

PROJECT ADMINISTRATION DATA SHEET

☒ ORIGINAL ☐ REVISION NO. _____Project No. E-16-660 (R6209-OA0) GTRC/~~XXX~~ DATE 9 / 24 / 86Project Director: Dr's. B.T. Zinn/J.I. Jagoda/E.A. Powell School/~~XXX~~ AESponsor: U.S. Department of CommerceNational Bureau of StandardsType Agreement: Grant No. 60NANB6D0650Award Period: From 9/12/86 To 1/11/87 (Performance) 1/11/87 (Reports)Sponsor Amount: 4/30/87 This Change 4-30-87 Total to DateEstimated: \$ 50,000 \$ 50,000Funded: \$ 50,000 \$ 50,000Cost Sharing Amount: \$ 2,416 Cost Sharing No: E-16-391 (F6209-OA0)Title: Soot formation and Corrosion Hazards in Fires

ADMINISTRATIVE DATA

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1) Sponsor Technical Contact:

2) Sponsor Admin/Contractual Matters:

Mr. Richard Bukowski Virgella E. RandolphNational Bureau of Standards National Bureau of StandardsCenter For Fire Research Grant Administration, Procurement SectionBldg. 224, RM. A247 Gaithersburg, Maryland 20899Gaithersburg, Maryland 20899301/921-3845Defense Priority Rating: N/A Military Security Classification: N/A(or) Company/Industrial Proprietary: N/A

RESTRICTIONS

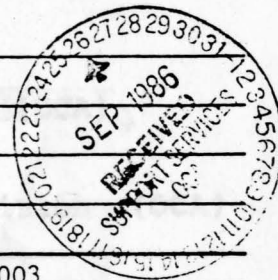
See Attached N/A Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval - Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of \$500 or 125% of approved proposal budget category.

Equipment: Title vests with Grantee.

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Soot Formation, Smoke and Corrosion Hazards in Fires

Quarterly Report

September - December 1986

Prepared by

J. I. Jagoda, E. A. Powell and B. T. Zinn

School of Aerospace Engineering

Georgia Institute of Technology

For

National Bureau of Standards

Grant No. 60NANB6D0650

NBS Scientific Officer

Richard Burkowski

Center for Fire Research, NBS

December 31, 1986

Task I

During the first four months a modified opposed flow diffusion flame burner was designed. An annular nitrogen sheet was added concentric with the reactant flows, as proposed. In addition, the burner assembly will be surrounded with an airtight enclosure which will permit the flame to be operated under a partial vacuum (Fig. 1). This will spread out the reaction zone and, thus, improve the spacial resolution of the measurements. Although this was not proposed, we feel that for a manageable amount of extra effort and cost the reduced pressure capability would result in considerable experimental advantages. In order to be able to carry out the absorption measurements at a number of angles, required for the tomographic deconvolution, the burner is being made rotatable while the vacuum shield which contains the optical windows remains stationary. A specially designed sealing system was incorporated into the base of the vacuum chamber to facilitate the differential rotation of the burner. In addition, a nitrogen purge system was included into the design which will keep the windows free from soot deposits. Finally, the burner will be water cooled to permit equilibrium to be attained rapidly. All designs were developed in close coordination with the AE shop, materials are being ordered and fabrication is scheduled to begin early in the New Year.

While the new burner was being designed, the tomography required to deconvolute the absorption measurements was coded into the data reduction software. The program was tested by assuming a typical expected soot distribution, calculating the resulting absorption intensities and reconstructing the original distribution. Except for a smoothing of sharp

and worn interior insulation material. Finally, several needed improvements

edges the reconstructed distribution was very close to that originally assumed.

Some preliminary tests were also carried out using the old burner. Temperature profiles across the flame were measured using a fine Pt-Pt,Rh thermocouple. Comparisons of temperature profiles with and without the wire, (which will be used to change the ion concentration in the flame) indicated that the wire causes a reduction in flame temperature of maximum 6% in its immediate vicinity. Preliminary absorption experiments carried out in the flame on the old burner indicated that the wire (without potential) induces an increase in soot loading in its wake. It is, at this point, not clear whether this sooting increase is caused by fluid mechanics effects or by catalytic effects caused by the wire. Further tests on the old burner will continue during the next reporting period, while the new burner is being constructed.

Task II

The combustion products test chamber (CPTC) and measurement systems have been inactive for approximately two years prior to the initiation of this project. Therefore, these facilities were refurbished during the first four months of this project. This included a thorough cleaning of the combustion products test chamber and the sampling section where the light scattering measurements are made and the particulate samples are withdrawn. Also all optical components were cleaned and realigned. The argon-ion and helium-neon lasers were tested and checked out by the AE Instrument Laboratory personnel. Also, needed repairs were made, which included replacing broken door latches and worn interior insulation material. Finally, several needed improvements

were identified which require additional design work. These improvements will be accomplished during the next quarter.

Task III

The sampling section and stack were removed and disassembled so that they can be modified to accommodate the new corrosion test section. This will be fabricated from the upper section of the existing stack. Measurements were made which indicated the need for some minor modifications to the designs presented in the proposal. The shop drawings were prepared, and the needed materials were ordered. The corrosion test section will be fabricated and installed in the combustion products test chamber next quarter.



Figure 1. Schematic of partially evacuated counter flow diffusion flame burner.

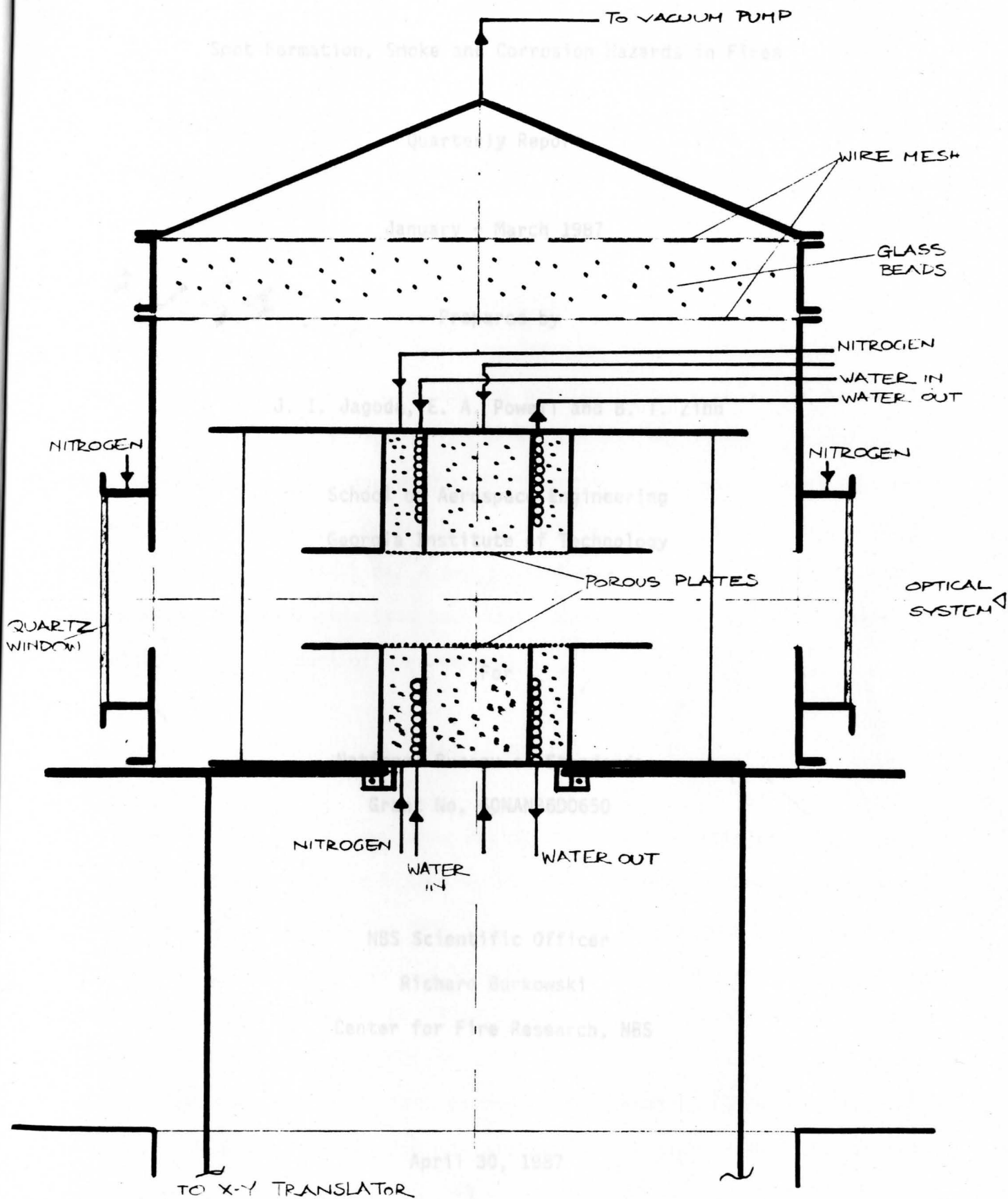


Figure 1. Schematic of partially evacuated counter flow diffusion flame burner.

