International Symposium on Water Desalination, Vol. 1, pp. 349 - 370, U.S. Government Printing Office, Washington, D.C. (1967).

3. "Mass Transport in Reverse Osmosis," Chapter 5, pp. 161-202, in Desalination by Reverse Osmosis, Ulrich Merten, Editor, Cambridge, MIT Press, c (1966).

4. "Concentration Polarization in Reverse Osmosis Desalination with Variable Flux and Incomplete Salt Rejection," Ind. Eng. Chem. Fundamentals, 4, 439 (1965).

5. "Concentration Polarization in a Reverse Osmosis System," Ind. Eng. Chem. Fundamentals, 5, 148 (1966).

6. "Desalination by Reverse Osmosis," with T. K. Sherwood and R. E. Fisher, Ind. Eng. Chem. Fundamentals, 6, 2 (1967).

7. "Water Desalination by Freezing," Paper No. 67-UNT-10, ASME Underwater Technology Conference, Hampton, Va., April 30 - May 3, 1967.

Chemical Reactor Simulation

1. "Steady-State Simulation of an Ammonia Synthesis Converter," with R. F. Baddour, B. A. Logeais and J. P. Eymery, Chem. Eng. Science, 20, 281 (1965).

2. "Transient Behavior of an Ammonia Synthesis Reactor," with R. F. Baddour and J. P. Eymery, Chem. Eng. Science, 20, 297 (1965).

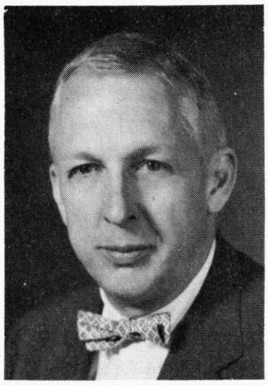
Thermodynamics

1. "Predicting Activity Coefficients from Liquid Phase Solubility Limits," Ind. Eng. Chem. Fundamentals, 4, 100 (1965).

Gas-Solids Reaction Kinetics

1. "Short Time, High Temperature Oxidation of Cobaltous Oxide," with A. R. Reti and L. C. Hoagland, Ind. Eng. Chem. Process Design and Devel., 5, 171 (1965).

JOHN B. GREGORY



Dynatech Corporation

EDUCATION: A. B., Chemistry Major, Physics Minor, Dartmouth College.

BACKGROUND: Director, Elastomer and Fluids Research, Frederick S. Bacon Laboratories.
Sales Manager and General Manager, Bacon Industries, Inc.
Chief, Materials Section, Chemical Warfare Service Development Laboratory, Massachusetts Institute of Technology.
Research Chemist, BB Chemical Company, Cambridge, Massachusetts.
Member: American Chemical Society, American Society for Testing and Materials, American Association of Textile Chemists and Colorists, and New England Society for Paint Technology.

EXPERIENCE: Mr. Gregory is a specialist in elastomers, adhesives, coatings and other colloidal systems. Mr. Gregory directs research projects involving elastomers, coatings and fluids. He also is responsible for the physical testing section and projects involving Expert Testimony.

Through his efforts a family of specialty elastomer seals was developed for the aerospace industry. Demand was such that the firm Bacon Industries, Inc., was formed to manufacture and market these products. Among specialized test procedures developed by Mr. Gregory is a technique for determining the homogeneity of functional fluids by measuring their thermal diffusion properties. Mr. Gregory has undertaken many assignments to develop polymeric materials or treatments used in the building and construction industries. In this field he has devised special procedures for ensuring that elastomeric bearing pads used in heavy construction such as bridges and buildings will meet the lengthy lifetimes required.

Prior to joining Bacon Laboratories, Mr. Gregory was responsible for the development of elastomers for use in protective clothing and gas masks for the Army Chemical Corps. He was awarded the Army Commendation Medal for his contributions to the knowledge of the use of elastomers in chemical warfare equipment. During World War II, he was a member of the War Production Board Technical Consulting Committee for Gas Mask Manufacture.