Soot Formation, Smoke and Corrosion Hazards in Fires

Quarterly Report

January - March 1987

Prepared by

J. I. Jagoda, E. A. Powell and B. T. Zinn

School of Aerospace Engineering

Georgia Institute of Technology

For

National Bureau of Standards

Grant No. 60NANB6D0650

NBS Scientific Officer

Richard Burkowski

Center for Fire Research, NBS

April 30, 1987

Task I

During the last reporting period the emphasis of this project has been shifted, at the sponsors' request towards Task II. Nevertheless some progress has been made on Task I. The construction of the new burner with reduced pressure capabilities was postponed to permit the AE shop to concentrate on manufacturing the test section required for Task II. Tests were, however, carried out using the old burner. The increase in sooting observed in the wake of the uncharged wire and reported previously can now be attributed, in part, to the catalytic effect of the wire. This was determined by coating the wire and repeating the measurements. Furthermore, it was established that the change in the flow field caused by the wire has some effect on the sooting rate downstream. In addition, a new student was brought up to speed on the experimental and data reduction techniques as well as the analytical model to be utilized in this part of the research.

Tasks II and III

Most of the work accomplished during the second quarter of this project was concerned with both Task II and Task III. Therefore, the discussion of these two tasks are combined into one section. During January and February the work concentrated on Task III as stated in the original proposal. After a meeting with the sponsors at Georgia Tech in early March, the principal investigators for this project were informed that the sponsors desired a shift of emphasis to Task II for the next several months. Therefore, the work originally planned for Task III was postponed, and efforts were focused on preparation of the Combustion Products Test Chamber (CPTC), the combustion

products sampling system, and the in situ optical particulate measuring system for testing new samples as soon as possible.

Most of this work centered on modifications of the upper stack section which connects the CPTC sampling section to a larger diameter refractory pipe leading to the roof. The CPTC and sampling section are shown in Figure 1, while the original upper stack is shown in Figure 2. The modifications of the upper stack were necessary in order to accommodate the Corrosion Test Section (CTS) needed for Task III and another test section required by a concurrent project funded by the Defense Nuclear Agency (DNA). The CTS and DNA sections need to be easily interchangeable, thus the upper stack was cut into three sections, each of which was fitted with flanges for bolting the sections together. These three sections are shown in Figure 3. The lowest section is a fixed six-inch long spacer of 8 5/8-inch diameter pipe needed to raise the CTS or DNA sections above the 90°-scattering optical systems which were bracketed to the lower flange of the original upper stack. Otherwise the 90°-scattering systems would have to be removed and replaced every time the CTS or DNA section was installed, requiring tedious realignment. The next section is a removable eleven-inch long pipe (8 5/8 inch O. D.) which will eventually be used to make the Corrosion Test Section. The upper section provides an improved connection to the 11 1/4-inch diameter refractory pipe leading to the roof. This was accomplished by attaching a 12-inch O.D. collar (11.5 inch I. D.) concentric to the original pipe just above the sampling exhaust line. This allows the refractory pipe to fit between the collar and the 8 5/8-inch diameter pipe, thus providing a much better seal. The gap between the collar and the refractory pipe is only about 1/8 inch wide and is

easily sealed with duct tape. The shop drawing of the transition section is shown in Figure 4.

In order to facilitate interchanging the CTS and DNA sections, the upper transition section, which weighs 51 lb, must be supported. A system of pulleys and counterweights was installed (Fig. 3) which keeps the transition section pulled up against the refractory pipe during removal or installation of the CTS or DNA section, but allows it to be easily lowered for bolting the sections together. This system will allow interchanging the two test sections by one person without disturbing the alignment of the laser systems.

Two other items required for Task II testing were completed during the quarter. The data reduction hardware and software, which had not been used for two years, was tested using data from a previously run test. The hardware includes a Hewlett-Packard 21005 computer with removable disk, a Tektronix Model 4012 graphics terminal, a Centrix 703 printer, a digital plotter, and a paper tape punch. Three programs were tested: (1) a data selection program which displays the raw data from the disk and allows selection of data points for further reduction, (2) a program to calculate particle characteristics (mean size, refractive index, and volume fraction) for the selected data, and (3) a program to calculate the optical densities for the selected data. All of these programs successfully reproduced data from the previous test using the above hardware. Also, arrangements were made with personnel at the Georgia Tech Research Institute (GTRI) for conducting the chemical analysis of the smoke particulates under Task II-B. These GTRI personnel are analytical chemists currently involved in air pollution studies using GC/MS

techniques, and, thus, very qualified to aid in the chemical analysis work on this project.

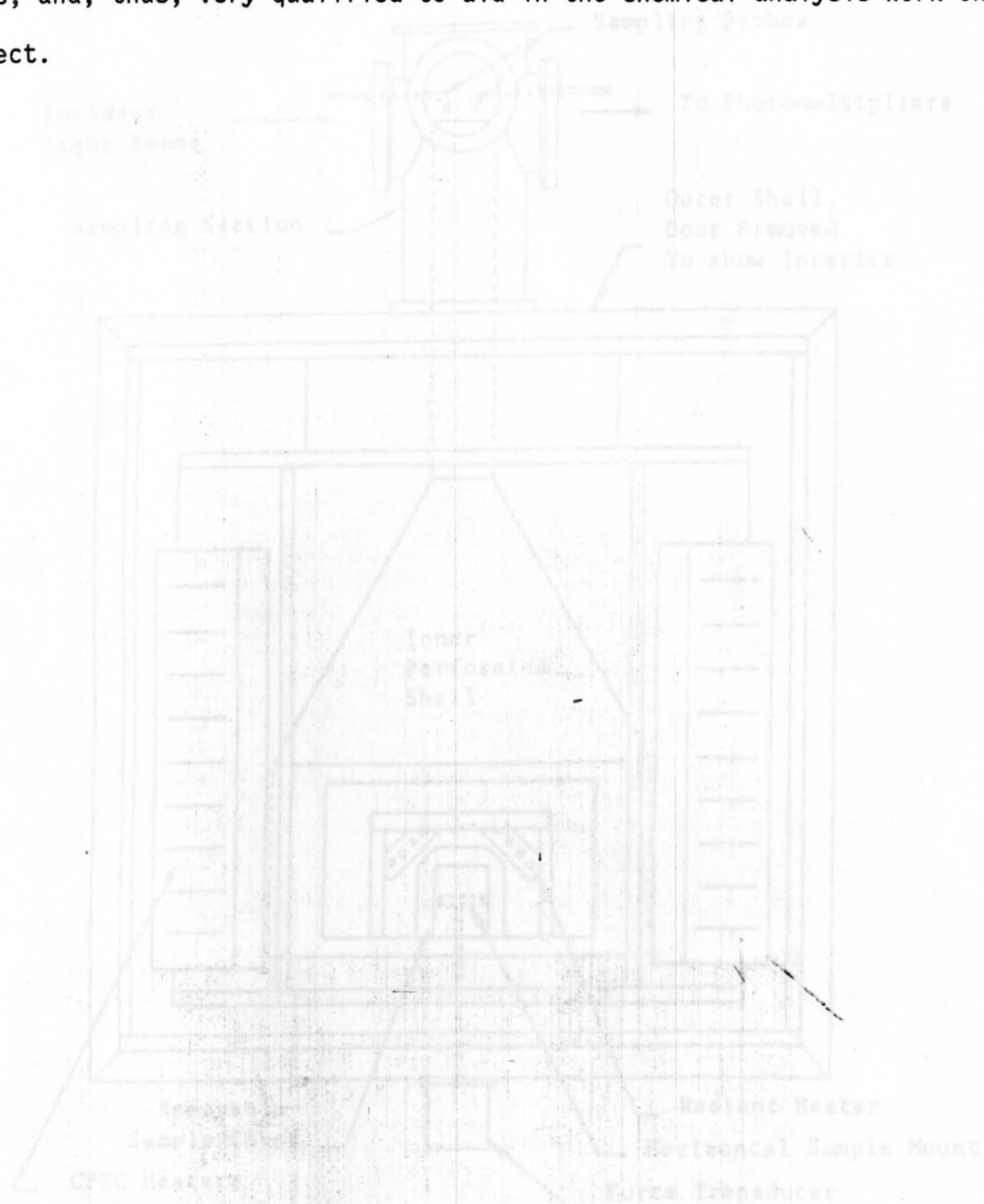


Figure 1. Combustion Products Test Chamber.

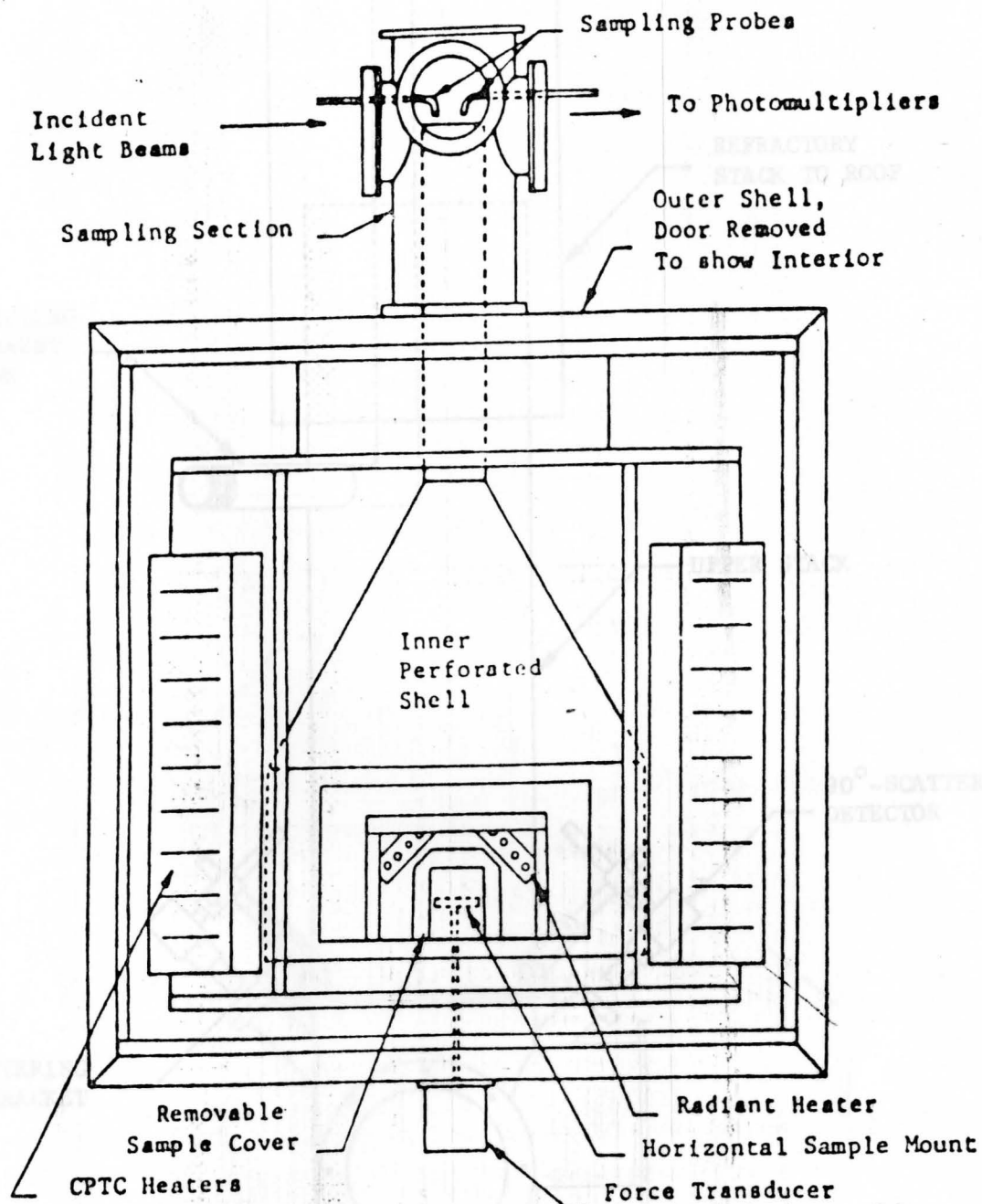


Figure 1. Combustion Products Test Chamber.

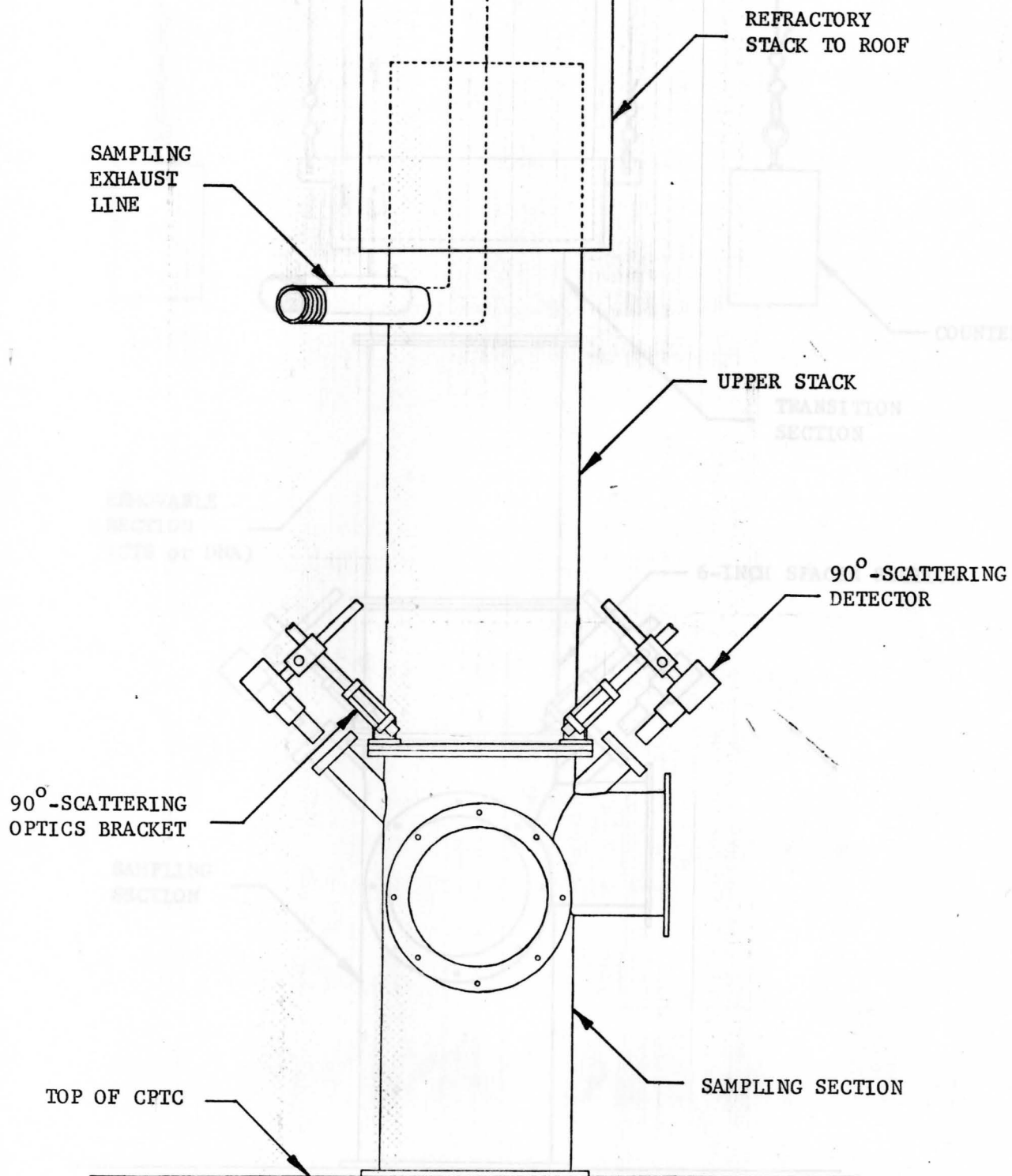


Figure 2. Original CPTC Upper Stack Assembly.