When at the BB Chemical Co., Mr. Gregory was in charge of all shoe adhesive development involving rubber lattices.

PUBLICATIONS:

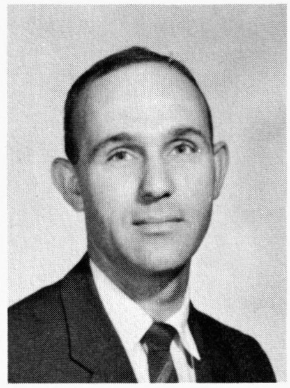
1. "Effect of Temperature on the Air Permeability of Silicone Rubber," Rubber World, December 1955.

2. "Improved Method of Determining Densities of Viscous Fluids with Babcock Bottles," Analytical Chemistry 25, 1773 (1953).

3. "Silicone Rubber--A Literature Review," Rubber Age, November 1951.

4. "Effect of Storage and Temperature on Flexibility of Natural and Synthetic Rubbers," India Rubber World, February 1948.

GLENN K. ARMSTRONG



Dynatech Corporation

EDUCATION: M. S., Chemical Engineering Practice, Massachusetts Institute of Technology.
B. of Ch.E., Georgia Institute of Technology.

BACKGROUND: Project Manager, Amicon Corporation.
Senior Product Development Engineer, Ford Motor Company.
Director of Program, Boston Museum of Science.
Staff Engineer, Instrumentation Lab, Massachusetts Institute of Technology.
Instructor, Petroleum Refining Engineering Department, Colorado School of Mines.
Research Engineer, Arthur D. Little Company
Research Engineer, G. L. Cabot Company
Member: ACS, AIChE, SIAM, ASEE, ASTM, Massachusetts Professional Engineer.

EXPERIENCE: At Dynatech Corporation Mr. Armstrong has investigated the kinetics of gas desorption from fluids, the kinetics of a hetrogeneous reaction in a sintered porous structure, rheology of pastes and coatings, dimensional and thermal stability of thermoplastics, the vibration resistance of lead-acid batteries, and has developed a high strength nonflammable writing paper.

As a plant engineer, Mr. Armstrong operated a mineral processing pilot plant and analyzed wet and dry grinding mills, air tables, magnetic separators and other beneficiation equipment. He has solved client problems in many areas of surface chemistry including coal tar emulsions, ball point pen inks, and the control of foam in caustic scrubbers for natural gas. He has also investigated the effect of particle size and absorbed water films on the rheology of oil-graphite dispersions, the colloidal dispersion and surface treatment of minerals, and has developed mineral-plastic composites, a wall tile body and glaze, and waterproofing cement additives.

His experience in heat and mass transfer operations include an experimental study of concentration polarization in a thin channel, reverse osmosis cell for desalination of brackish water, measurement of the emmisivity of various aluminum flake-organic lacquer formulations, and the effects of particle shape and size distribution on the drying rate of porous solids.

In plastics fabrication technology he has investigated the use of plastic foam for prototype tooling, the vacuum forming of foamed plastic sandwich panels and was principal engineer for the design and fabrication of the ABS, sandwich-panel car, "The Ford Bordinat Cobra".

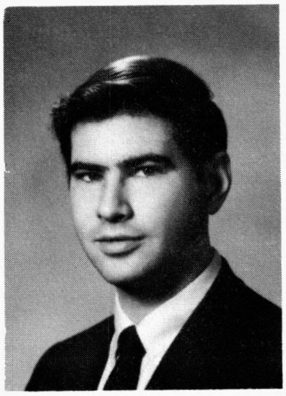
Mr. Armstrong's electrochemical experience includes an investigation of the surface finish obtained by electropolishing of steel and aluminum and a feasibility study of fuel cell applications in automobiles.

He has designed a fiber optic meter movement, a process control refractometer and has assisted in the design of a planetarium projector.