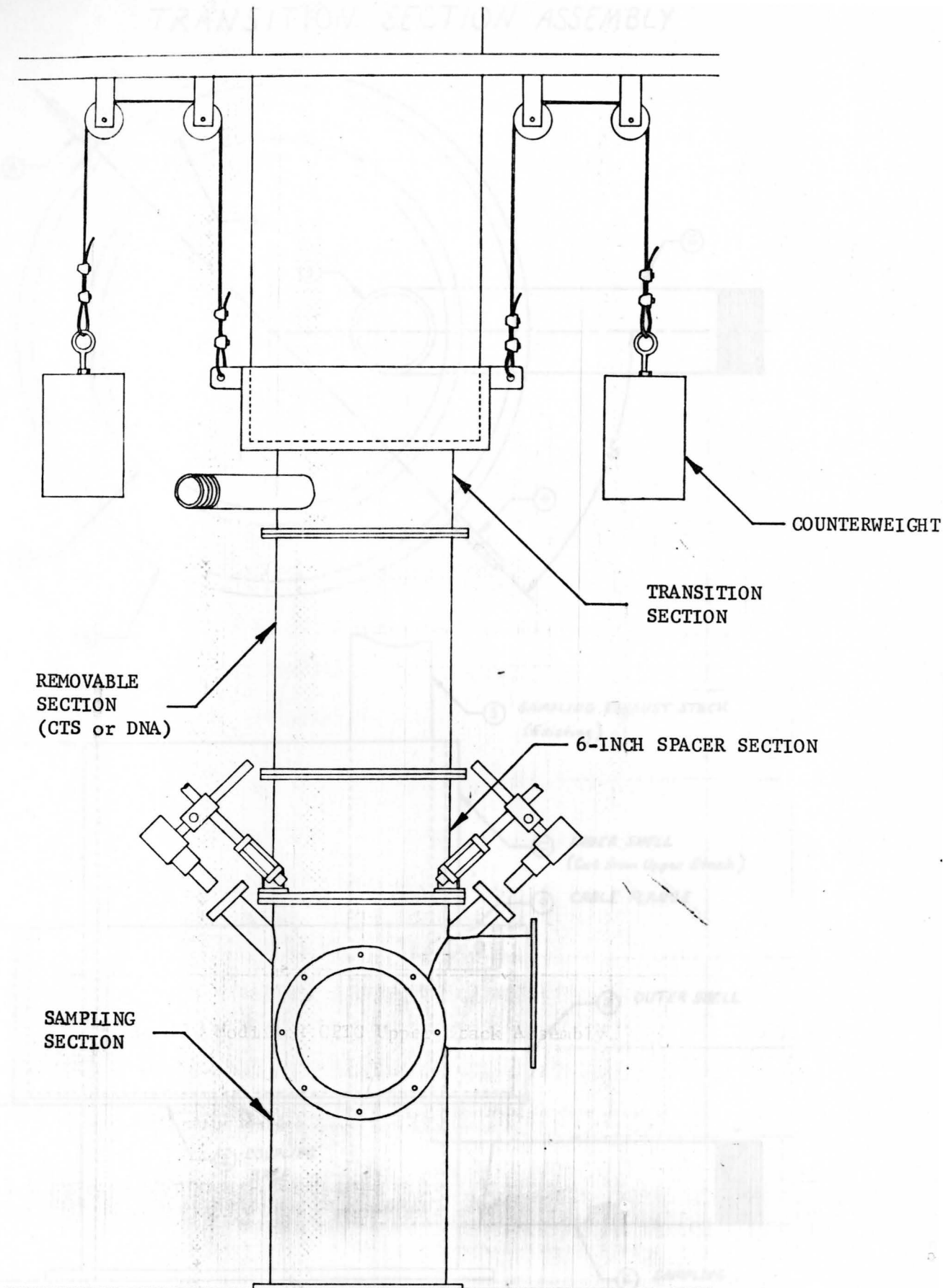


Figure 3. Modified CPTC Upper Stack Assembly.

TRANSITION SECTION ASSEMBLY

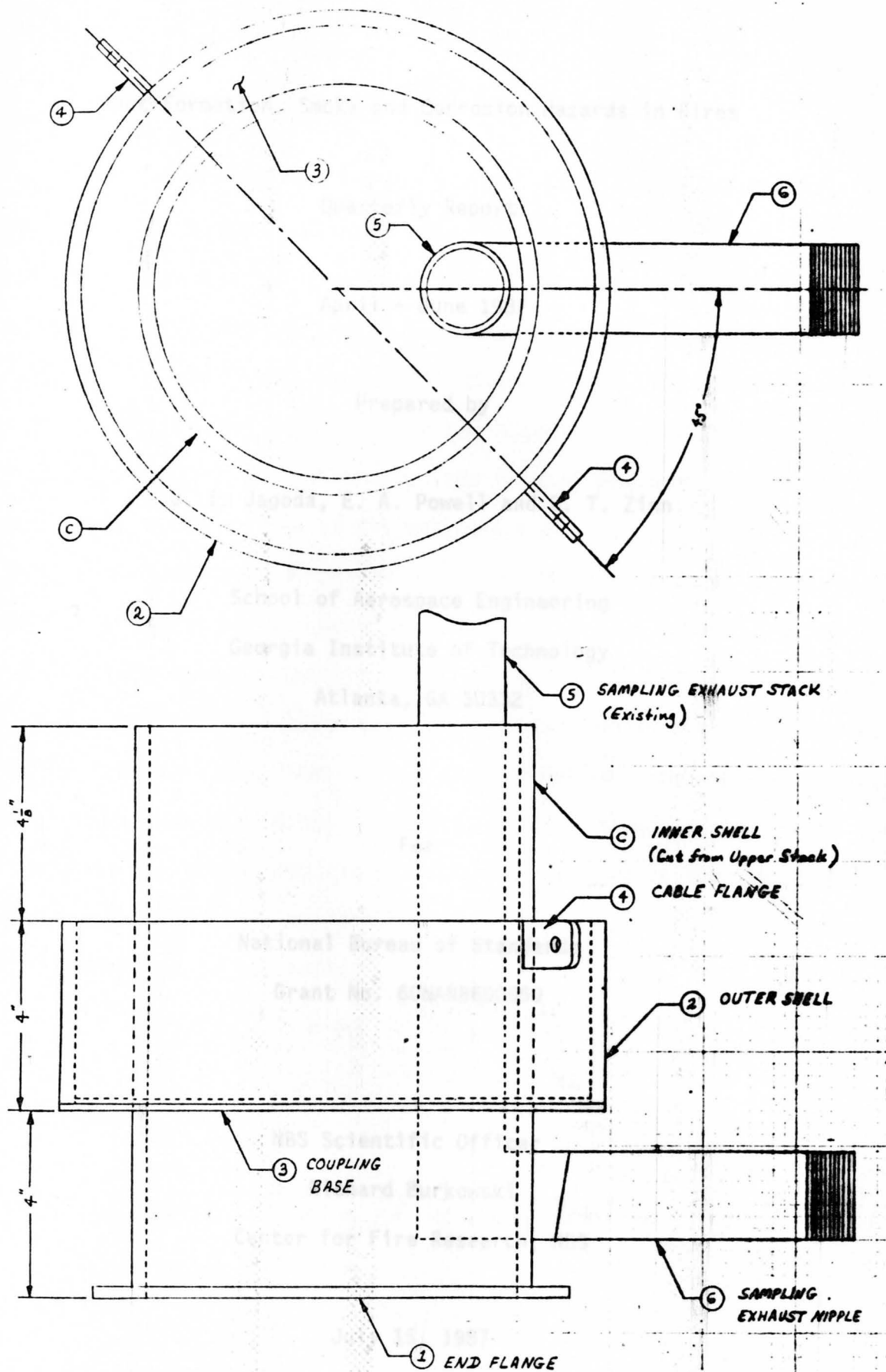


Figure 4. Transition Section.

Soot Formation, Smoke and Corrosion Hazards in Fires

Quarterly Report

April - June 1987

Prepared by

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Atlanta, GA 30332

For

National Bureau of Standards

Grant No. 60NANB6D0650

NBS Scientific Officer

Richard Burkowski

Center for Fire Research, NBS

July 15, 1987

Task I

As discussed during the sponsors last visit to Georgia Tech, the emphasis of this project was shifted, for the time being, to Task II. Nevertheless, progress has continued on Task I. The building of the new burner was scheduled such that it did not interfere with the construction of the test sections for Tasks II and III. None the less, the machining of the burner parts for the new test assembly has essentially been completed. What remains to be done is the building of the reduced pressure chamber and the assembly and bringing on line of the entire system.

During this construction period work has also continued on the existing atmospheric pressure burner. Both a cylindrical and a spherical probe for varying the ion concentrations in the flame have been made. The associated circuitry was assembled and the system fully tested. Measurements carried out with those probes in the flame have indicated that the theories which were proposed to be used to predict the effect of the charged probe on the ion concentrations are indeed applicable to the flame plasma in the test region.

The new student is now up to speed on all existing software and hardware and is fully engaged in the work.

Task II

During the third quarter of this project, work continued under Task II with the preparation of the Combustion Products Test Chamber (CPTC), the combustion products sampling system, and the in situ optical particulate measuring system for testing the new samples. Near the end of the reporting period, two specimens of the composite material were received from the Naval Ship Research and Development Center in Bethesda, Maryland. This material is a woven carbon fiber composite with a bismaleimide binder. A sample of this material was tested to obtain pyrolysis products for chemical analysis.

In preparing the CPTC for testing, the inner shell door assembly was found to be in poor condition; the insulation material was deteriorating and was structurally unstable. Thus a new improved inner shell door assembly was designed, and the shop drawings were completed during the quarter. This door assembly is to be fabricated from 1/8 " thick stainless steel instead of the structurally weak insulation material used previously.

In preparing the optical systems and their data acquisition systems for resumption of testing, several improvements were made. The laser system was modified to make alignment adjustments easier and more accurate. Fine tuning of the argon-ion laser increased its power from 9 mw to 22 mw. The plane of polarization of the incident laser beam was aligned at an angle of 45° to the vertical axis of the CPTC stack as required by the 90° -scattering optics system. In this procedure it was discovered that the thick quartz incident beam window caused a 5° rotation and an unacceptable depolarization of the incident laser beam. Thus the quartz window was replaced by a thin optical glass window. Fine alignment adjustments were made on the forward scattering receiving optics and detectors so that both 5° and 15° detectors receive

scattered light from the same optical sampling volume in the smoke plume. A new rack and new input and output cables for the DC amplifiers that process the photomultiplier signals were obtained and installed.