Mr. Armstrong's four years of academic experience included teaching strength of materials at Wentworth Institute and three years as an instructor of Petroleum Refining Engineering at the Colorado School of Mines.

PUBLICATION: "Artificial Initiation of Lightning Discharges", with M. Brook, et. al., Journal of Geophysical Research, Vol. 66, No. 4, p. 3967, November 1961.

KENNETH R. SIDMAN



Dynatech Corporation

EDUCATION: S.M., S.B., Chemical Engineering, Massachusetts Institute of Technology.

BACKGROUND: Engineer, American Cyanamid Company, Union Carbide Corporation, Ionics, Inc.
Member: Sigma Xi, American Institute of Chemical Engineers.

EXPERIENCE: Mr. Sidman has specialized in materials technology, surface chemistry, and membrane separations.

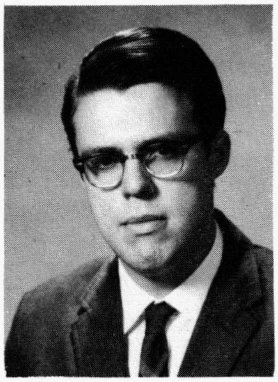
At Dynatech Corporation Mr. Sidman's project responsibilities have included the development of flameproof coatings for synthetic fibers, the preparation of papers from non-cellulosic fibers, and the preparation of reinforced plates for lead-acid batteries. He has carried out analysis and experimentation to develop chemical heat sources of readily regulated release rate.

At the American Cyanamid Company, Mr. Sidman directed a research effort to investigate the ink stability and manufacture of particular inorganic pigments. The investigation led to a better understanding of the complex reactions and surface chemistry involved in the production and the stabilization of aqueous dispersions of lead pigments.

While working at the Oak Ridge National Laboratory for Union Carbide Corporation, Mr. Sidman was a member of project teams investigating advanced separation techniques. One of these techniques involved the use of silica-filled, silicone rubber membranes for the multistage cascade separation of radioactive, inert gases from reactor atmospheres. In another assignment Mr. Sidman assisted in the development of a novel technique for achieving extremely fine degrees of separation using a solvent and ionic strength gradient in the ultracentrifuge.

At Ionics, Inc., Mr. Sidman was engaged in the development of an electrochemical system for simultaneous generation of oxygen gas and reduction of carbon dioxide to liquid products. The project was concerned with determining the physical properties of electrode materials and surfaces that promote specific desired organic reactions.

KEITH J. SIMS



Dynatech Corporation

EDUCATION: M. S., Chemical Engineering, Rensselaer Polytechnic Institute.
B. S., Chemical Engineering, University of Illinois.

BACKGROUND: Engineer/Manager, Plastics Project Planning, Research, and Action Institute of Uttar Pradesh (India).
Research Engineer, Monsanto Company.
Member: American Institute of Chemical Engineers.

EXPERIENCE: At Dynatech Corporation, Mr. Sims has investigated polymer coatings for steel with the objective of obtaining reliable corrosion protection, low coefficient of friction, and high impact resistance. The coatings under development are low cost systems suited to high speed, volume production.

Mr. Sims' background in plastics technology resulted in his developing and managing a fiberglass/polyester laminating business. Furniture and piping were principal products of this plant. This assignment in India was undertaken at the direction of the American Peace Corps.

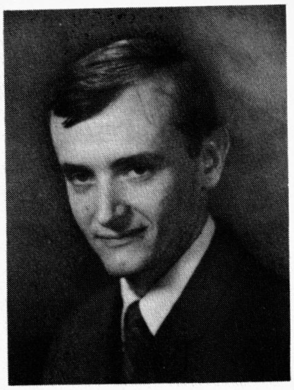
At Monsanto, Mr. Sims developed ABS sheet materials and products; he also studied the relations among orientation, chemical resistance, and mechanical properties of ABS in varying environments. His duties included research support for marketing and production.

At RPI, Mr. Sims studied the kinetics and fracture morphology of crazing in PMMA and polystyrene.