The first test of the composite material was conducted a few days after the specimens were received. A 1/8 " thick slab of the material was cut (3" square) and exposed in the CPTC to a radiant flux of 5 W/cm^2 without pilot flame in room temperature ventilation air (15 SCFM ventilation flow rate). The horizontal sample orientation was used in this test. Sampling was accomplished using two glass fiber filters in series with a sampling rate of 1 SCFM. The laser systems were operated, but the amplifiers and computer system were temporarily unavailable, so the 5° scattering and transmitted blue light channels were monitored using a chart recorder. The test required sixty minutes with a four minute heating period before any smoke was visible. Peak light scattering and optical density occurred at 10 minutes with a slow gradual decline in smoke production thereafter. The smoke appeared white like cigarette smoke and seemed to be issuing from cracks in the surface. Nearly 15% of the original sample mass was evolved as gases and particulates during this test. About 18.9 mg of a yellow-brown tarry liquid was collected on the first filter, while only 0.4 mg was collected on the second filter. Approximately 7% of the mass lost during this test appeared as particulates. These samples were then delivered to the Georgia Tech Research Institute personnel for GC/MS analysis.

Task III

Although the Task II work was emphasized during the third quarter of this project, work continued on Task III at a reduced level. The test section for the Defense Nuclear Agency (DNA) project was completed and installed above the CPTC. This allowed the existing 11-inch pipe section to be removed and taken to the machine shop for making the Corrosion Test Section (CTS). The remaining design work and drawings were completed for the CTS shell assembly, viewport flange and viewport cover. Work has begun on fabrication of the CTS; holes have been cut in the vertical 11-inch pipe for the 6-inch and 4-inch horizontal pipe sections, and the flanges have been made.

July 1969

US Scientific Officer: Dr. Richard Burkowski

Prepared for

Center for Fire Research
National Bureau of Standards
Gaithersburg, Maryland

Under Grant No. 60NANB600650

SOOT FORMATION, SMOKE AND CORROSION IN FIRES

Final Technical Report

September 12, 1986 - September 11, 1987

Prepared by

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July 1989

NBS Scientific Officer: Dr. Richard Burkowski

Prepared for

Center for Fire Research
National Bureau of Standards
Gaithersburg, Maryland

Under Grant No. 60NANB6D0650

INTRODUCTION

This report describes the results obtained under NBS Grant No. 60NANB6D0605 during the period September 12, 1986 to September 11, 1987. Due to circumstances beyond the control of the principal investigators, the source of funds was lost after the first year. Since this project was originally proposed as a three year effort, only partial results are reported here.

The objectives of this research project were to determine the importance of ions in the soot formation process and to obtain information on the smoke production and corrosive behavior of various commonly used materials in fire situations. This study was divided into three major tasks to be carried out simultaneously.

In Task I the effect of flame ions on the nucleation and growth processes in diffusion flames was investigated. Only partial results were obtained during the grant period (Ref. 1), however the work continued under institutional funding.

In Task II the Combustion Products Test Chamber (CPTC) at Georgia Tech was used to obtain data on the physical and chemical characteristics of smoke particulates emitted by a composite material provided by the sponsor. Only a limited number of tests were completed in the abbreviated grant period, and the results are reported herein.

In Task III the objective was to determine the short and long term corrosive effects of the exhaust gases and particulates generated under Task II on various structural and electrical conductor materials. However this task required the development of additional test facilities. The design and fabrication of these facilities was nearly complete by the end of the first year, but because of the loss of funding no testing was conducted. Since no results from Task III are available, no further discussion of this task will appear in the report. Descriptions of the corrosion test facilities are given in the three quarterly reports submitted under this grant and will not be repeated herein.

TASK I: EFFECT OF IONS ON SOOT FORMATION PROCESSES

In Task I the effect of flame ions on the nucleation and growth processes in diffusion flames was investigated. The original objective was to carry out these tests on an opposed flow diffusion flame at sub-atmospheric pressure. The reduced pressure spreads out the reaction zone resulting in better spatial resolution of the optical measurements. An opposed flow diffusion flame burner inside an enclosure was designed, and construction was completed. The enclosure was provided with windows for optical access, which permits the flame to be established under conditions of reduced pressure.

Preliminary tests have been carried out on an existing counter flow diffusion flame burner at atmospheric pressure. In these tests the ion concentration in the flame was varied using a charged probe. This technique has the advantage of permitting a change in local ion concentration without inducing a significant electric field in the flame. Such a field has in the past been found to manipulate the charged soot particles causing a significant change in the soot formation process which would interfere with the measurements. Laser light absorption measurements were used to characterize the soot volume loadings, in situ, in the flame (Ref. 1).

In the atmospheric pressure tests, theoretical results were confirmed regarding the change in ion concentration induced by the probe as a function of applied voltage and ion mobility. Temperature measurements were carried out using fine, coated thermocouples and preliminary absorption measurements have been made. The effect of introducing the probe into the flame upon the soot formation process has been quantified. This effect was found to be due mostly to a catalytic effect of the probe material.

TASK II: SMOKE CHARACTERIZATION OF A COMPOSITE MATERIAL

The combustion products test chamber and measurement systems had been inactive for approximately two years prior to the initiation of this work. Therefore, these facilities were refurbished and improved during the first six months of this project. Additional modifications of the upper stack section were also accomplished during this period. These were necessary in order to

accommodate the corrosion test section of Task III and another test section required by another concurrent project. These modifications required considerable new design and shop work. A system of pulleys and counterweights was also installed in order to support the heavy upper stack section when the two test sections are being interchanged.

During the third quarter of the project two specimens of a composite material were received from the sponsoring agency. This material is a woven carbon fiber composite with a bismaleimide binder. A sample of this material was tested in the CPTC to obtain pyrolysis products for chemical analysis. A thin slab of the material (7.6 x 7.6 x 0.32 cm) was exposed to a radiant flux of 5 W/cm^2 without a pilot flame in room temperature ventilation air (425 liters/min flow rate). The horizontal sample orientation was used in this test. Sampling was accomplished using two glass fiber filters in series with a sampling rate of 28 liters/min. The test required sixty minutes with a four minute heating period before any smoke was visible. Peak light scattering and optical density occurred at 10 minutes with a slow decline in smoke production thereafter. The smoke appeared white like cigarette smoke and seemed to be issuing from cracks in the surface. Nearly 15% of the original sample mass was evolved as gases and particulates during this test. About 18.9 mg of a yellow-brown tarry liquid was collected on the first filter, while only 0.4 mg was collected on the second filter. Approximately 7% of the mass lost during this test appeared as particulates.

The collected samples were subjected to analysis by gas chromatography and mass spectroscopy (GC/MS). The results of the chemical analysis of the particulates for the nonflaming test under 5 W/cm^2 radiant flux are presented in Table I. In spite of considerable efforts four peaks could not be identified. The presence of large quantities of methylphenyl-acetamide suggests that the binder actually consists of a methylphenyl-maleimide. In addition it should be noted that the benzopyran is a particularly toxic material. Most of these compounds are polycyclic aromatic hydrocarbons (PAH) with molecular weights ranging from 280 to 360. Many of the remaining compounds are nitrogen containing substances, both heterocyclic and acyclic. Most of these compounds possess varying degrees of toxicity or carcinogenicity.

Additional tests were carried out under conditions of 5 W/cm^2 and 7.5 W/cm^2 radiant flux. For a flux of 5 W/cm^2 the tests were carried out under non-flaming conditions while under a flux of 7.5 W/cm^2 the sample auto-ignited without the presence of a pilot flame. For both conditions a full series of tests were carried out which included the determination of the fraction of the sample mass loss which was converted to particulates and that which remained as char. The size distribution of the particulates was measured using a cascade impactor (D_p) as well as by optical scattering technique (D_{32}). The optical densities of the particle laden exhaust flows were monitored during the tests.

Results of the nonflaming tests under 5 W/cm^2 radiant flux are presented in Figures 1 through 3. The size distribution obtained with the cascade impactor is shown in Figure 1. This distribution departs from a log normal curve for sizes above one micron. A best fit log normal distribution using the four data points yields a mass median diameter (D_{mmd}) of 0.44 micrometer while extrapolating the first two points yields a value of D_{mmd} of 0.37 micrometer.

Figure 2 shows the volume-surface mean diameter (D_{32}) as obtained from the in situ optical measurements. The scattered light intensity at 5° is also shown to give an indication of the variation of smoke concentration during the test. Smoke was first detected 4 minutes after initiation of exposure to the radiant source, and the first size measurements were obtained two minutes later. Values of D_{32} rose from about $0.65 \mu\text{m}$ to a peak of nearly $1.1 \mu\text{m}$ at 12 minutes, and then decreased gradually to $0.3 \mu\text{m}$ at 45 minutes. The peak in 5° -scattering intensity occurred just prior to the D_{32} peak at 11 minutes. The optical densities in blue ($\lambda = 488 \text{ nm}$) and red ($\lambda = 633 \text{ nm}$) light for this condition are shown in Figure 3. The optical densities were low throughout this test, with a maximum OD_B of about 0.27 m^{-1} occurring near 11 minutes (coinciding with peak scattering intensity). This corresponds to a minimum transmission of 93% for the 11.4 cm optical path length used in this experiment. The mean particle diameter at peak optical density was about $1.05 \mu\text{m}$.