PUBLICATIONS:

1. "Propagation Rates and Fracture Morphology of Solvent-Induced Crazes," S. S. Sternstein and K. J. Sims, American Chemical Society, Division of Polymer Science, Preprints 5 (2), 442-6 (1964).

STEWART C. SPINNEY



Dynatech R/D Company

EDUCATION: B.S., University of Massachusetts

BACKGROUND: Research Assistant, University of Massachusetts.

EXPERIENCE: At Dynatech, Mr. Spinney has studied the static and dynamic properties of elastomeric pads used for truss support in highways, bridges and buildings. He has the responsibility for quality control testing various elastomer and plastic compounds to insure that the materials conform to various commercial, state, federal, and military requirements. Tests are conducted strictly according to applicable ASTM, FED, or MIL test procedures. Mr. Spinney is adept at determining the physical properties of such critical materials as lubricants and custom high density fluids. Many of his determinations require densities accurate to four significant figures and viscosities determined at elevated temperatures $\pm 0.02°$ C. He has studied the effect of composition variables on the physical properties of latex films exposed to heat and weather. As a result of his work optimum latex film compositions have been determined. Work done by Mr. Spinney has resulted in unique porous epoxy-rubber composites which are of interest as materials of construction where controlled release of lubricant or liquid is needed. Among some of the other varied materials studied by Mr. Spinney are photoresists, shoe finishes, metal cleaning solvents and special bearing lubricants. He has classified the effect of thermal diffusion on various high density, high viscosity fluids.

At the University of Massachusetts, Mr. Spinney did a research study on plant growth regulators with particular emphasis on high cation concentrations as growth promotors. In the process of collecting specimens needed for phycological study, Mr. Spinney developed proficiency as a scuba diver and collected specimens at depths of one hundred and fifty feet. His graduate study at the University of Massachusetts was in Food Science and Technology with emphasis on the changes in the physiology and biochemistry of foods which take place after they have been harvested.

DR. ALLAN S. HOFFMAN

Professor, Chemical Engineering, MIT
Consultant, Dynatech Corporation

EDUCATION:

S.B., Chemical Engineering Practice, Massachusetts Institute of Technology, 1953.
S.M., Chemical Engineering, Massachusetts Institute of Technology, 1955.
Sc.D., Chemical Engineering, Massachusetts Institute of Technology, 1957.

EXPERIENCE:

Teaching and Research

Applied surface and colloid chemistry (adhesion, wetting and surface forces; application to composite systems).
Polymer materials (synthesis, structure and properties of polymers--viscoelasticity, permselectivity as membranes, flammability mechanisms, reinforcement mechanism in composites, coacervation phenomena).
Biomedical materials (swelling and viscoelasticity in structural proteins).
Radiation processing technology (cure of coatings, textile finishing operations).

Industrial

California Research Corporation, Richmond, California. Worked on thermal stability and flammability mechanisms of polymers, polymerization of - olefins, polymer processing: extrusion and melt rheology.

Radiation Applications, Inc., New York, N.Y. Worked on radiation grafting of monomers to polymers to improve dyeing, bondability; new ion-exchange membranes synthesized.

PUBLICATIONS:

1. Burlant, W. J. and A. S. Hoffman, "Block and Graft Polymers", Reinhold Publishing Co., N. Y. (1960).

2. Patents: Nine applied for: two on process for improving bondability of Teflon via radiation and post-graft polymerization (1959); one on molecular weight control of poly 4-methyl 1-pentene (1962); one on a process for fabricating a longer-wearing durable press fabric (1967); one on a process for improving stain-release in blended fabrics (1967); one on new compositions for radiation-curable resins (1968); one on a process for improved wet strength paper (1968); and on a radiation-chemical process for treating nylon surfaces (1968).

3. Porter, R. S., A. S. Hoffman, and J. F. Johnson, "Gravimetric Introduction Device for Gas Chromatography, Application to Pyrolysis Studies", Analytical Chemistry, 34, 1179 (1962).