The mass collected as particulates as a fraction of the total mass loss of the sample was found to be 0.06. The mass remaining in the test chamber as

char at the end of the experiment expressed as a fraction of the original sample mass was found to be 0.85.

Results for spontaneously flaming tests are shown in Figures 4 and 5. In these tests, conducted at 7.5 W/cm^2 , the sample began to evolve smoke much more rapidly than in the tests at 5 W/cm^2 . Products of nonflaming combustion (pyrolysis) were observed until ignition occurred at 2.8 minutes into the test. During the time of vigorous flaming combustion, which lasted about three minutes, yellow-orange flames with much soot were observed, reaching a height of about 15 cm. Numerous large sooty agglomerates, many forming chains and strings, were seen floating in the chamber, which was reminiscent of observations made during the burning of polystyrene.

Because of the nature of the soot particles evolved during the flaming tests, their size distribution could not be measured using the cascade impactor. The soot particles were found not to stick to the impactor's plates but, instead, distributed themselves all over the inside of the instrument.

Figure 4 shows the time evolution of the mean particle diameter D_{32} and 5° -scattering intensity. This shows that D_{32} was nearly $1.35 \mu\text{m}$ during the period of vigorous flaming with a pronounced dip at the end of the flaming period. As the smoke concentration decreased rapidly (as indicated by the 5° -scattering curve) the mean particle size remained nearly constant. The optical densities for these tests are shown in Figure 5. The peak values were about 4.2 m^{-1} for blue (488 nm) and 2.8 m^{-1} for red (633 nm), with the peak occurring at 3.7 minutes, shortly after ignition occurred. The mass fractions recovered as particulates and remaining in the test chamber as char were found to be 0.017 and 0.70 respectively.

The results of the chemical analysis of the particulates in the exhaust for the spontaneously flaming tests under 7.5 W/cm^2 radiant flux are shown in Table II. Clearly, the composition is significantly different from that obtained in the nonflaming tests under 5 W/cm^2 radiant flux.

REFERENCES

1. Travelho, J. S., "The Role of Ions in Soot Formation," Ph.D. Thesis, Georgia Institute of Technology, August 1987.



Figure 1. Size distribution of particulates as determined using the Cascade Impactor for Sandlamis test at 5 w/cm².

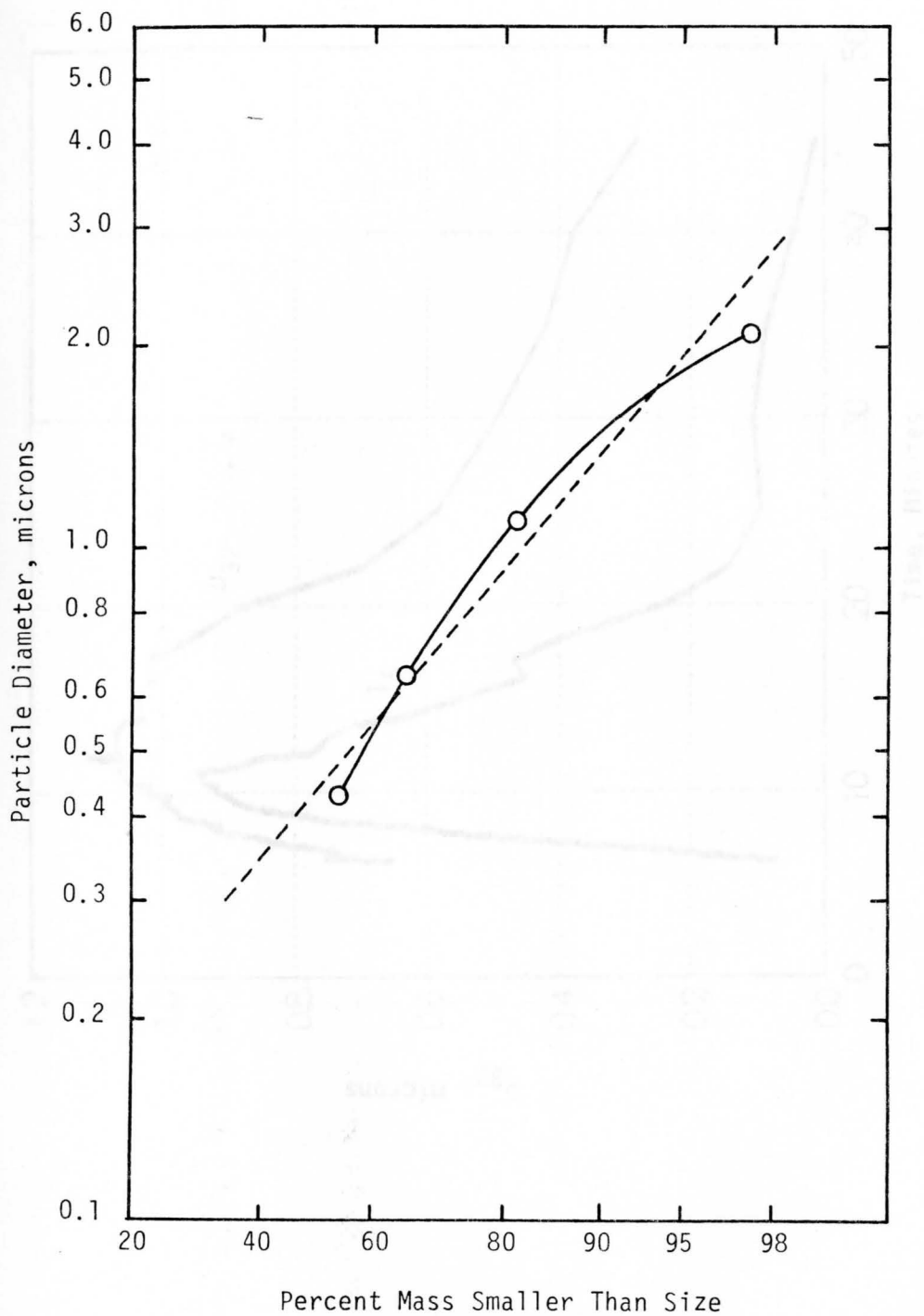


Figure 1. Size Distribution of Particulates as Determined Using the Cascade Impactor for Nonflaming Test at 5 W/cm^2 .