4. Stannett, V. and Hoffman, A. S., "Radiation Techniques in the Textile Industry", presented at the Annual Technical Conf. of the Amer. Assn. of Textile Colorists and Chemists, New Orleans, La., Oct. 19-21, 1967 (accepted for publication in Amer. Dyestuff Reporter, 1968).

5. Hoffman, A. S. and R. Bacskai, "Block and Graft Copolymers", Chapter in "Copolymerization" ed. by G. Ham, Interscience-Wiley Publishing Co., N. Y. (1964).

PHILLIP ISSENBERG

Consultant, Dynatech Corporation
Professor, Department of Nutrition and Food Science

EDUCATION: B.S., Massachusetts Institute of Technology.
Ph. D., Massachusetts Institute of Technology.

EXPERIENCE: Research Assistant, Massachusetts Institute of Technology, Research on volatile food components.
Instructor, Massachusetts Institute of Technology, Research and teaching in radiation preservation of foods, food chemistry.
Biochemist, Pioneering Research Division, U. S. Army.
Natick Lab., Development of methods for gas chromatographic and mass spectrometric analysis of materials of biological origin.

Current research projects are in the field of food chemistry and food composition and analysis. These projects include: a study of the volatile components of bananas and the mechanisms of production of these components during ripening of the fruit; investigation of the composition of wood smoke and volatile wood smoke components absorbed by foods in the smoking process; interactions between volatile food components and non-volatile components at low water activities; and a study of the lipid components of microorganisms which have potential value as sources of dietary proteins.

PUBLICATIONS: Issenberg, P., and Hornstein, I., Analysis of Volatile Flavor Components of Foods, In Advances in Chromatography, (R. A. Keller, Editor). M. Dekker, Inc., N.Y. In Press (1969).

Myers, M.J., Issenberg, P., and Wick, E.L. Vapor Analysis of The Production by Banana Fruit of Certain Volatile Constituents.

Wick, E. L., Yamanishi, T. Kobayashi, A. Valenzuela, and S. Issenberg, P. Volatile Constituents of Banana. J. Agri. & Food Chem., In Press (1969).

Issenberg, P., Kobayashi, A., and Mysliwy, T.J. Combined Gas Chromatography - Mass Spectrometry in Flavor Research: Methods and Applications. Submitted for Publication in J. Agri. & Food Chem.

Merritt, C., Jr., Issenberg, P., Bazinet, M.L., Green, B.N. Merron, J.O. and Murray, J.G. Fast Scanning of High Resolution Mass Spectra. Anal. Chem., 37, 1037 (1965).

Section 5
CORPORATE QUALIFICATIONS

Dynatech R/D Company, with offices and laboratories in Cambridge and Watertown, Massachusetts, is the engineering, research and development division of Dynatech Corporation. The Corporation was founded in 1957, through the growth of an engineering consulting practice established several years earlier by Professors Warren M. Rohsenow and J. P. Barger of the Mechanical Engineering Department at the Massachusetts Institute of Technology.

The Dynatech R/D Company has successfully completed over three thousand projects for various government and industrial clients. Dynatech R/D Company now employs over 130 professional and supporting personnel. The technical staff of 80 members are all college graduates with a degree in engineering or science. A majority possess one or more advanced degrees. In order to supplement the technical staff in specialized problem areas whenever needed, the Dynatech R/D Company retains competent consultants in fluid mechanics, cryogenics, heat transfer, chemistry, physics and electrical engineering.

Fields of Technical Activity

The Dynatech R/D Company laboratories are fully equipped to perform research and development in a variety of areas, including:

Chemical Engineering:	Industrial Chemistry Process Engineering Process Economics Materials Engineering
Thermal Engineering:	Heat Transfer Thermodynamic Cycles Thermophysical Properties
Fluid Mechanics:	Fluid Machinery Internal Fluid Dynamics Two Phase Flow Non-Newtonian Flow

Applied Mechanics:

- Stress Analysis
- Shock and Vibration
- Acoustics
- Machine Design
- Dielectrophoretic Devices
- Superconducting Electrical Machinery

Facilities

Dynatech R/D Company headquarters are located at 17 Tudor Street, Cambridge, Massachusetts, in a 15,000-square-foot, modern, air-conditioned building. Additional facilities are located nearby in 24,000 square feet on Erie Street. Approximately 40% of the Tudor Street facilities and a larger portion of the Erie Street facility are devoted to laboratory space. Support services, such as a shop equipped for building special test equipment, drafting services, and a print shop are available, Machine work and welding for small and medium-sized fabrications are done within the Dynatech R/D Company. Larger pieces and work of especially high precision are jobbed-out to qualified local machine shops specializing in such work.

The Chemical Engineering Laboratory at the Dynatech R/D Company is equipped with conventional apparatus for chemical preparations, analyses, physical-chemical measurements, experimental electrochemistry, papermaking, and industrial chemical operations. This laboratory contains facilities for handling toxic materials. Many projects have involved the construction of specialized pilot equipment. The complexity of these pilot units has ranged from simple bench and rack installations to large-scale processing equipment involving as much as a quarter-million dollars investment. In addition complete facilities for research, development, and testing in the field of adhesives, elastomers, plastics, coatings, and fabrics, including production equipment such as heated presses, processing ovens, rubber mills, mixers, and specialized test equipment are available.

The laboratory facilities of other technical departments at Dynatech R/D Company are equipped with experimental apparatus specialized for work in the fields of thermal engineering, fluid mechanics, vibrations and acoustics, and applied physics. The Thermal Engineering Laboratory contains apparatus for experimentation with heat exchangers designed for single- and two-phase fluid systems. Several test loops, such as a 1,000 psi steam-water loop, have been used for combined heat transfer and fluid mechanics programs. Instruments for the measurement of thermophysical properties of materials are available at Dynatech to conduct measurements of thermal conductivity, specific heat, and linear expansion over a broad temperature range. The Applied Physics Group is equipped with apparatus for the simulation of zero-gravity environments and the operation of electrical equipment composed of superconducting elements. In the area of vibrations and acoustics, Dynatech is currently equipped to make tests both in the laboratory and in the field with a wide range of acoustic and vibration recording and analysis equipment.

In the technical library at Dynatech, general and specialized holdings of books, periodicals, and reports from government and industry, are maintained. Dynatech maintains library privileges at the libraries of the various universities in the Cambridge area.

AIR FORCE PRIME CONTRACTS

AF 33(615)-8099	
Aeronautical Systems Division Air Force Systems Command Wright-Patterson Air Force Base, Ohio	High-Temperature Thermal Conductivity Measurements Instrument
AF 33(616)-8295, AF 33(657)-9095 AF 33(657)-10797, AF 33 (657)-10785	
Aeronautical Systems Division Air Force Systems Command Wright-Patterson Air Force Base, Ohio	Chemical Process for O_2 - N_2 Separation from Air
AF 33-(615)-67-C-1587	
Aerospace Medical Research Laboratories Wright-Patterson Air Force Base, Ohio	Study of CO_2 Freeze-Out and Design of a CO_2-H_2O Control System
AF 33(657)-9423	
Aeronautical Systems Division Air Force System Command Wright-Patterson Air Force Base, Ohio	Oxygen-Breathing Converter in a Weightless Environment Utilizing Dielectric Forces for Fluid Positioning
AF 49(638)-1096	
Air Force Office of Scientific Research Washington, D. C.	Investigation of Structural Fatigue
AF 33(657)-10784	
Aeronautical Systems Division Air Force Systems Command Wright-Patterson Air Force Base, Ohio	Development Work on Orientation of Liquid Hydrogen and Cesium
AF 33(657)-11062, AF 33(615)-1574	
Aeronautical Systems Division Air Force Systems Division Wright-Patterson Air Force Base, Ohio	Feasibility Study of Application of Superconductor Techniques
AF 33(657)-126	
Aeronautical Systems Division Air Force Systems Command Wright-Patterson Air Force Base, Ohio	High Temperature Heaters for Thermal Conductance Apparatus