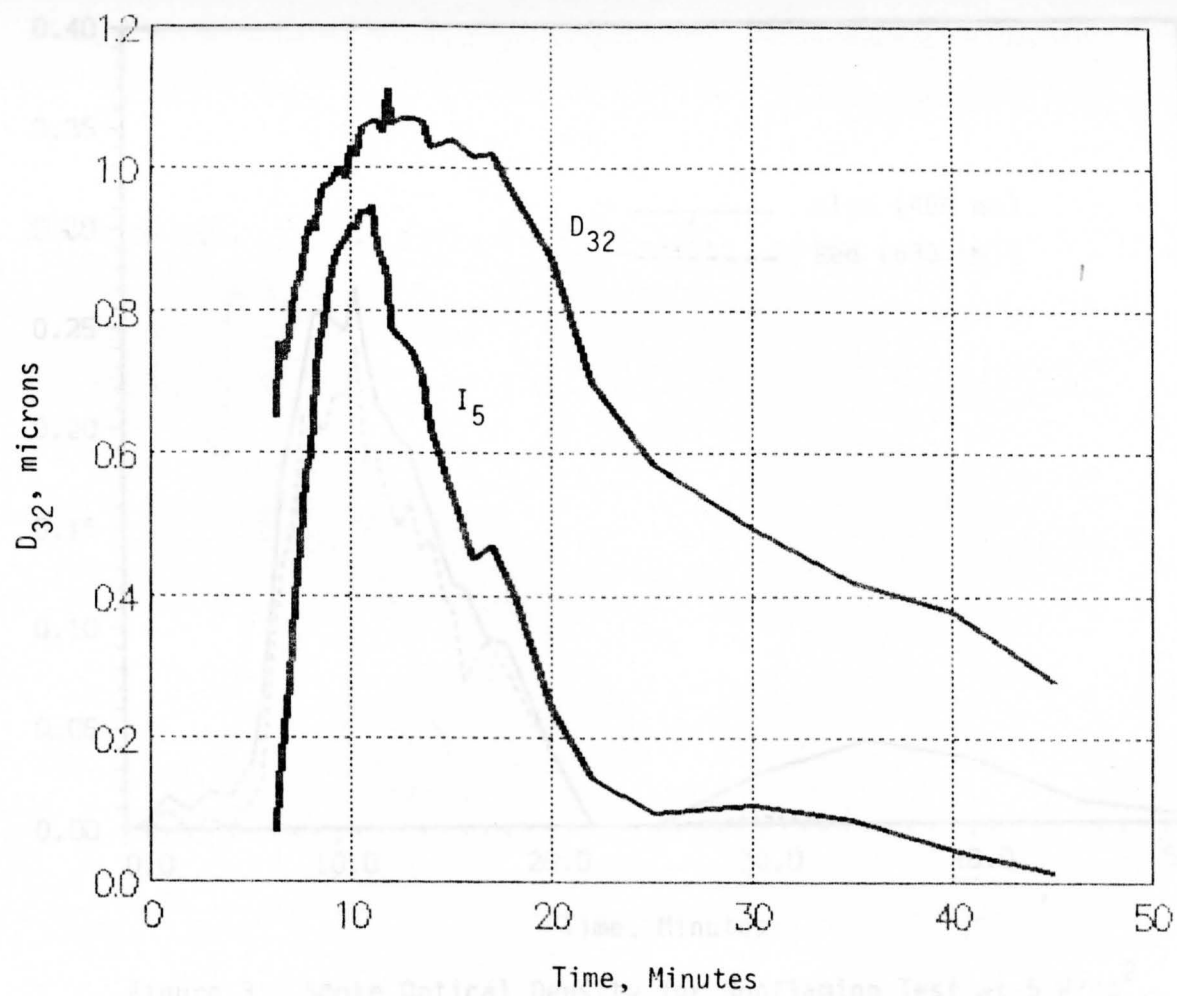


Figure 2. Mean Particle Diameters and Scattering Intensity for Nonflaming Test at 5 W/cm².

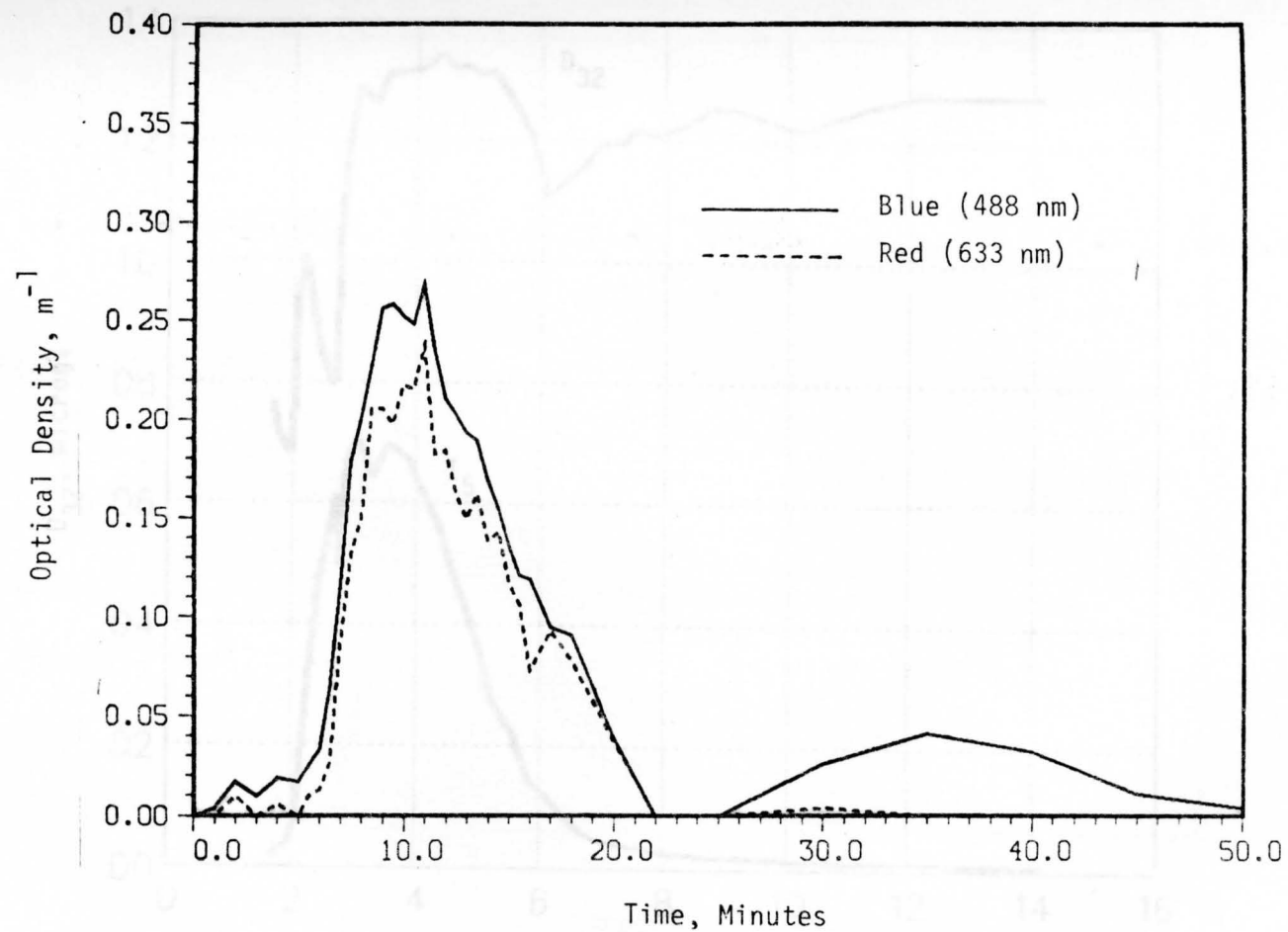


Figure 3. Smoke Optical Density for Nonflaming Test at 5 W/cm^2 .

Figure 4. Mean Particle Diameters and Scattering Intensity for
Flaming Test at 7.5 W/cm^2 .

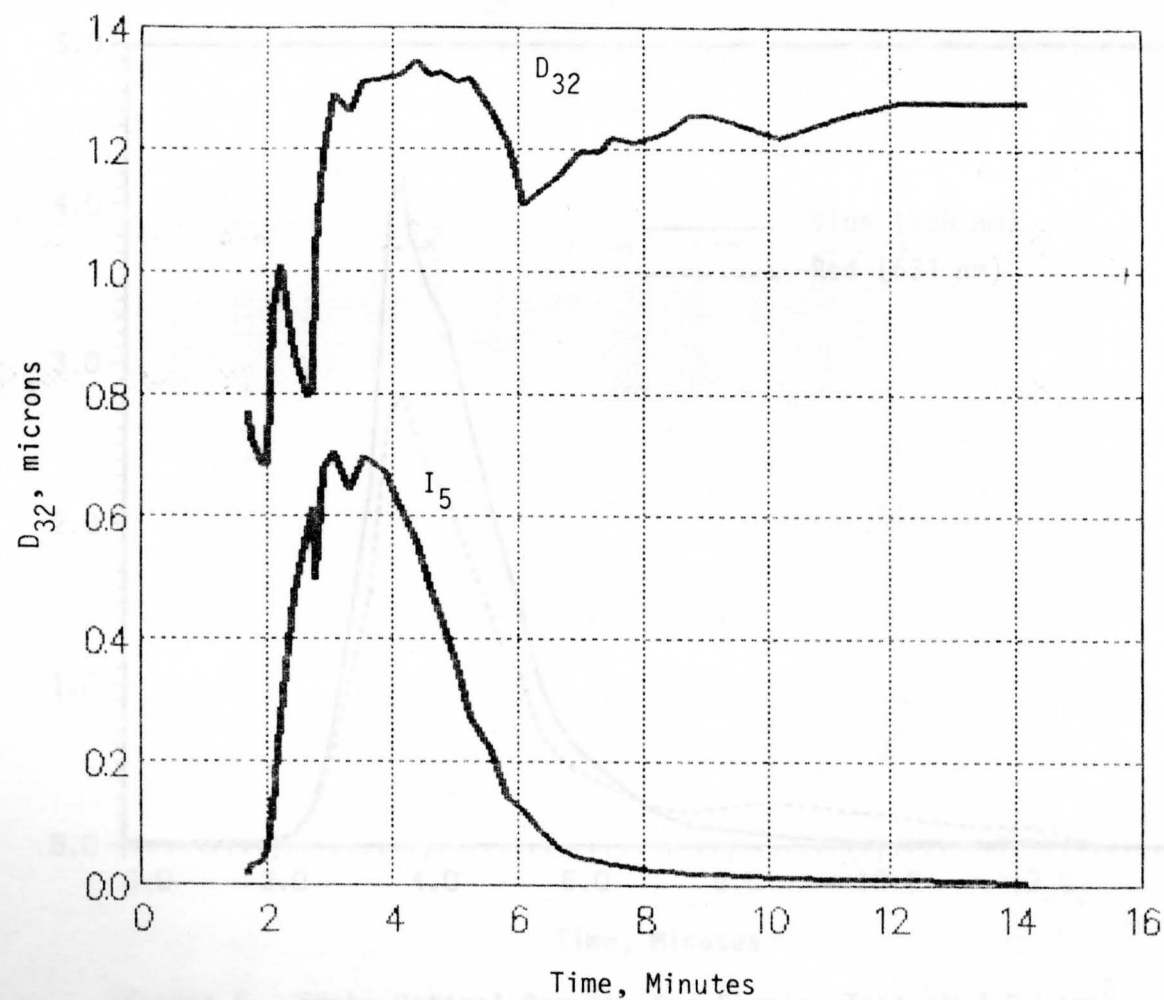


Figure 4. Mean Particle Diameters and Scattering Intensity for Flaming Test at 7.5 W/cm^2 .