AF 33 (615)-2687	
U. S. Air Force Aero-Propulsion Laboratory Wright-Patterson Air Force Base, Ohio	Development of Prototype Super-conducting Generator
AF 33(615)-307	
U. S. Air Force Aero-Propulsion Laboratory Wright-Patterson Air Force Base, Ohio	Bomb Rate Tester
AF 33(615)-2950	
6570th Aerospace Medical Research Labs Wright-Patterson Air Force Base, Ohio	Investigation of a Water and Carbon Dioxide Precipitation System Utilizing Thermal Radiation Prinicples
AF 33(615)-3580	
Headquarters Systems Engineering Group Wright-Patterson Air Force Base, Ohio	Research Program for Dielectro-phoretic Oxygen Converter
AF 33(615)-67-C-1151	
Headquarters Systems Engineering Group Wright-Patterson Air Force Base, Ohio	Experimental Evaluation of 50 KW Superconducting Generator

ARMY PRIME CONTRACTS

DA 44-177-TC-601	
Transportation Research and Engineering Command Fort Eustis, Virginia	Vapor Cycle Plants for Low Horse-Power Mobile Applications
DA-19-016 ENG-7229	
Corps of Engineers, New England Division Waltham, Massachusetts	Dynamic Tester and Evaluation of Soil Freezing Cabinet
DA 19-016-ENG-7704	
Corps of Engineers, New England Division Waltham, Massachusetts	Design of Soil Freezing and Measurement Instrument
DA 19-020 AMC-0139 (T)	
U. S. Army Automotive Tank Center Center Line, Michigan	Feasibility Study on Magnetic Suspension of Tracked Vehicles

DA 118-035 AMC-5 (A)

U. S. Army Edgewood Arsenal
Edgewood, Maryland

Design Layout and Equipment Specification for Pilot Paper Making Machine Facility

DA 44-177 AMC-288 (T)

U. S. Army Transportation Research Command
Fort Eustis, Virginia

Study of Superconducting Electrical Machinery for Aircraft Applications

DA 22-079-ENG-848

U. S. Waterways Experiment Station
U. S. Army Corps of Engineers
Vicksburg, Mississippi

Development of Urea-Based Polymer System for Dust Control in the Theater of Operations

DAAG 23-67-C-007

U. S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire

TCFG-F5 Instrument

NASA PRIME CONTRACTS

NAS 5-3021

Goddard Space Flight Center
Greenbelt, Maryland

Thermal Analysis of the Naval Research Laboratory Telescope Package of the OSO S-17 Satellite

NASw-600
NASw-881

NASA Headquarters
400 Maryland Avenue, S. W.
Washington 25, D. C.

Analysis of Thin-Walled Torus Membranes

NASw-955

NASA Headquarters
400 Maryland Avenue, S. W
Washington 25, D. C.

Analytical Study of Wall Bending Thickness

L-35, 972

Langley Research Center
Hampton, Virginia

Thermal Property Measurements

L-5460 Langley Research Center Langley Station Hampton, Virginia	QTA Specific Heat Measurements
S-60784 Goddard Space Flight Center Greenbelt, Maryland	Specific Heat Measurement Services
S-73788 Goddard Space Flight Center Greenbelt, Maryland	Thermal Conductivity Measurements
NAS 5-7324 Goddard Space Flight Center Greenbelt, Maryland	Thermal Conductivity Instrument
NAS 9-3834 Manned Spacecraft Center Houston, Texas	Development of Specular-Diffuse View Factor Computer Program
NAS 2-3220 Ames Research Center Moffet Field, California	Thermophysical Properties Instruments
NAS 8-2-0553 National Aeronautics and Space Administration Marshall Space Flight Center Huntsville, Alabama	EHD Fluid Control System
NASw-1372 National Aeronautics and Space Administration Headquarters Washington, D. C.	Study of an Electrohydrodynamic Vapor Absorption Refrigerator for Weightless Environments
NAS 1-6586 National Aeronautics and Space Administration Langley Research Center Hampton, Virginia	Study of Dynamic Buckling of Shallow Spherical Shells in Accordance with NASA RFP L-6752

NAS 1-6632

National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

Development of an Analysis for the Free Vibration of Prestressed Toroidal Shells with Varying Thickness and Various Support Conditions

NAS 7-530

National Aeronautics and Space Administration
NASA Pasadena Office
4800 Oak Grove Drive
Pasadena, California

Study and Design of High Performance Fuel Cells

NAVY PRIME CONTRACTS

N 60921

Naval Ordnance Laboratory
White Oak, Silver Springs, Maryland

Aftercooler Design, NOL Heat Exchanger Research Channel

N 161-25297

Naval Engineering Experimental Station
Annapolis, Maryland

Technical Services in Connection with Noise and Vibration Investigation of Equipment

N 161-26137

Marine Engineering Laboratories
Annapolis, Maryland

Study of Cryogenic Electrical Machinery for Main Propulsion

NObs-84282

Bureau of Ships, Washington

Gas Turbine Duct Design

NObs-69223 (X)

Portsmouth Naval Shipyard
Kittery, Maine

Ships Motion Studies

NOw 66-0405-C

Naval Weapons Support Agency
Bureau of Naval Weapons
Washington, D. C.

Preliminary Experimental Survey of Temperature Activated Galvanic Cells for Self-Powered Aircraft Fire Detection System

NOLWO-48849 S

Naval Ordnance Laboratory
Silver Springs, Maryland

Specific Heat Measurements of Armco 17-4 Ph Stainless Steel

NObs-94456

U. S. Navy
Naval Ships Systems Command
Washington, D. C.

Modify Navy Engine to Multi-Fuel Capability

60530/4513Y41599-67

U. S. Naval Ordnance Test Station
China Lake, California

TCCGM Upper and Bottom Heaters

NOO-102-67C-2554

Portsmouth Naval Shipyard
Kittery, Maine

Submarine Hull Heat Exchanger Study on USS Dolphin

NOO-102-67C-2565

Portsmouth Naval Shipyard
Kittery, Maine

Design Evaluation of Cooling Jackets for AGSS-555 Diesel Exhaust Engine

ATOMIC ENERGY COMMISSION PRIME CONTRACTS

AT (30-1)-2907

New York Operations Office
New York, New York

Flow Balancing in Boiling Water Reactors

AT (30-1)-3304

New York Operations Office
New York, New York

Experimental Study of Forced Convection Burnout in Two-Phase Flow

SMALL BUSINESS ADMINISTRATION CONTRACTS

SBA-1097-EA

Small Business Administration
Washington 25, D. C.

SBA Feasibility Study for Polaris Program

DEPARTMENT OF THE INTERIOR PRIME CONTRACTS

14-01-0001-331 14-01-0001-382 Department of the Interior Office of Saline Water Washington 25, D. C.	Engineering Study of the Use of Electric Fields to Improve Performance of Fluid-Fluid Heat Exchangers in Water Desalinization Systems
14-01-0001-505 Department of the Interior Office of Saline Water Washington 25, D. C.	Boiler and Condenser Performance Improvements
14-01-0001-681 Department of the Interior Office of Saline Water Washington 25, D. C.	Process Evaluation: Size Scale-up Correlations for Current Process Components
14-01-0001-1462 Department of the Interior Office of Saline Water Washington 25, D. C.	Evaluation of State-of-the-Art of Pumping for Reverse Osmosis Plants
14-01-0001-1191 Department of the Interior Office of Coal Research Washington, D. C.	Evaluation of Existing and Unconventional Means for Pumping and Energy Recovery in a Reverse Osmosis Desalination Plant