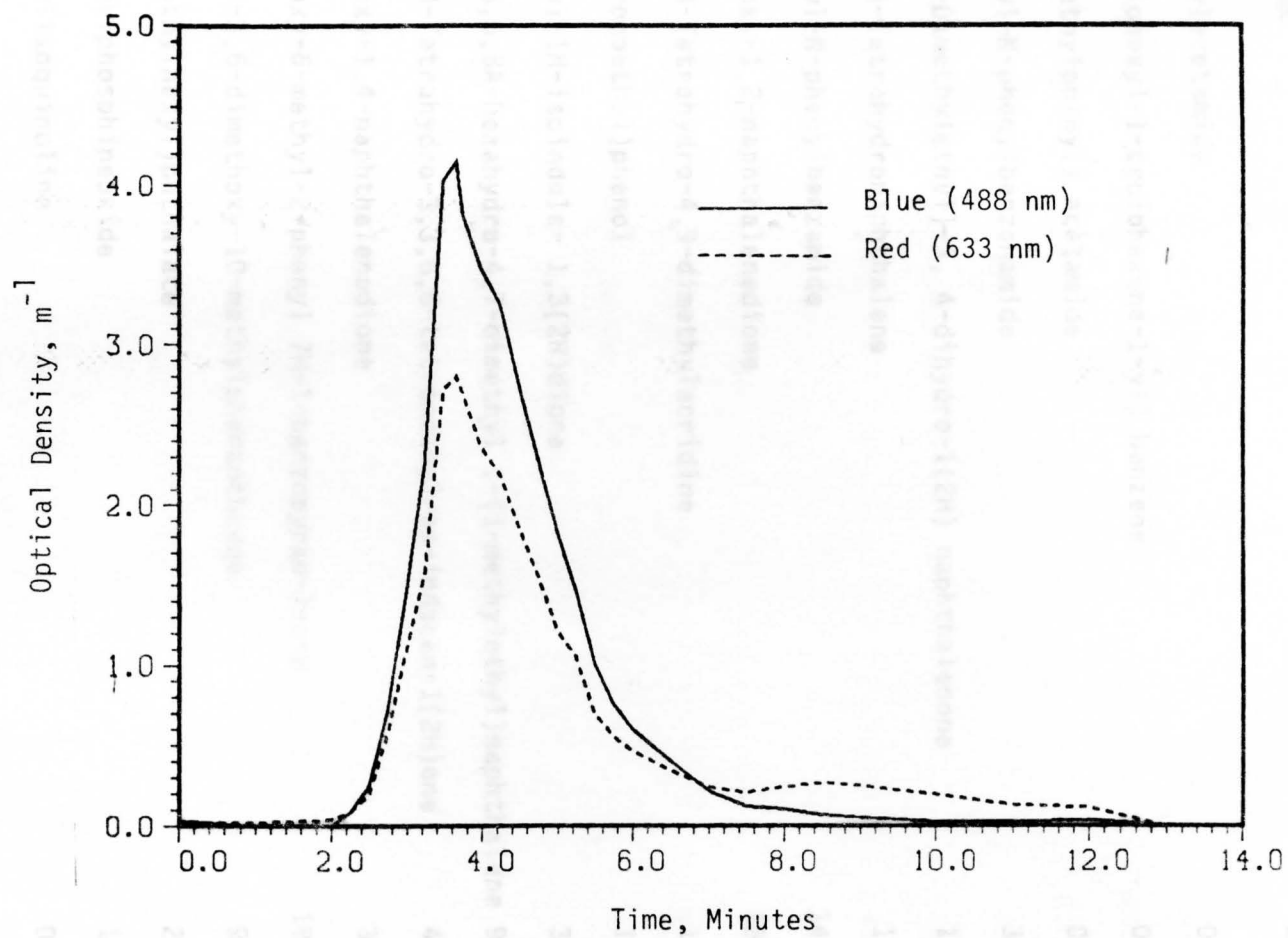


Figure 5. Smoke Optical Density for Flaming Test at $7.5 W/cm^2$.

Table I

Carbon/Bismaleimide Composite, 5 W/cm⁵, nonflaming;

<u>COMPOUND</u>	<u>μG/MG</u>
N-Phenylacetamide	0.447
(4-Cyclohexyl-1-cyclohexene-1-yl) benzene	0.436
N-(4-Methylphenyl) acetamide	0.449
N-Methyl-N-phenylbenzenamide	3.49
7-(1,1-Dimethylethyl)-3, 4-dihydro-1(2H) naphthalenone	1.81
1,2,3,4-Tetrahydronaphthalene	1.41
2-Methyl-N-phenylbenzamide	14.8
6-Hydroxy-1,2-naphthalenedione	18.2
1,2,3,4-Tetrahydro-4,9-dimethylacridine	1.37
3-(2-Bromoethyl)phenol	1.37
2-Phenyl-1H-isoindole- 1,3(2H)dione	3.48
1,2,3,5,6,8A-hexahydro-4,7-dimethyl 1-(1-methylethyl)naphthalene	9.46
3,6,7,8-Tetrahydro-3,3,6,6-tetramethyl-as-indacen-1(2H)one	4.58
2-Hydroxy-1,4-naphthalenedione	3.83
5-Methoxy-6-methyl-2-phenyl 7H-1-benzopyran-7-one	18.8
9-Ethyl-3,6-dimethoxy-10-methylphenanthrene	9.83
Bis(2-ethylhexyl)phthalate	2.72
Triphenylphosphineoxide	1.18
1-Methylisoquinoline	0.475
1,2,2a,7,8,12b-Hexahydro-1-methoxy-1,8:2,7-dimethanoldibenzo[a,e]cyclobuta[c]cycloocten-13-one	0.475
N-Prop-1-ene-3-(4-methylphenyl)-acetamide	59.4
5-Amino-6-phenyl-1-hexene	69.0

N-(p-Tolyl)-1-cyclohexylcarboxamide	24.4
N-(2-Heptene)-N-(p-toly)-1-amine	14.9
N-(p-Tolyl)-1-(2-butene)carboxamide	16.9
2-Methyl-N-phenylbenzamide	14.8
6-Hydroxy-1,2-naphthlenedione	18.2
N-Dimethylimine-1-ethylcarboxamide	21.5
N,N-Methylphenyl-1-butylcarboxamide	26.2
4,4'-Methylenebis-benzenamine	20.1
1,6-Dihydroxy-9H-xanthen-9-one	0.825
5-Methyl-1H-indole-3-ethanamine	0.825
3-Ethyl-2,4-imidazolidinedione	9.13
5-(1,1-Dimethylethyl)-1H-indene	0.622
N-Benzofuran-1-phenylcarboxamide	5.00
3,8-Dihydrocyclopent[a]indene	4.80
3,9-Ethyl-6-methylphenanthrene	2.30
(E,E)-2,4-Nonadien-6-yn-1-ol	42.4
3,3'-Dimethyl-1,1'-biphenyl	2.60

*Unable to identify 4 major peaks

Table II

Carbon/Bismaleimide Composite, 7.5 W/cm², Spontaneously Flaming

<u>COMPOUND</u>	<u>ug/mg</u>
7-(1,1-Dimethylethyl) -3,4-dihydro- 1(2H)naphthalenone	0.152
4-Methyl-1-naphthalenone	0.094
N-(Phenylmethylene) cyclohexanamine	0.094
Butyl-2-methylpropylphthalate	0.144
Dibutylphthalate	1.01
Delta.2-1,2,4-triazolin-5-one	0.840
2-Methyl-6-methylene-3,7-octadien-2-01	0.196
1-Nitro-4-(phenylmethyl)benzene	1.75
(4-Methylphenyl)phenylethanedione	1.75
N-(4-Hydroxyphenyl)benzamide	2.43
Alpha-(Benzoyloxy)benzeneacetone	2.43
3,9-Bis(1,1-dimethylethyl)phenanthrene	0.306
Ethyl 1H-indole-2-carboxylate	0.306
Ethyl 2-methoxybenzoate	0.098
2-Methylbenzoxazole	0.098
N-(3-Pyridinylmethylene)benzenamine	0.130
2,3-Dihydro-3,3,5,6-tetramethyl-1H-inden-1-one	0.204
N-Prop-1-ene-3-(4-methylphenyl)acetamide	0.218
2-Butyl-2,3-dihydro-1,3,2-benzoxaboxolidine	6.84
(1,3-Butadiene)carboxamide	0.497
Benzenemethamine	0.305
6-Methyl-1H-indole-2,3-dione	0.305
6-(1,1-dimethylethyl)-3,4-dihydro-1(2H)-naphthalenone	0.305